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Co-operative R&D: why and with whom? An integrated framework of analysis

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Abstract

Firms use R&D partnerships to access knowledge and build global R&D networks. This article develops an integrated framework to examine the determinants of the choice of partners with which firms co-operate on R&D. This resource-based perspective underscores the interactions between three major questions: why co-operate, who does and with whom? It argues in particular that the choice of partners is dictated by the complementary resources which the latter command. The framework is then expanded to predict the relative efficiency of R&D co-operation with different partners, including suppliers, clients, rivals, academic institutions and foreign firms. The empirical analysis, which is based on responses to France's version of the second European community innovation survey (CIS-2), strongly supports the overall framework of analysis.

Keywords: Co-operation; R&D partnerships; Innovation; Resource-based theory of the firm; European R&D consortia

1. Introduction

In the context of the emerging knowledge-based global economy, both supply and demand for technology have been increasing at the world level. Since the late 1980s, the role of innovation as a factor of competitiveness and the accelerating pace of technological progress have combined to make firms deepen and broaden their innovative capabilities. Firms have allocated increasing resources to R&D to speed up the pace of innovation and diversify their technological capabilities. Firms have also designed new R&D practices, including both internal organisational changes and the building up of complex networks to deal with growing outsourcing and various types of technological partnerships. Since transactions involving the exchange of knowledge are notoriously imperfect, they tend to be embedded in various types of alliances. More frequent and diverse knowledge exchanges have thus constituted one major driving force behind the growing number of domestic and international technological alliances since the 1980s.

This article focuses on inter-firm co-operative agreements as one of the major modes firms use to access knowledge and build global R&D networks. The relative flexibility of co-operative agreements has been underscored as one of the main reasons for their remarkable development since the 1980s (Kogut, 1988; Ciborra, 1991; Teece, 1992; Gomes-Casseres, 1996; Sachwald, 1998).Strategic and organisational perspectives have further shown that the choice of co-operative R&D, rather than internal R&D, equity relationships or outsourcing, depends on the

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characteristics of the technologies involved, as well as on the characteristics of firms' competencies.[1] This article does not focus on the choice of R&D partnerships among the diverse organisational and inter-organisational arrangements that firms use to acquire technology, but rather on the choice of partners. It shows that the choice of R&D partners with a specific profile depends on the type of complementary R&D resources firms seek to access, which, in turn, depends on their own profile. Partnerships have developed in particular between high-tech (HT) start ups and larger incumbents, but also between suppliers and clients in various sectors, and more rarely between competitors. At the same time, firms tend to enter various co-operations with universities and public institutes, including as part of large research consortia. Furthermore, since national innovation systems tend to nurture specific creative activities and more generally reflect national specialisation patterns, R&D networks may have an international dimension.

The contribution of this article to the analysis of R&D co-operation is threefold. First, it develops an integrated framework which relates the set of external R&D resources firms target to the choice of partners. This resource-based perspective underscores the interactions between three major questions: why co-operate, who does and with whom? Second, this framework is used to predict the relative efficiency of co-operation with different types of partners to innovate. Third, the empirical analysis is based on a French survey of firms' innovation practices, which provides a large sample of observations. Co-operation on R&D is defined as a firm's behaviour rather than measured by a count of technological partnerships as in databases on alliances.

The paper is organised as follows. Section 2 discusses the results from the literature on the interactions between the motivation of alliances and the profile of partners. This discussion is used to build the integrated framework that relates the profile of co-operating firms with the profile of their partners, including suppliers, clients, rivals, public institutions and foreign partners. Section 3 describes the data, explains differences with 'literature-based alliance counting' data[2] and tests the set of hypotheses on the reasons for co-operation and the profile of R&D partners. Section 4 then examines the relative efficiency of R&D co-operation with the different types of partners. The conclusion summarises the results and discusses theoretical and policy implications.

