Interfirm technological alliances and the evolution of industries: a critical survey

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1. Introduction

The aim of this paper is to review the empirical literature on interfirm technological agreements. Together with the phenomenon it intends to describe, this literature has increased exponentially in the last years. Several suggestions on the rationale and effects of interfirm technological agreements have been proposed, receiving various degrees of confirmation by the empirical evidence. At the same time, the effort has been interdisciplinary, with contributions coming from different disciplines, like economics, sociology and management (see Caloghirou *et alii* (2003); Gulati *et alii* (2000); Hagedoorn *et alii* (2000); Powell and Grodal (2004), for previous recent surveys).

By organizing the empirical evidence, this paper suggests a perspective which is relatively uncommon in the literature: interfirm technological agreements and R&D networks as *structural elements* in the evolution and dynamics of industries. My main point is that the existing empirical knowledge can constitute the basis for an appreciative theory of the role of R&D networks in industry evolution, which should be of obvious interest for economists interested in improving our knowledge on the fundamental link between technological progress and market structure. Furthermore, such a theory can be conceived as a step towards further empirical analysis and formal modelling, The paper is structured as follows. Section 2 is introductory: I define interfirm technological agreements, I discuss the sources of data, I provide some basic evidence on the relevance and the evolution over time of the phenomenon, and on the broad motives leading firms to collaborate in the technological domain. Section 3 and 4 constitute the core of the paper. Section 3 reviews the studies that consider technological agreements as dependent variables. First, I consider the characteristics at the firm, industry and dyadic level that affect firms' propensity to enter into cooperative agreements; second, I discuss the structural properties of the network resulting from the collaborations firms have in place. Section 4 surveys the studies that treat technological agreements as explanatory variables, considering the effects of agreements on firms' innovative and economic performance and firms' technological profiles. This distinction is mainly adopted for expository reasons, since the two aspects are clearly interrelated. On the basis of the existing empirical evidence, section 5 proposes some themes for an appreaciative theory of R&D networks and industry evolution. Finally, section 6 concludes.

2 Definition, data and basic evidence

2.1 Definition

The definition of interfirm technological agreements is adapted from Hagedoorn (2002):

Interfirm technological agreements are defined as common interests between independent industrial partners, which are not connected through majority ownership, and in which R&D is at least part of collaborative effort, through some arrangements for transferring technology or joint research.

This definition immediately excludes from the analysis all the agreements that are only concerned with production (like standard long term buyer-supplier contracts) or marketing joint ventures. Agreements that have *also* production or marketing aspects, which are quite common in practice, are included. For instance, an agreement involving the joint development *and* the production of a component to be used by the collaborating firms fits our definition. At the same time, I do not consider informal cooperation among firms, occurring for instance through information exchange among engineers or scientists (Von Hippel, 1987), or cooperation among firms and universities (Mowery and Sampat, 2004)[1].

The definition is broad enough to accomplish several ways in which firm can collaborate in the technological domain. Cooperation can occur through several legal arrangements, implying different degrees of resources commitment, different levels and directions of technological flows, different coordination mechanisms, and different time horizons. Examples of interfirm technological agreements are R&D joint ventures, where two or more firms constitute a new legal entity in order to perform R&D activities; joint R&D agreements, where firms share resources to undertake joint R&D projects; licensing and cross-licensing agreements; research contracts, where one partner, usually a small R&D specialized firm, performs research activity in favour of another firm.

2.2 Data sources

The lack or limited availability of data has been a typical concern in the literature, weakening the reliability of results. The datasets used in the empirical analyses can be grouped in three classes, each of them having their own limits.

1. Literature-based datasets.

Several datasets has been collected by consulting specialized journals, financial newspapers and other publicly available sources of data. The MERIT-CATI dataset (Hagedoorn, 2002), which I discuss more at length in the following sections, is probably the most comprehensive in terms of coverage of industrial sectors and time horizon. At the same time, industry specific datasets have been collected as well, like the ARPA database developed at Politecnico di Milano for information technology sectors (Colombo and Garrone, 1996).

[1] Nevertheless, some of the studies I will survey consider datasets including both formal and informal cooperation, and interfirm and firm-university technological agreements.

Although the collection of these datasets has greatly improved our knowledge of interfirm technological alliances, these types of data suffer of several limitations: arrangements are known only if made public by the firms themselves; a general bias exists in favor of large, well-known firms, more fashionable technologies, Anglo-Saxon countries; information about agreements dissolution is less easily available than data on their formation.

2. Surveys.

Some works have used data collected through questionnaires, in which firms are asked explicit questions about the extent of their collaborative activities, the motives behind them, and types of collaborators (i.e., competitors, customers, suppliers or universities).

In particular, a number of papers (for instance, Veugelers and Cassiman, 2002: Tether, 2002) used data from the Community Innovation Surveys (CIS), collected by the statistical offices of the Member States according to a common European Standard, for the analysis of innovative inputs and outputs by European firms.

The problems with these kinds of data are those that are usually implied by survey analyses: results may depend on questions formulations; a degree of discretion in respondents' answers cannot be avoided; a careful analysis for non-respondent biases must be performed.

3. Data from public-funded R&D programs and antitrust authorities.

A third class of data concerns government sponsored cooperative agreements and antitrust laws.

In Europe, a cornerstone of technological policy has been constituted by the several programs (in particular, the Framework programs) promoted by the European Union to foster collaboration among firms (but also universities and research centers). Data on projects resulting from these programs have been recently collected and analyzed (see for instance Breschi and Cusmano, 2004).

For the US, datasets have been collected using information from the Federal Register at U.S. Department of Justice. Under the National Cooperative Research Act, voluntary filings of R&D partnerships give firms benefits in case of anti-trust interventions. Such data have been collected by Vonortas (1997).

For Japan, finally, Branstetter and Sakakibara (2002) have analyzed R&D consortia with a degree of government subsidization and intervention.

These types of datasets may suffer from selection biases: these may be given by the criteria according to which firms ask and obtain funds or they decide to register the partnership.

2.3 Basic evidence: relevance and trends

In order to give a flavor of the basic stylized facts concerning interfirm technological agreements, I will refer to the MERIT-CATI database, whose data have been collected through years by John Hagedoorn and colleagues. The references are given by the papers containing a descriptive account of the database (Hagedoorn, 1993; Hagedoorn, 2002).

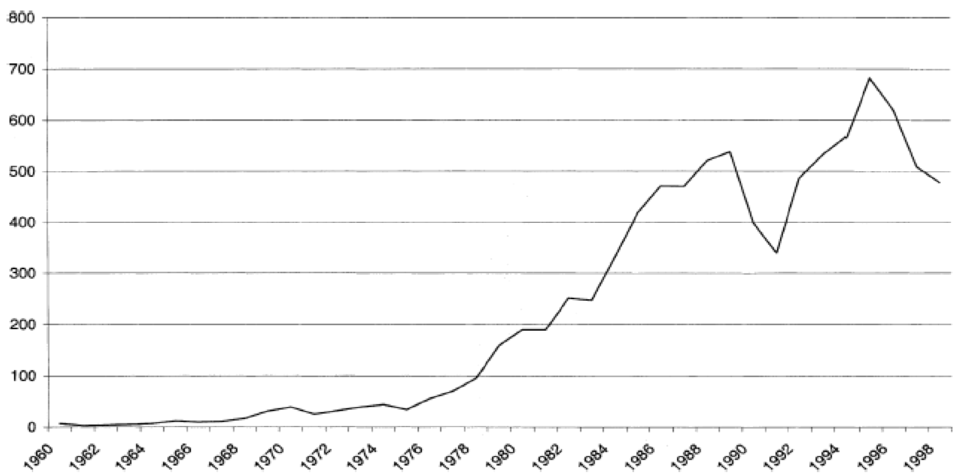
The dataset is constituted by more than 10'000 agreements signed among more than 4000 firms, between 1960 and 1998. Data involve several sectors, at different level of R&D intensity, at the worldwide level. The dataset excludes from the analysis publicly-funded agreements.

Some of basic stylized facts, which find generally confirmation in the analysis of other datasets, can be summarized as follows.

1. In terms of the number of *newly established* agreements, worldwide and for all sectors, we see that, after a quite limited growth in the 60s and 70s, the number of agreements has exhibited highly significant growth rates in the 80s, and it has showed since then a cyclical behavior with a positive trend in the 90s (see Figure 1). We observed no more than ten partnerships established each year during the 60's; 160 at the end of the 70's; nearly 700 new partnerships in the peak in 1995.

Overall, we can say that technological agreements have been playing a substantial role in the innovative activities of firms in the last two decades.

Figure 1- New established R&D partnership (1960-1998) Source: Hagedoorn (2002)-MERIT-CATI database.



2. Sectoral differences exist and they are significant. Classifying sectors in high tech, medium tech and low tech, according to their R&D intensities, we can see that the overall increase in the number of agreements has been accompanied by a significant increase of the high tech industries share. Figure 2 shows that, while in 1960 medium tech sectors (instrumentation and medical equipment, automative, consumers electronics and chemicals) accounted for about 70% of the total numbers of newly established agreements, and the remaining share was composed by partnership in the high tech sectors (Computers, software, microelectronics, telecommunications), in 1998 the situation is reversed, with high tech sectors accounting as a whole for more than 80% of the newly established agreements.

At a more disaggregate level, we observe that, within the sectors constituting the high tech aggregate, the IT industry (Computers, software, microelectronics, telecommunications) plays a strikingly important role, constituting alone the 50% of the total number of agreements at the end of the sample period. Pharmaceutical (which includes biotechnology) contributes also in a significant way, with approximately the 30% of all newly established partnerships.

Figure 2: new R&D partnerships, for low, medium, high tech industries (percentages). Source: Hagedoorn (2002).

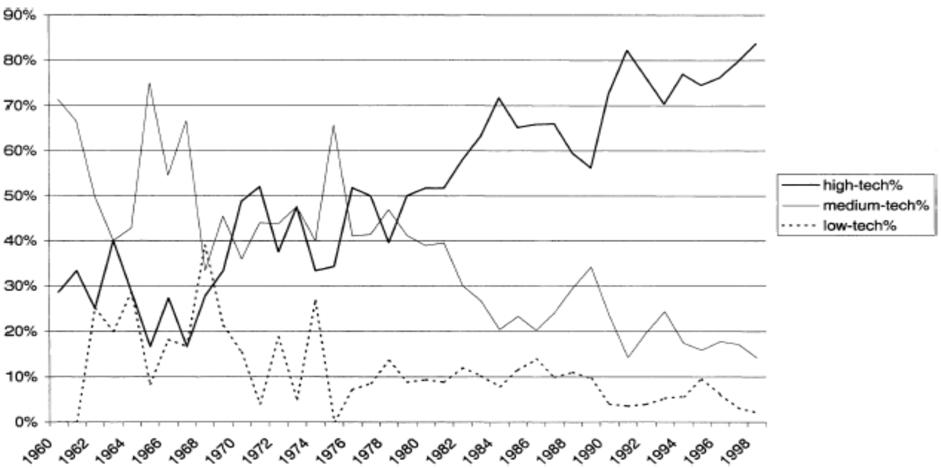
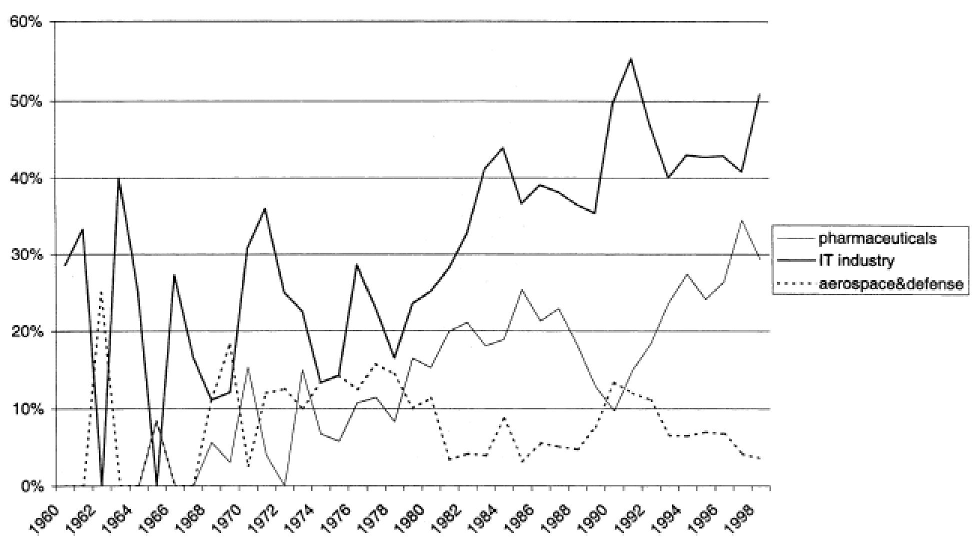