2. The why–who framework of R&D co-operation

A large proportion of the literature on technological alliances has focused on the issue of the motivation for co-operation. In view of the increasing complexity and multi-disciplinarity of research, firms seek to access complementary resources from beyond their boundaries. In this context, R&D partnerships have been analysed as organisational answers to the requirements of innovation-based competition and rapid technological change, the 'why' issue being related to the forms taken by co-operation. Interactions between the motivation for co-operation and the profile of partners have been less systematically explored. This section reviews the literature with the view to establish a set of hypotheses relating the motivation for co-operation to the profile of partners. Some of these hypotheses have already been discussed in the literature and the purpose here is to build an integrated framework, which relates the R&D resources firms seek to access—why co-operate?—to their own profile—who co-operates ?—and to the profile of their partners—with whom?

2.1. Why co-operate on R&D?

The literature has extensively discussed the motivations for entering into co-operative agreements as organisational forms. The transaction cost perspective studies the circumstances under which co-operative agreements are the most efficient form of organization (Stukey, 1983; Hennart, 1988, 1991; Robertson and Gatignon, 1998). In depth studies of the attributes of the knowledge involved and of the characteristics of the innovation process itself have further contributed

[1] For different perspectives and types of empirical support, see (Kogut and Zander, 1993; Nagarajan and Mitchell, 1998; Narula, 2001).

[2] This term is used by Hagedoorn (2002) in his presentation of the MERIT-CATI database.

to the analysis of the role of internalisation in the evolution of firms' capabilities.[3] Besides, the logic of transaction cost minimisation does not capture many of the strategic advantages of alliances, and strategic management perspectives are complementary (Foss, 1994; Gulati, 1998; Tidd and Trewhella, 1997; Sachwald, 1998; Hagedoorn et al., 2000). In the resource-based perspective, partnerships are driven by a logic of strategic resource needs and, this approach is well suited to studying simultaneously the motivations of alliances and the characteristics of partners.

The resource-based perspective suggests that firms conducting expensive, risky or complex research projects will seek R&D co-operation. In turn, these firms tend to be concentrated in high-tech sectors. Sectoral studies broadly support the idea that R&D is a major area of co-operation in high-tech or emerging industries. Incumbents may use alliances to enter new product areas or technological fields, as they allow them to expand their knowledge sources with limited investment exposure. Incumbents can thus test the importance of the new market or technology as well as evaluate strategic solutions (Mitchell and Singh, 1983). Such behaviour has been well documented in the pharmaceutical industry, where incumbents have extensively resorted to alliances in order to expand their knowledge base in biotechnology (Pisano et al., 1988; Arora and Gambardella, 1990; Powell and Brantley, 1992; Sharp et al., 1994). Conversely, entry by new biotechnology firms is eased by vertical alliances with pharmaceutical, chemical or marketing firms, which possess complementary assets (Shan et al., 1994; Calabrese et al., 2000). In the emerging multimedia fields, where speed to market and innovative product combinations constitute major competitive strengths, firms actively knit networks of complementary assets (Gomes-Casseres, 1996; Quélin, 1996).

In the MERIT-CATI database, the proportion of "R&D partnerships"[4] in pharmaceuticals and information technologies has increased from 40 to 80% of the total between 1980 and 1998.[5] The positive influence of R&D intensity on the propensity to co-operate has been recently confirmed for large cross-sectoral samples of German and Spanish firms (Fritsch and Lukas, 2001; Bayona et al., 2001). The first hypothesis below is thus included to start building our integrated framework, in which the *quantity* and *quality* of R&D resources influence both the propensity to co-operate and the propensity to co-operate with specific partners.

Hypothesis 1. The propensity to co-operate on R&D is higher for firms from sectors with relatively high R&D intensity.

The strategic need for high R&D efforts may also explain intra-sectoral co-operative patterns. During the 1980s, electronic products at the earliest stages of the life cycle exhibited a higher number of R&D alliances (Cairnaca et al., 1992). Similarly, among a sample of new American semiconductor firms, the most innovative ones and those faced with the fastest pace of technological change exhibit a higher propensity to co-operate on product development (Eisenhardt and Schoonhoven, 1996).