Figure 3: newly established R&D partnerships in high tech industries (percentages). Source: Hagedoorn (2002)



3. Finally, it is possible to investigate the role of different modes of cooperation, in different sectors, over time. Hagedoorn (2002) divides the modes of cooperation in two broad categories: joint ventures and contractual arrangements (as R&D pacts, customer-supplier relations and licenses). Although the second groups of modes is quite heterogenous, joint ventures are characterized by higher set up costs and a long term orientations, opposed to the flexibility and generally shorter term orientation of contractual forms. Then he defined a relative contractual partnering index for each sector

defines as $RCI_i = \frac{CP_i / JV_i}{TCP / TJV}$, where CP_i is the number of sectoral contractual partnerships, JV_i the number of sectoral joint ventures, and *TCP* and *TJV* the total number contractual partnerships and joint ventures, respectively. The value of the index across decades and sectors is reported in Table 1. The range for this index is $[0,\infty)$, where values larger than 1denote a relative importance of contractual forms. We can notice that, especially focusing on the last two decades, contractual forms are prevalent exactly in those industries where partnerships are numerous (ICT and pharmaceuticals).

Table 1. Relative contractual partnering index of selected sectors during 1960-1998 Source: Hagedoorn (2002)

Sectors	*1960-1998*	*1970-1979*	*1980-1989*	*1990-1998*
Pharmaceuticals	2.65	2.48	2.29	1.48
Information Technology	1.06	0.91	1.27	1.64
Aereospace/Defence	7.94	5.34	3.57	0.58
Automative	1.32	3.16	0.46	0.57
Chemicals	0.38	0.26	0.35	0.24
Instruments and medical equipment	0.00	0.18	0.92	1.64
Consumer electronics	0.00	0.99	0.28	1.18

In a nutshell, these “stylized facts” show that what has to be explained is prominently a "recent" phenomenon, concerning flexible, short-term forms of cooperation in high tech industries (ICT and pharmaceuticals).

2.4 Basic evidence: motives

Several industry case studies have stressed the rationale for cooperation in specific cases. For a broader view, it can be useful again to refer to the CATI database. On the basis of the several and (partially) contrasting motives for cooperation mainly put forth by business scholars in terms of appreciative theoretical or empirically grounded considerations (see Hagedoorn, 1993, for references to relevant theoretical literature), each agreement of the database is assigned to one or more of the following motives:

1. Searching for complementarities, synergies, and cross-fertilization between technological and scientific fields, in sectors characterized by increased technological complexity, in which no firms can master all the relevant knowledge base required to innovate.

2. Reduction of costs and risks in R&D, as in the case for instance of basic or "pre-competitive" R&D, and the exploitation of economies of scale.

3. Monitoring new technological opportunities, possibly followed by the development of new products, and new markets entry.

4. The shortening of the product life cycle and the reduction of innovation time-span, i.e. the period between discovery and introduction into the market, which lead firms to cooperate to reduce the period of development.

5 Market positioning, i.e at modifying market structure in firm's favor against rivals in domestic and international markets.

6. Mostly "hidden" motives, like capturing rival's tacit knowledge, technology transfer, "technological leaprofrogging".

Several alliances are assigned to more than one category, since some of these categories operate at different levels (i.e. "market" vs "technology" level) and consequently they are not mutually exhaustive. Hagedoorn (1993) provides a ranking of *importance* among the different motives across different sectors.

Table 2: motives for cooperation, 1980-1989. Selected sectors. Source: Hagedoorn, 1993.

	Technological complementarities	Basic R&D	Lack of financial resources	Reduction innovation time span	Market access/ structure	High cost/risks	Monitoring technology/market entry
Pharmaceuticals	35%	10%	13%	31%	13%	1%	15%
Computers	28%	2%	2%	22%	51%	1%	10%
Software	38%	2%	4%	36%	24%	1%	11%
Microelectronics	33%	5%	3%	33%	52%	3%	6%
Aerospace/Defense	34%	0%	1%	26%	13%	36%	8%
Automative	27%	2%	2%	22%	52%	4%	4%
Chemicals	16%	1%	1%	13%	51%	7%	8%
Instruments and medical equipment	35%	2%	4%	40%	28%	0%	10%
Consumer electronics	19%	0%	4%	19%	53%	2%	11%

Two comments are possible: first, sectoral differences exist, and they are significant; but nevertheless some motives exhibit a general prominence. Such motives are technological complementarities, shortening of the innovative time span and the goal of influencing market structure.

Then, a general, broad view of the role of R&D partnerships emerges. In high tech industries, innovation is more and more complex and building on several technological fields. This is the case in pharmaceuticals, after the new discoveries in molecular biology in the mid 70s, and in microelectronics, where innovation hinges on competences in fields as different as solid physics, construction of semiconductor manufacturing and testing equipment, and programmic logic. Firms cannot possess all the relevant knowledge required to innovate and therefore they look for partners having complementary capabilities to face an increased rate in the introduction of new products and processes, to monitor new opportunities and enter new markets, to sustain long-lasting competitive advantage.

3. Technological agreements as dependent variable

After the broad introduction to the general relevance and underlying motives of technological alliances, in this section I go more in depth reviewing the empirical studies that treat interfirm technological agreements as the dependent variable. In this respect, I distinguish three levels of analysis.

1. A first series of studies has focused on *the firm level*. Scholars have tried to identify firms' characteristics (for instance, size, age, technological capabilities) and industries' characteristics (for instance, concentration and appropiability of innovation) that affect firms' propensity to enter into collaborative agreements, the total number of agreements and the total number of partners.
2. The second level of analysis is the *dyad* (i.e. the single pair of firms involved in an agreement). In this case, studies investigate the characteristics of the firms that make more likely an agreement between them, and how the choice of mode for cooperation is affected by firms' attributes (including their history of collaboration).
3. The third level is the *network* of R&D alliances. Recent studies have investigated the structural properties of these networks, their evolution over time, and the relation between network measures at the firm level and the propensity to enter into new alliances.

3.1 Technological agreements as dependent variable: the firm's and industry level

Several studies have estimated econometric models that link firms' and industries characteristics to the propensity towards cooperative ventures (Logit or Probit models) and to the intensity of collaborative activities, measured by the number of technical agreements firms are involved in or by the number of partners they have (Poisson and negative binomial regressions).