Hypothesis 2. The propensity to co-operate on R&D is higher for firms that draw the most on scientific resources to innovate, as opposed to firms further away from the technological frontier.

The literature on innovation and technology transfer has established that access is not sufficient to learn from external knowledge sources, adequate absorption capacity being a necessary complement (Cohen and Levinthal, 1989). Absorption capabilities depend on specific investment, including in particular the existence of an R&D department and enough qualified personnel. Internal R&D capabilities have thus a complex influence on the propensity to co-operate. On the one hand, co-operation may become necessary because internal resources are insufficient to meet the firms' strategic objectives. On the other hand, the existence of adequate absorption capabilities increase

[3] Kogut and Zander (1993) studies the role of complexity and tacitness; Nagarajan and Mitchell (1998) and Narula (2001) studied the impact of the extent to which new knowledge is related to core R&D resources or to more peripheral assets.

[4] Which includes joint ventures and other inter-firm agreements that "contain some arrangements for transferring technology or joint research" (Hagedoorn, 2002, p. 491).

[5] The share of R&D partnerships in aerospace and defense has rather decreased since the 1970s, which may be related to the shrinking of defense activities in the 1990s, while IT activities have expanded.

the returns firms can expect from access to external resources. This second effect has been found to be stronger in biotechnology (Arora and Gambardella, 1990) and in a survey of UK firms (Lowe and Taylor, 1998).

Hypothesis 3. The propensity to co-operate on R&D is higher for firms with stronger absorptive capabilities.

2.2. And with whom?

This section relates the above set of hypotheses on the profile of firms that choose to co-operate on R&D to complementary hypotheses on the profile of their partners.

2.2.1. Partners with the right complementary resources

The resource-based perspective considers that the necessity for complementary resources is a key driver of inter-organisational co-operation.[6] It suggests that the adequate partners should possess the resources which the firm is seeking. The latter may be classified into two broad categories, depending on the needs of the partners. If partners aim at reducing costs and risks through economies of scale and rationalised innovation processes,[7] they will pool *similar* resources to the alliance. If partners aim instead at managing technological convergence such as in the multimedia nexus or inter-dependence among innovation processes, they will combine *complementary* resources. This distinction is crucial for choosing the right partners.

Suppliers and clients play an important part in the innovation process as they can contribute crucial information on technologies, users' needs and markets. Hence, innovation requires vertical interactions and communication flows. The latter may be more important in some sectors and may be organised in different ways, but the general need is quite pervasive. Vertical R&D co-operation is thus hypothesised to be an integral part of the innovation process, especially so now that firms tend to focus on a smaller set of businesses Bresnahan (1999) emphasises this feature in the case of the computer industry by forging the notion of 'co-invention' involving buyers and sellers.

Rivals may nevertheless possess complementary R&D resources. They may also be attractive partners to team up with in order to reduce costs and risks for large projects. They are however potentially dangerous because they sell on similar markets and may access the firm's own R&D resources through collaboration. The industrial organization literature has developed models to analyse both the incentives and the risks of and R&D co-operation. They draw attention to the risks involved in co-operation, related to involuntary 'outgoing spillovers' to partners (Cassiman and Veugelers, 1998). Such considerations suggest that co-operation between competitors is particularly risky and should be limited to two types of cases: first, when a particularly strong common interest has been identified and, second, when the co-operation concerns far-from-market research leading to generic results.

The tension between the resource considerations, which constitute an incentive to co-operate, and the risks involved, which may inhibit co-operation, is stronger in the case of alliances with rivals since risks are lower with suppliers and clients. In high-tech sectors, firms may nevertheless co-operate with rivals as they feel strong incentives to pool R&D resources and/or integrate networks in order to establish standards. The literature has amply documented such cases (Mariti and Smiley, 1983; Garrette and Dussauge, 1995), which may give the impression that co-operation with rivals is frequent.

Hypothesis 4a. Vertical R&D co-operation is more frequent than horizontal co-operation with rival firms.

Hypothesis 4b. Horizontal co-operation with rival firms is more frequent in high-tech sectors.

Co-operation with public partners does not involve commercial risk. Public research institutions do not seek commercial applications and tend to focus on the most generic or basic end of the R&D complex. Con-

[6] This perspective is widely adopted, explicitly or implicitly, by the management literature (Roberts and Berry, 1985; Kogut and Chang, 1991; Gomes-Casseres, 1996; Eisenhardt and Schoonhoven, 1996; Doz and Hamel, 1998; Mowery et al., 1998).

[7] This rationale for R&D co-operation has been explored from different perspectives, including industrial organization models (Katz, 1986; Jacquemin et al., 1985).

sortia involving a large number of firms, including rivals, tend to focus on this type of research and have often been supported by public funds (Sachwald, 1990; Sakakibara, 1997, 2001a,b; Branscomb and Keller, 1999). More generally, when co-operative research is supported by public funding, it is designed in order to maximize disclosure and spillovers.[8]

Hypothesis 5. Co-operation with public research institutions is most attractive to firms that conduct R&D at the technological frontier.

2.2.2. Why choose foreign partners?

The dynamic global competitive environment and efforts by firms to expand and reorganize their innovative capabilities have led to reconsidering a number of results from the economic literature on multinationals and on national innovation systems. Evolutionary and resource-based perspectives emphasize the stickiness of innovative capabilities. The latter evolve along specific trajectories, which depend on both geography and history as firms' capabilities are embedded in national systems of innovation. Yet, in the context of globalization, as firms strive to access external resources through webs of technology transfer and learning, they act upon national trajectories. Likewise, as internationalization provides access to foreign systems, innovative activities become somewhat less dependent on the innovation system of home countries.

International co-operative ventures can provide firms with access to country-specific advantages embedded in their partners and R&D co-operation can be viewed as a vehicle for tapping into the comparative advantages of foreign countries. The nationality of R&D partners should thus depend on the relative technological strength of their country in the relevant fields. From this perspective, there is a broad distinction between European firms and American firms as the US tends to be closer to the technological frontier in a number of high-tech sectors. Studies based on diverse data sources indeed show that European firms tend to choose American partners in sectors where the US has developed the strongest technological advantages, such as biotechnology, electronics or medical equipment (Hobday, 1994; Sharp et al., 1994; Veugelers, 1995; Mouline, 1999; Sachwald, 2000).

Hypothesis 6a. Co-operation with American partners is more frequent in sectors where the US has a comparative advantage, especially in high-tech.

Hypothesis 6b. Firms conducting research at the technological frontier co-operate more with American partners.

National innovation systems and technological specialisation are closer between European countries than between European countries and the US, co-operation R&D. As a result, intra-European R&D co-operation will typically not aim at pooling *complementary* resources. It may however be used to pool *similar* resources in order to reduce costs.

Hypothesis 6c. R&D co-operation of French firms with European partners aims at sharing the costs of innovation.

3. Testing the determinants of choice of partners

This section describes the data and presents the empirical test of the why–who framework developed above.

The empirical work is based on the French CIS-2 survey conducted in 1997 by the SESSI (Ministry of Industry) and covering manufacturing firms located in France. Questions related to innovation practices over the period 1994–1996. Albeit non-compulsory, the survey features an outstanding response rate of 85%. The sample of 4215 firms gives a reliable image of the behaviour of the manufacturing firms with more than 10 employees.[9] The survey includes a question on whether firms have co-operated in order to innovate, meaning active participation in joint R&D and projects (contracting out is thus excluded). Firms that co-operate in R&D are innovative, i.e. they have stated that they innovated over the 1994–1996 period (prod-

[8] Which corresponds to the suggestions of theoretical models on the role of disclosure within alliances (Katz, 1986).

[9] The sample weighted with the expansion coefficient represents 20,997 firms; firms with more than 500 employees are all included.

uct, process, patent). The innovative sample includes 2378 firms (9832 when weighted).