3.1.1 The firm's level

Empirical studies have recurrently found a *positive* impact on firm's collaborative activities for some variables at the firm's level.

1. *Size*. Firms that are active in interfirm technological agreements are typically large. This is actually one of most robust finding of this literature. A positive relation between size and propensity to form interfirm alliances or between size and the number of technical agreements is found by Link and Bauer (1987), Kleinknecht and Reijen (1992), Hagedoorn and Schakenraad (1994), Colombo (1995), Colombo and Garrone (1996), Siebert (1996),Vonortas (1997), Ahuja (2000a), Fritch and Lukas (2001), Bayona *et alii* (2001), Tether (2002),Veugelers and Cassiman (2002), Hernan *et alii* (2003), Becker and Dietz (2004). This evidence is recurrent across time sectors and countries[2]. Large firms are likely to engage in a wider range of economic activity, increasing the opportunities for cooperation. A "cost spreading" argument (Cohen and Klepper, 1996) may apply to technological agreements as to R&D in general: large firms can spread the gain from innovation over a larger base of economic activity, increasing their incentives towards cooperative agreements (as a form of R&D investment). Some forms of cooperative agreement (for instance R&D joint ventures) imply high physical and legal set-up costs for which small firms can lack financial resources. Finally, large firms can have significant bargaining power in contracting with their partners.

2. *R&D intensity and technological capabilities*. Using data from the UK CIS 2 survey on 1275 innovating firms, Tether (2002) shows that performing R&D on continuous basis and intensively has a significantly positive effect on firms' propensity to cooperate. Similar results are obtained by Fritch and Lukas (2001) from a survey on German firms, and by Bayona *et alii* (2001) from a survey of Spanish firms. Link and Bauer (1987) find a positive value for *absolute* R&D in explaining cooperation activity. Ahuja (2000a), in

[2] For exceptions, see Shan (1990) (who found a negative sign) , Pisano (1989) and Arora and Gambardella (1990) (who found size as non significant) and Burgers Hill and Kim (1993) (who found a non-monotonic relationships). However, Shan focuses on small biotech firms, Pisano and Arora and Gambardella on large pharmaceutical firms, Burgers Hill and Kim on the world largest car producer. Then, these studies focus on a relatively small number of size classes. This can explain the results.

his sample of 97 leading firms in the chemicals industry, shows that technical capital, defined as the stock of patents, positively affects the number of agreements. Sakakibara (2002) introduces the variable “R&D capabilities”, defined as the difference between firm’s and industry R&D intensity, and she finds it positively affects Japanese firms’ participation to government sponsored R&D consortia. Arora and Gambardella (1990) find that increasing the stock of patents that large pharmaceuticals and chemicals firms have in biotechnology increases the number of external linkages these firms have with specialized biotech firms[3]. In a similar vein, Stuart (1998) shows that technologically “prestigious” firms (i.e., firms whose patents are highly cited) are more likely to form technological agreements, in a sample of semiconductor firms.

The possibility that R&D intensity and the number of technical agreements are not strongly exogenous has been tested by Colombo and Garrone (1996), which actually find confirmation of this in their data. Their sample is composed by agreements by firms in the semiconductor, data processing and telecommunication sectors. Then, Colombo and Garrone (1998) estimate a simultaneous two equations structural model, to find a significantly positive effect of R&D intensity on the number of technical agreements, while the coefficient for the reverse relation is not significant. A similar two equation models is estimated by Becker and Dietz (2004), who find significantly positive effects in both directions.

These results suggest than internal and cooperative R&D should be seen as complimentary rather that substitute. The most common explanation for this result claims a role for absorptive capacity (Cohen and Levinthal, 1989): in order to evaluate and absorb fully the outcomes from cooperative ventures, firms need to have pre-existing capabilities in those scientific or technological fields. This implies that firms lacking technological capabilities are not in the position to reap the benefits from cooperation. This view is confirmed by Stuart (1998), which shows that firms in more crowded technological areas are more likely to form new agreements. This is explained by the author claiming that such firms have many potential partners for which they possess the relevant absorptive capacity.

[3] However, Pisano (1990) finds that biotech experience decreases the propensity of pharmaceuticals firms to start external projects with specialized biotech firms.

3. *Experience*. Firms that have more experience at managing collaborative ties (usually measured by cumulative number of past alliances or by number of partners in previous years) are more likely to enter into collaborative agreements. This is the result obtained by Gulati (1995a), Powell *et alii* (1996), Ahuja (2000a), Sakakibara (2002), Hernan *et alii* (2003), Okamura and Vonortas (2004). In the business literature, this result is usually explained by referring to the notion of "cooperative capability" (Gulati, 1998). With experience, firms learn how to manage their collaborative ties; to develop interfirm knowledge sharing routines and funnel results inside the organization; to govern contractual arrangements where there is room for moral hazard and incompleteness; to initiate necessary changes in the partnership as it evolves over time. All this increases their returns from technical agreements.
A second, complementary explanation points at the role of previous partners as information source, about new opportunities for agreements and new potential partners. We will come back to this point in section 3.2 and 3.3, discussing the dyadic and the network level.

The relevance of these variables (size, R&D intensity, and experience at managing ties) is already enlightening on the "strategic" nature of cooperative agreements. Interfirm technological alliances are an important, persistent part of the innovative strategies by large and technologically leader firms, rather than a defensive tactics by small firms which lack the ability of innovating alone[4]. In that respect, this perspective is confirmed by the results of surveys (Fritch and Lukas, 2001; Tether, 2002) which show that firms' propensity to enter into collaborative agreements is higher when firms aim at introducing "breakthrough innovation" (e.g., radically new products).

3.1.1 The industry level

Concerning industry level factors, section 2 already showed that the intensity of the phenomenon of interfirm strategic alliances varies across sectors, and at level of aggregation in Hagedoorn (1993), a positive relationship exists between sectoral R&D

[4] See for instance the IBM's webpage dedicated to partners for a practical example (www.pc.ibm.com/ww/alliances)

intensity and the number of R&D alliances in that sector: technological agreements are particularly frequent in high tech sectors. More rigorously, Hernan *et alii* (2003) confirm this evidence, finding a significantly positive coefficient for R&D intensity on firms' participation to R&D joint ventures in the Eureka and Framework programmes.[5] We focus in this section on two others industry specific variables. It is worth noting, however, that the number of cross industries studies have been restricted by the limited availability of large data sets. For this reason, the evidence seems less robust than the one presented in the previous paragraphs.