3.1. Scope of R&D co-operation in France

According to Table 1, a third of the firms choose to co-operate in R&D. This is substantial but also means that only a minority of firms enter into R&D co-operation as part of their innovative process. The proportion is substantially higher for firms from high-tech sectors (53%)[10] and for the largest firms (67%). Firms from inter-related groups of firms also tend to have a relatively high propensity to co-operate (49%), but their major partners are other firms from the group. This means that firms consider that co-operation within groups involving subsidiaries does indeed constitute co-operation. From the point of view of inter-firm co-operation, however, intra-group co-operation has to be considered as a specific case. Competitive risks are a priori much lower, which may for example be an incentive to co-operate for relatively small firms from a group. The specific contribution of intra-group R&D co-operation may also be different in nature.

The propensity to co-operate with competitors is particularly low, which confirms that firms tend to avoid R&D co-operation with rivals (Hypothesis 4a).[11] Conversely, Table 1 confirms the more important role played by clients and suppliers in the innovative process. Co-operation with academic organisations, which is substantial, is markedly more intense for the largest firms and for patenting firms.

Table 2 indicates that firms co-operate first with French partners. The domestic scope of the majority of technological partnerships has been underscored mainly in the case of the US (EU, 1997; Hagedoorn, 2002), but may actually be a quite general phenomenon. The reason for this different observation may be due to the type of data used in different studies. Databases on technological partnerships largely rely on public sources to identify alliances and thus tend to be more exhaustive on operations from large firms, and probably too on firms from the largest countries. National surveys, such as the one used here provide a better coverage of smaller firms, which tend to have a smaller geographical reach. As indicated in Table 2, large firms and firms in high-tech sectors are more likely to choose foreign partners.

The table also indicates that among foreign partners, French firms tend to first choose EU partners. As a result, intra-European alliances are substantially more frequent than transatlantic alliances—more than twice as much for all firms. The share of intra-European technological partnerships is on the contrary lower than the share of transatlantic ones in the MERIT-CATI database.[12] The source of this difference may also be the more systematic coverage of smaller firms in the CIS survey. Large firms and high-tech firms exhibit a relatively higher propensity to team with American partners.

Fig. 1 further describes the data set. It shows in particular, that R&D co-operation is relatively intense in mid-high-tech (MHT) sectors, such as chemicals and automobiles. It means that R&D co-operation in France is not strongly concentrated in high-tech sectors, which actually reflects the structure of the French industrial activities in France.

3.2. Test design

The different tests below are built on a similar design in order to test the integrated framework developed above. Dependent variables are dummy variables, which are equal to 1 when a firm co-operates on R&D with certain types of partners. The same set of independent variables is used to successively test the different hypotheses—with the exception of one variable in the test of the geographical origin of partners. This design results in a set of logit specifications, which allows a clear interpretation of the influence of the different independent variables.[13] The regression coefficients estimate the impact of the independent

[10] Kleinknecht and Reijnen (1992) reported a different result but used a broad classification to distinguish sectors and did not really isolate high-tech industries (their Table 3 includes such aggregates as chemicals and plastics and does not isolate electronics for example).

[11] For similar observations see (EU, 1997) and sectoral studies. According to data not restricted to R&D alliances, co-operation between rivals is relatively more important (Veugelers, 1995).

[12] In the 1980s and 1990s, but not in the 1960s and 1970s according to Hagedoorn (2002).

[13] A multi-nomial specification has been run, but interpretation was difficult and this design is more satisfactory to test successively the whole set of hypotheses and reflect on the framework.

Table 1
Propensity to co-operate on R&D among innovating firms by type of partner (%)

Partners	Firms' characteristics					
	All firms[a]	Groups	>500	In high-tech sector[b]	Patent in 1994–1996	New product in 1994–1996
All types of partners	33.6	49.0	66.8	52.7	47.4	40.2
Within groups[c]	16.9	33.6	50.1	31.6	24.8	21.8
Clients	15.0	20.9	27.9	23.5	21.8	20.9
Suppliers of components	11.6	17.3	33.5	22.2	18.9	16.8
Suppliers of equipment	8.8	13.2	28.9	16.6	14.6	11.9
Competitors	4.3	7.3	15.4	12.8	7.1	5.5
Universities, institutions	13.3	19.8	37.6	22.1	25.8	16.2
Number of firms[a]	9832	4766	717	608	3044	4377

[a] Innovative firms of the survey with more than 10 employees; weighted numbers (unweighted total is 2378). The propensity to co-operate is the ratio of the number of firms that co-operate over the total number of firms.
[b] OECD classification.
[c] Inter-related groups of firms including subsidiaries (50% threshold).

variables on the probability that the firm will conduct co-operative R&D, either in general or with specific partners.

3.2.1. *Dependent variables*

The dependent variable in the first test is a dummy variable which is equal to 1 when the firm co-operates to innovate, whatever its partners. It thus provides a general perspective on the determinants of R&D co-operation and a sort of baseline for the other tests, which address the hypotheses on the choice of partners. They are conducted on the sample of firms which co-operate and each singles out one type of co-operation. To test for the determinants of co-operation with rivals for example, the dependent variable is a dummy variable which is equal to 1 if the firm co-operates with rival partners, and 0 otherwise. The dependent variable is designed in the same way for other types of partners: clients or customers, public institutions.

In the case of foreign partners, the sample is reduced to firms co-operating with American and/or European firms in order to specifically identify the determinants of the choice of an American or of a European partner. In the test of the determinants of R&D co-operation with US partners for example, the dependent variable is a dummy which is equal to 1 when firms co-operate with American partners and 0 otherwise. The sample is further restricted to French firms, as foreign subsidiaries tend to co-operate with their parent company.

3.2.2. *Independent variables*

Four sets of independent variables are included as determinants of the propensity to co-operate in R&D; they relate to sectoral characteristics, firms' character-

Table 2
Geographical distribution of partners, in percentage of the firms that co-operate on R&D[a]

Nationality of partner	Firms' characteristics				
	All firms[b]	>500	In high-tech sector[c]	Patent in 1994–1996	New product in 1994–1996
French	83.3	88.4	87.0	85.6	83.0
European	44.3	69.4	57.4	51.8	50.4
American	19.9	45.3	36.4	29.3	25.3
Japanese	6.5	19.1	12.1	10.7	8.7
Others	9.2	14.5	16.5	10.5	11.4

[a] As indicated in Table 1, these represent 33% of the total of innovative firms.
[b] Innovative firms of the survey with more than 10 employees; weighted numbers (unweighted total is 2378).
[c] OECD classification.