1.*Concentration*. Link and Bauer (1987), Sakakibara (2002), Hernan *et alii* (2003) find that R&D cooperation is more likely in concentrated industries. It is argued that in oligopolistic structures is easier to find the appropriate partners or finding the consensus towards cooperation, when few firms are involved. Furthermore, market power associated with such structures allows firms to appropriate the return from the cooperative investment. This sign for the relationship is also found in a pioneering study by Pfeiffer and Nowack (1976), who found a positive relation between concentration and the number of joint ventures at the industry level in US manufacturing firms[6].

It is worth mentioning that the opposite result (a negative relation between concentration and the rate of formation of strategic alliances) is found by Eisenhardt and Shooven (1996). These authors consider a sample of 102 US new firms in the semiconductor business, and find that the number of competitors in the segment in which the firm operate positively affects the rate of alliances formation. The authors relate this to the gains of accessing external resources, when market conditions are difficult. This result can be conciliated with the previous ones if one considers that, while Eisenhardt and Shooven focus on new (and then typically small) firms, the papers we discussed in the previous paragraph are mainly concerned with large, established firms. This suggests that the cooperative strategies of new and established firms may significantly differ, being differently affected by industry characteristics.

[5] However, Becker and Dietz (2004) found that technological intensity has a *negative* impact on the likelihood of cooperation.

[6] Becker and Dietz (2004) find that the concentration is not significant as explanatory variable of cooperation.

2. Appropiability. Authors inspired by the economic theories of R&D cooperation have tested the link between the degree of appropiability of R&D investments and R&D cooperation. Indeed, models of R&D cooperation in the IO tradition (d'Aspremont and Jacquemin, 1988; Kamien, Mueller and Zang, 1992) individuate in the internalization of R&D spillovers (a form of externality, whose relevance is inversely related to the degree of appropiability) one of the main rationale for R&D cooperation.
When sectoral measures of R&D appropiability are introduced as explanatory variable for firms' propensity to cooperate, the sign of coefficients turns out to be negative, consistent with the theory: higher spillovers lead to more cooperation (Hernan *et alii*, 2003; Sakakibara, 2002, Okamura and Vonortas, 2004)[7].

3.2 Technological agreements as dependent variable: the dyadic level

The studies considering the characteristics of the dyad and the probability of cooperation have focused on two main dimensions:

1. The first dimension is technological. One concern of the literature has been to assess the probability of two firms forming a collaborative link, as a function of their technological distance, empirically measured on the basis of their patent portfolios.
A first argument claims that firms need to be close in the technological space for being good partners. This is related, again, to an absorptive capacity argument. As long as firms use technological alliances in order to learn, they need to have preexisting knowledge in the partner's field of expertise to absorb its capabilities; at the same time, cognitive proximity is required for effective communication to take place.
This hypothesis is confirmed by the works by Stuart (1998) and Okanamura and Vonortas (2004). Stuart (1998) defines firms' technological positions using patents citations for a sample of semiconductor firms, and he finds that closeness in such a space

[7] This result partially contrasts with Veugelers and Cassiman (2002). These authors find that the relevance of outgoing spillovers *at the firm level* (that are related, but do not coincide, with the inverse of the degree of appropiability in a industry) negatively affects cooperation.

increases the likelihood of alliance formation. Okanamura and Vonortas (2004), for US research joint ventures, find that increase in technological proximity (measured by the similarity of patent portfolios) has a positive effect on link formation.

However, if firms are technologically too close, opportunities for learning decrease. Firms need to be sufficiently dissimilar for technological complementarities to be exploited through collaboration.

Mowery *et alii* (1998) find evidence of such an effect. In a sample of 151 international joint ventures in several sectors, they find an inverted U relationship between partners' technological overlap (measured by the cross citation rate and common citation rate in patent portfolio) and the probability of alliance formation. Firms need to be "not too distant nor too close" from the technological point of view (Nooteboom, 1999).

2. The second dimension can be defined as "social" or "relational". Technological alliances are usually complex arrangements for which uncertainty and investment appropiability are relevant issues. For the particular nature of transaction involved, there is significant room for opportunistic behavior, and, conversely, there is a role for trust building among partners.

A quite robust result in this stream of literature is that firms tend to ally with previous partners (Gulati, 1995a; Stuart, 1998, Gulati and Gargiulo, 1999, Okamura and Vonortas, 2004). Firms, with familiarity, can build trust, lowering transaction costs and limiting the risk of opportunistic behaviors; also, they can choose organizational forms that are more flexible (Gulati, 1995b). At the same time, they can develop routines and codes in order to increase the effectiveness of communication with the partner and control the flows of knowledge.

Indirect links among firms can matter as well. Common previous partners have two main roles to play: first, they constitute source of information about potential partners for new collaborative opportunities; second, they can reduce the asymmetric information among the potential partners, providing an indirect reputation effect. Gulati and Gargiulo (1999) find that the number of indirect links (common partners) has a positive effect on the probability of link formation at the dyadic level.

3.3 Technological agreements as dependent variable: the network level

In recent times, there has been a substantial shift of attention from the dyadic to the network level, spurred by the massive contributions by sociologists in the field.

The structure of the overall network of alliances resulting from firms (uncoordinated) choices matters for two reasons: first, theoretical contributions stress that the network structure have an impact on the level of efficiency of the system (i.e. industry) (Cowan and Jonard, 2003 and 2004). In other words, the structure network of alliances is a factor that may explain cross-sectional variation in the rate of technological progress. Second, firms' position in the network can affect their propensity to enter into new alliances, in general and at the dyadic level, as well as their economic and innovative performance.

The first structural characteristic that has been extensively considered is the existence of *cliques*, or more in general cohesive sub-groups of firms within the network[8].

There are two main reasons for which we could expect cliques to emerge in networks of technological alliances. Both are related to the contributions that cliques can give to the building of "social capital", defined as the sum of resources that accrue to a firm by virtue of possessing a durable network of relationships.

The first reason can be labeled as "cognitive": firms that share many partners in common can develop a common language for cooperation, practices and routines, which favours the creation of new knowledge and its transmission among the firms in the clique. The second reason can be labeled as "reputational", and in turn can be divided into two motives. *Ex-post* (once the link is formed), partecipation to a clique can favor cooperation in a context of contractual incompleteness, because in presence of opportunistic behavior, the information about a "deviation" by a firm can spread among the partners, increasing its cost. *Ex ante* (before the alliance is formed) common partners can reduce the degree of information asymmetry about firms' competences and their trustworthiness, then favoring the link formation.