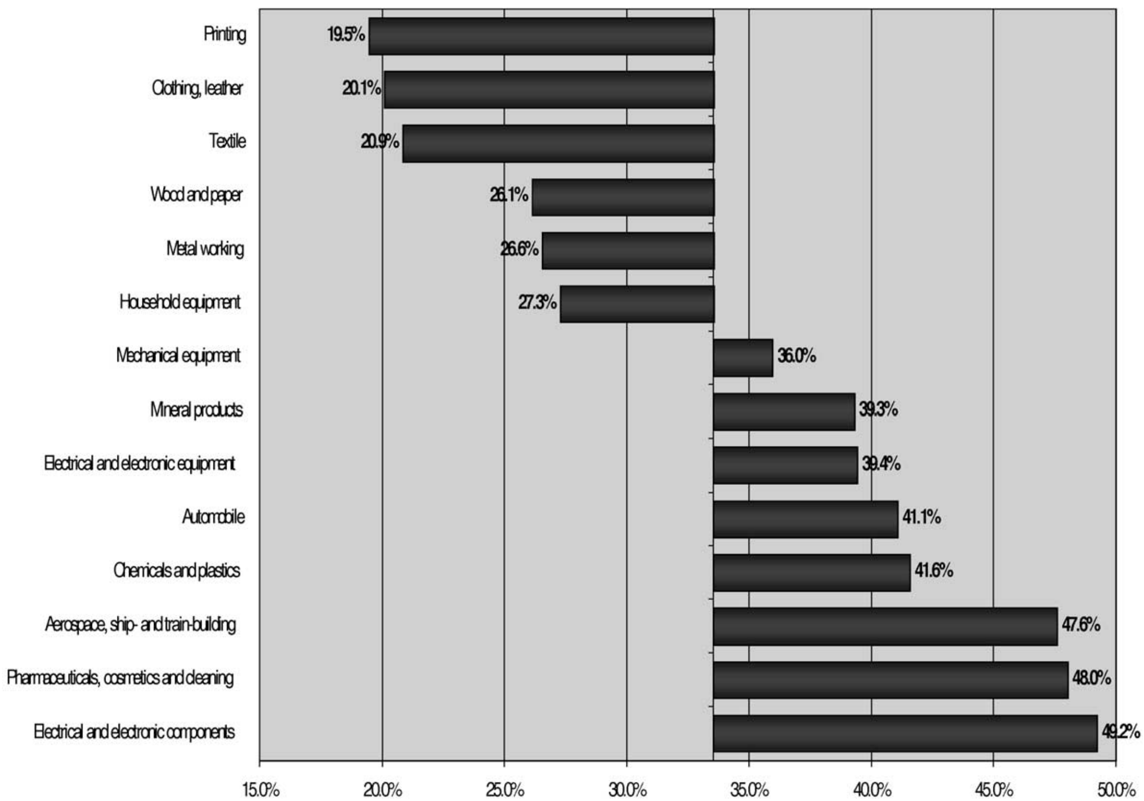

Fig. 1. Propensity to co-operate on R&D among innovating firms, by sector. Note: as in Table 1, the propensity to co-operate is the ratio of the number of co-operating firms to the total number of firms. The average propensity in the total sample is 33.6% (Table 1).

istics, obstacles to innovation and public funding. The focus of the discussion below is on R&D variables, which are central to our hypotheses.

3.2.2.1. Sectoral variables. In order to test Hypothesis 1, sectoral R&D intensity variables are introduced. Dummy variables are included to indicate whether the sector to which the firm belongs is high-tech, mid-high-tech, mid-low-tech (MLT) or low-tech (LT), using OECD classification. Fig. 1 above suggests to expect a positive influence of both HT and MHT on the propensity to co-operate.

The discussion above argues that the propensity to co-operate with partners of a given country should depend on their competitive advantage. Hypothesis 6a is based on the idea that firms' competitive advantage are related to national comparative advantage. A measure of the US comparative advantage (USCA) is introduced in the equation of the propensity to co-operate with American firms, and a positive impact is expected.

3.2.2.2. Firms' characteristics. Most statistical studies show that the propensity to co-operate in R&D is positively related to the size of the firm (Bayona et al., 2001; Fritsch and Lukas, 2001).[14] Veugelers (1997) goes deeper into this issue by exploring the interactions between internally financed R&D expenditure and co-operation. She finds that big R&D

[14] Kleinknecht and Reijnen (1992) found no influence of firms' size on the propensity of Dutch firms to co-operate in R&D (except for co-operation with research institutes). This surprising result may be due to the fact that the estimate of the probability to co-operate included other independent variables positively related to size, in particular the propensity to export and the existence of an R&D laboratory in the firm.

spenders have a significantly higher probability of co-operating, but that smaller innovative firms are more likely to co-operate than larger ones. In other words, the most relevant variable would not be the size of the firm but the research orientation of firms.[15] Furthermore, the existence of a permanent R&D structure within firms positively influences their propensity to co-operate (Kleinknecht and Reijnen, 1992; Veugelers, 1997; Colombo and Garone, 1998; Bayona et al., 2001).