The existence of cohesive sub-groups has been proved for a number of sectors. Nohria and Garcia-Pont (1991) consider the 35 leading firms in the automobile industry, and the

[8] See Wasserman and Faust (1994), ch. 7, for a general discussion on the different notions of cohesive sub-groups.

133 alliances they formed in the 80's. They can detect six "strategic" blocks, as they call them. It turns out that strategic blocks are composed by firms with complementary capabilities, and they are such that firms in each block have access to a similar set of capabilities. Gomes-Casseres analysis (1996) shows that competition in the personal digital assistants market has been characterized since its inception by alliance groups of firms coming from different sectors (computer hardware and software, telecommunications and consumer electronics).

The view of social capital as "closure" (Coleman, 1988) is often set against the "structural holes" argument (Burt, 1992). Burt considers players (individual or organizations) in a competitive arena (for instance, a market). Such a competitive arena is characterized by a "social" context, defined as a social network among the players.

The theory suggests an explanatory power of players' position in the network on their performance in the competition. In particular, a player's performance should be positively correlated with the extent the player manage non redundant contacts in its network. Contacts can be defined as redundant if they are connected by a strong relationship (cohesion criterion), or when they have, in turn, the same contacts (redundancy by structural equivalence). Whenever two contacts are non-redundant, a structural hole is assumed to exist between them.

Players that occupy structural holes can enjoy higher rates of return from their investments. Non redundant contacts are more likely to give them timely access to diverse sources of information (being the players exposed to more rewarding opportunities), as well to give control over such information, in order to secure more favorable terms in the opportunities they choose to pursue.

Applied to the technological alliances case, the networks among firms is mostly seen as a conduit of information about technology (say, for instance about more or less promising technological directions). In this perspective, firms in a clique have by definition redundant links, and according to this view, a non efficient structure of the ego-network.

Burt's argument has clearly a normative flavor. Firms should fill structural holes, because this consents them an higher rate of return. We will mention in the next section studies that test this hypothesis.

However, we can mention here the study by Walker *et alii (1997),* which compares the rate of alliance formation as a function of the structure of the networks firms are embedded in. They find that firms endowed with “social capital” (located in dense areas of the network) form more links that firms active in less dense areas (full of structural holes). At the same time, new links tend to increase the level of social capital. They find these results on a sample of biotech firms in the period 1984-1988.

The social capital and structural hole views are not incompatible. If we assume advantages (at the firm level) of being located in a clique and having (some) non-redundant contacts, we could expect firms in a cliquish network having some “long-distance” connections. Watts and Strogatz (1998) show that networks with these characteristics exhibit the “small world” property (low average distance, even in a cliquish, sparse network), because some “short-cuts” among otherwise disconnected areas dramatically reduce the average distance among actors. Theoretical models (Cowan and Jonard, 2003 and 2004) have shown that “small world networks” (networks exhibiting both high cliquishness and low average distance) are the most efficient in the process of knowledge creation and diffusion.

Then, it is natural to ask if firms’ innovative networks are “small worlds”.

The answer from existing studies is generally “yes”. Verspagen and Duysters (2004) find a “small world” network for the alliances of the two sectors they analalyze: chemicals and food (639 firms in their sample) and electronics and ICT (837 firms). Cowan and Jonard (2003) find a small world in the network of firms participating in the BRITE/EURAM programme and the network of research institutes from the TSER programme. Breschi and Cusmano (2004) find high clustering and low average distance for the network of firms, universities and research institute participating to the 3rd and 4th Framework programmes.

A question that has not been addressed by the empirical literature on the technological networks is the identity of firms that activate “short cuts” between separated cliques. However, from a methodological point of view, it is worthwhile to mention the work by Baum *et alii* (2003). Their research question is concerned with the formation of “small world” network. Their theory is that small world structure emerges from cliquish network, through clique-spanning ties. They want to understand the identity of the actors that activate such ties. They propose three alternatives explanations: 1) chance: while firms add new links, this increase the probability that some of them will be outside the cliques; 2): insurgent partnering, activated by peripheral firms in the network that aim at increasing their status; 3) control partnering, activated by central firms that attempt to preserve their privileged position. They consider the network of investment banks, emerging from underwriting syndicates. Firms are Canadian, and the sample period is 1952-1990. They find support for all the three explanations, but especially for the chance and insurgent partnering motive.

This kind of exercise seems worthy to be replicated on interfirm technological alliances networks. It seems reasonable to assume that the characteristics of the information that circulate in the network (information on technology vs other kind of information) may affect firms’ incentives towards clique spanning ties.

Finally, the distribution of collaborative links across firms has been studied. Typically, we observe a *hierarchy* within the firms in the network: few firms have many links and many firms have few links. The distribution of links typically follows a power law distribution ($P(k) = k^{-\gamma}$, where k is the firms’ number of links, and typically $\gamma \approx 2$): these structures are defined as scale-free networks. Barabasi and Albert (1999) show that this structure can emerge in a growing network if a preferential attachment mechanism is at work: the probability of a new connection at time $t+1$ positively depends on the number of connections a firm has at time t. We have seen in section 3 that this property is found at the firm level. Studies that find evidence of scale free networks are Krebs (2004) for the Internet Industry; Breschi and Cusmano (2004); Riccaboni and Pammolli (2002) for networks in life sciences and ICT. Typically large firms take the role of “hubs” (highly connected firms).

4. Technological agreements as explanatory variable

This section surveys the studies that treat several dimensions of firm R&D cooperative activity as explanatory variables. Sub-section 4.1 considers the fundamental question of the causal relation between technological agreements and economic and innovative perfomance. Sub-section 4.2 considers the effects of technological alliances on firm's technological specialization.

4.1 Technological agreements and economic and innovative perfomance

Close to tautology, firms enter technological agreements because they predict to increase in this way their *expected* performance. However, two questions remain relevant: first, the distribution of returns from cooperative ventures; second, a more precise quantitive assessments of such effects in general, and the factors that positively or negatively affect their magnitude.

In general, assessing the success or the failure of a cooperative venture is not an easy task: often the true goal of cooperation is not known, to the public and to partners, and also when it is the case, side effects can be important. When the termination date of an agreement is not fixed *ex ante*, its dissolution is both consistent with a failure, i.e the objective for cooperation has not been reached and cannot be reasonably reached in the future, and with a success, i.e. the goal has been reached (Kogut, 1988).

However, it is less problematic to assess the relationship between the different dimensions of a firm cooperative strategy and overall economic performance (measured in terms of rate of profits, sales growth, market shares, productivity, or survival). In some cases, object of study has been the link between innovative output and technological agreements (Sampson, 2003; Cusmano, 2005).

Several are the dimensions of cooperative strategy that have been considered.

1. Usually, a positive relationship is found between firm's participation in cooperative ventures, number of agreements and number of partners and firms' performance.

First, a number of studies with a policy orientation have aimed at estimating the effects on firms' performance of their participation to government sponsored agreement. Benfretello and Sembenelli (2002), in their sample of firms from several sectors participating to the Eureka and Third and Fourth Frameworks Programs sponsored by the European Union, find a significantly positive effect on the *ex-post* firm performance measured in terms of total factor productivity, labor productivity and price cost margin. On a similar sample, Cusmano (2005) finds a positive effect from participation in research joint ventures on innovative output for the medical and biotechnological sector, but not for information technology. Studying the performance of R&D Japanese consortia in the period, Branstetter and Sakakibara (2002) show that partecipation to the consortia increased the productivity of firms in terms of innovative output. Similar results have obtained for non-government sponsored partnerships: Siebert (1996) shows that elasticity of profit margin to R&D is higher for firms participating in Research Joint ventures filled at the US Federal registered.

The intensity of cooperative activities (measured by the number of technical agreements) has usually a positive effect on company's performance. Hagedoorn and Schakenrad (1994) find a positive effect of the intensity of strategic alliance with an R&D orientation on firm's profitability for a sample of large firms in different sectors and countries. Mitchell and Singh (1996), on a sample of US firms in the hospital software systems industry, show a positive effect of the number of technical agreements on firm's survival. In a sample of 85 biotech firms, Shan, Walker and Kogut (1994) show that commercial ties have positive effect on innovation output.

Some studies have considered the number of partners (in the social network analysis terminology, the degree centrality of the firm in the innovative network), and their characteristics, as explanatory variables.

A positive relation between sales growth and the degree centrality in the network is found by Powell *et alii* (1996) in a sample of 225 dedicated biotech firms. For plant biotechnology, Delackere *et alii* (1998) find a positive relation between the number of partners and innovative output, measured by scientific publications. Stuart (2000), in a sample of semiconductor firms, shows that partners' innovativeness has a greater impact on firm's patent rate and growth than the simple number of technical agreements, and sales of your partners matter for firms' growth especially if firms are small or young (this is explained with reference to the status enhancing effect of these alliances). Baum *et alii* (2000) consider a sample of 142 start-ups in biotechnology, and show a positive effect on firms'performance (measured by revenues, employment and patents) for the number of alliances with pharmaceutical firms, the variety in the type of partners (pharmaceutical firms, university, biotech firms, etc) and the number of alliances with rivals with a narrower product scope. As indirect evidence for the same effect, Singh and Mitchell (1996) show that a firm's likelihood of survival in the hospital software system industry decreases if a partner shuts down, and the firm does not form a new partnership.

2. A small class of studies have tried to assess the impact of characteristics at the dyadic level (or more, generally, at the project level) on firm's innovation performance. Consistent with the evidence on alliance formation, the result generally shows that technological proximity has a positive and significant effect, with evidence of an inverted U relationship. Branstetter and Sakakibara (2002), in their sample of R&D Japanese Consortia, find that technological proximity among consortium members has a positive effect on ex-post firm's patenting activity. Sampson (2003) finds an inverted U relationship between technological distance and ex-post innovation output (measured by citation weighted patent count) in sample of 463 alliances in the international telecommunication equipment industry.

3. Finally, recent papers have studied how the structure of the ego networks impacts on firms' performance. The main question has been addressed is the opposition between a notion of a social capital *à la* Coleman and the Burt's structural holes argument.
Ahuja (2000b) considers a sample of 107 chemicals firms, and investigate the roles of direct ties, indirect ties and structural holes in explaining innovation output measured by patents. He finds that direct ties (more concerned with knowledge creation) have a strong positive effect on innovation output; indirect ties (concerned with information diffusion) have a positive effect but smaller than direct ties; filling structural holes has a negative effect on innovative output; the coefficient for the direct tie-indirect tie interaction is

negative, indicating a substitution effect between the two. This result supports, then, the "social capital as closure" perspective.
Hagedoorn and Duysters (2002) consider 88 firms in the computer industry, and they use patent intensity (defined as the number of computer patents divided by size) as measure of technological performance. They find that having non redundant contacts and bridge ties has not significant effects on firm's perfomance (which contrasts with Burt's view), while multiple, repeated links with the same partner have a positive effect on firms innovative output. They claim that this result is consistent with a learning view of alliances, while it contrasts with the static, efficiency-based view by Burt.

4.1 Technological agreements and firms' technological capabilities

Together with the effects of cooperation on firms' performance, some interest has been raised by the effect of technological alliances on firms' technological profiles. An empirical assessment of this issue is relevant for two main reasons. First, such exercises can be seen as empirical test for hypothesis of technological alliances as source of learning. *Ex-post* technological convergence among partners would be consistent with such hypothesis. Second, these results have implications for a dynamic theory of partnership formation, as long as the (resulting) technological positions affect the probability of firms to form links in the following periods (Section 3.2).

There is evidence that strategic alliances are significant factors in explaining firms' movement in the technological space. Stuart and Podolny (1996) consider a small sample of 10 Japanese semiconductor firms, and they characterize their technological positions using patent citations. They find that alliances are part of the strategies of firms that want to move from a peripherical to a core position in the technological space.
However, there is evidence of an ambiguous effect of alliances on technological positions. Mowery *et alii* (1996) consider a sample of 792 alliances in several sectors. They measure firms' technological overlap by cross citation rates in patent portfolio, and they test the hypothesis of an increase in the technological overlap after collaboration. They reject this hypothesis, but they found a significant and positive effect of

collaboration in the absolute value of variation in cross citation rate. This leads the authors to distinguish between alliances through which firms acquire new capabilities (causing technological convergence, 191 alliances in their sample), and alliances in which firms aim at accessing new capabilities (leading to divergent technological positions, 601 alliances in their sample). The authors do not investigate the factors (at the level of industry, technology, or mode of organization of the alliance) that lead to one outcome or the other, nor I am aware of studies that consider this issue. This seems an interesting line of research to pursue.

5 Interfirm technological agreements and industry evolution

As the previous sections have shown, the evidence on interfirm technological agreements is becoming very rich, although some aspects still wait for a satisfactory analysis. In this section I will argue that the existing empirical knowledge can constitute the basis for an "appreaciative theory" (Nelson and Winter, 1982) that links the self-organization of R&D networks to the rate and the direction of technological progress, to the actors involved in the innovative process, and through these to the evolution of industries. The formation of R&D networks is a self organizing process because such networks are the result of uncoordinated firms' choices over time, as a function of technological variables (for instance, firms' technological positions) and economic variables (for instance, firms' size). In turn, these variables change over time as a function of the network, so that the dynamics of the system is characterized by several feedbacks, mostly positive (self-reinforcing) in nature (like, for instance, the "preferential attachment" mechanism). Such an appreciative theory, whose elements have been already put forth by some authors, at least partially (Gomes Casseres, 1996), should be of obvious interest to economists. Furthermore, it can be conceived as a step towards further empirical analysis and formal modelling, which are instead basically missing.

There are at least three, interrelated, themes that show up as important in the relationship between technological collaborations, R&D networks and industry evolution.

The first is the role of *path dependency*. If firms that are active in the network in the early stages are more likely to be central actors in the subsequent periods, and this reflects in firms' performance, events at the beginning of an industry (or network) life cycle can have long lasting effects on firms' competitiveness. Such events can be due to initial, significant differences in capabilities, or they can take the form of "historical accidents", as geographical location or preexisting social contacts among entrepreneurs. Theories of industrial dynamics with an evolutionary flavor (as industry life cycle theory, Klepper, 1997) frequently argue for the importance of first mover advantages in explaining both the prosperity of firms and some stylized facts of industry evolution, like the shake-out (i.e. the drastic reduction in the number of firms that often occurs in industry in the early stages). R&D networks seem to work in this direction, and their role in this aspect of industry evolution deserves further empirical and theoretical analysis.

The second theme, which directly refers to the first one, is related to the role of networks as both mechanism of technological knowledge diffusion for firms within the network and exclusionary mechanism for firms outside the network. This has clear implications for the evolution of industries.

If no firm possesses all the relevant technological capabilities to innovate, it is the network to act as the "locus of innovation" (Powell *et alii*, 1996). This tends to favor competition: no firms can control the market via distinctive technological capabilities. However, path dependency and self-reinforcing mechanisms, both at the firm and the dyadic level, tends to limit over time the number of actors that actively participate in the network. An oligopolistic market structure emerges, where a core of "networked" firms controls the rate and the direction of technological progress, erecting barriers to entry and to survival against firms outside the network ("knowledge-based networked oligopoly", in the terminology by Delapierre and Mytelka, 1998). This view is consistent with the so-called Schumpeter Mark II paradigm for the link between market structure and technological progress (Schumpeter, 1942): incumbent, "networked" firms are the main actors of innovation. In a policy perspective (for antitrust authorities and governments' that subsidize technological cooperation) this logic suggests that anti-competitive effects may be more dynamic than static, and this must be traded-off with the dynamic gains from an increased technological progress. Finally, the network can be composed by different cohesive sub-groups, so that competition occurs among groups, rather than at the firm level. In an industrial dynamics perspective, belonging to different groups can explain interfirm differences in exit rates, growth, economic performance and innovativeness (Gulati *et alii*, 2000).

A third theme is related to the role of network in affecting the "collective" direction of technological change in industries. The different degree to which collaborations lead to technological convergence or technological divergence among the firms in the network can matter for two main reasons.

First, from the society point of view, a certain degree of experimentation at the technological level must be preserved. Using an evolutionary terminology, variety generation mechanisms must be present. Firms need to explore different routes in environments characterized by substantive uncertainty, a distinctive feature of Schumpeterian competition. If firms in a network explore collectively the same areas of the technological space, risks of technological "lock-in" are possible. Indeed, some authors have argued that advantages of the network form of organization compared to more integrated forms lie in the capacity of preserving variety at the technological level (Kogut, 2000). Apart from the theoretical plausibility of this claim, we clearly need empirical confirmation.

Again, an important role under this respect can be played by the existence of different cliques. Even if lock-in may exist at the level of the single sub-groups of firms, this can be counterbalanced by different groups exploring different technological directions. Similarly, as argued in section 3.3, variety and access to novel information can be guaranteed by short-cuts or clique-spanning ties in a "small world" network.

Second, networks matter when firms face technological discontinuities. A traditional distinction here is between competence-enhancing discontinuities, favoring incumbent firms versus new entrants, and competence-destroying discontinuities, favoring new entrants versus incumbents (Tushman and Anderson, 1986). This distinction has been adapted to networks by Madhavan *et alii* (1998). These authors define structure reinforcing events as those discontinuities which favours incumbent firms in the network, leading to an increase in their centrality; structure loosing events as those discontinuities which favor more peripheral agents, reducing the degree of centralization in the network. Similarly, Rosenkpof and Tushman (1998) discuss the link between network intensity and the stages of technological life cycles. They show that in the flight simulation industry the rate of founding of technical agreements is high at the discontinuities, and cliques emerge in mature phases. In general there are opportunities, both at the theoretical and empirical level, for studying the role of network structures in mediating between technological discontinuities and their consequences on industries evolution. When we can distinguish between different cliques, their internal structure and the capabilities they access to may influence how they react to environmental shocks.

6. Conclusion

This paper has surveyed the several streams of the empirical literature on the phenomenon of interfirm technological alliances. As I tried to show, the evidence is rich, coming from several disciplines whose theoretical frameworks are sometimes radically different.

It seems to me, however, that an effort to obtain a more unified framework is under the way. Two different directions, both at the empirical and theoretical level, need to be pursued. At a higher level, we need theories and empirical studies that identify general mechanisms for the formation of alliances and networks and their evolution. This paper has mainly followed this perspective. At the same time, clear sectoral specificities exist, in the form of intensity of alliances, their content, their mode of alliances and network structures. All these characteristics may depend on the technological regimes that are specific to industries (Malerba, 2004). Under this respect, we need detailed case studies of network evolution, taxonomies and theories for specific mechanisms of collaboration in specific context.

Given the relevance of the phenomenon, its complexity and multidimensionality, these are surely exciting opportunities for future research.

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