Having no data on the amount of R&D spending, we include both the size of firms (log of the number of employees) and an indicator of their absorption capacity (dummy variable for internal R&D) as independent variables. They should both have a positive influence on the propensity to co-operate (Hypotheses 1 and 3). "Science", is introduced to test Hypothesis 2; its value varies between 0 and 9 as the firm draws more heavily on external sources close to scientific research, including patents, universities and research institutes. Science should positively influence the probability to co-operate on R&D.

The market share of each firm is also included in log form as it influences incentives to innovate and may thus increase the propensity to co-operate.[16] Finally, since descriptive statistics in Table 1 underscore the extent of intra-group R&D co-operation, we incorporate group as a control variable. It is a dummy that is equal to 1 when the firm belongs to a group. Group should influence positively the propensity to co-operate. Besides other reasons, both the size of the firm and its integration into a group may have a positive influence on co-operation as they indicate access to a substantial pool of resources which are complementary to R&D.[17]

[15] Interestingly in this perspective, Arora and Gambardella (1990) found no statistically significant influence of the size of biotechnology firms on their propensity to co-operate with firms or universities. On the contrary, the number of patents had a positive influence on the number of partnerships.

[16] The role of R&D co-operation in oligopolistic sectors has been emphasised (Delapierre and Mytelka, 1998; Sakakibara, 2001a,b).

[17] Lowe and Taylor (1998) suggest that the positive influence of size on the inward licensing could be due to the fact that it is a proxy for complementary assets that are necessary to benefit from licensing.

3.2.2.3. Obstacles to innovation. R&D co-operation is motivated by not only the need to draw on complementary external resources but also by the risks and costs of innovation. It may help in overcoming a number of specific obstacles to innovation. Co-operative behaviour may thus be positively related to a number of obstacles to innovation. The following ones are included with dummy variables: cost of innovation, high risks, and lack of market information. Variables are constructed with firms' answers in the CIS survey on questions about obstacles to innovation.

3.2.2.4. Public funding. Public funding tends to have a positive influence on firms' R&D spending. Veugelers (1997) considers that public funding thus has an indirect influence on the propensity to co-operate in R&D. The European innovation policy as well as national schemes sponsor co-operative R&D projects, which may constitute a further incentive to co-operate. The survey questionnaire does not allow distinguishing this specific source of R&D funding. As a consequence, equations include a public funding dummy, which is equal to 1 when the firm benefits from R&D subsidies.

3.3. Results

The equations have a good explanatory power and strongly support the set of hypotheses which build our integrated framework of interpretation of co-operative R&D.

3.3.1. Propensity to co-operate on R&D

Table 3 presents the results of the first test on the determinants of R&D co-operation, which may be considered as a reference points for the other tests on co-operation with specific partners.

The hypotheses founded on the resource-based theory of the firm and the need to access complementary R&D resources are strongly supported. Firms from high-tech, but also from mid-high-tech sectors tend to co-operate more than firms in less R&D intensive sectors (Hypothesis 1). Moreover, firms which conduct R&D close to the technological frontier also exhibit a higher propensity to co-operate on R&D (Hypothesis 2). The positive interactions between internal R&D capabilities and co-operation with external partners are also confirmed (Hypothesis 3): The exis-

Table 3
Determinants of R&D co-operation

Variable name	Coefficient	$P > \chi^2$
Constant	−6.8836	0.0001
Size	0.8103	0.0001
Group	0.5461	0.0001
Public Funding	0.4059	0.0001
Permanent R&D	0.2921	0.0061
High-tech	0.2739	0.0390
Mid-high-tech	0.1551	0.0761
Science	0.1526	0.0001
Market share	0.1069	0.0174
Lack of technological information	0.1315	0.1428
High cost	0.0340	0.7071
High risk	−0.0449	0.6146
Lack of market information	−0.0389	0.6424
McFadden R^2	27.73	–
log Likelihood	−2424.88	–
Probability (LR stat)	0.000	–

Sample: 2378 firms (weighted: 9832).

tence of an internal laboratory in a firm substantially increases its probability to co-operate on R&D. Overall, the set of variables indicating a strong research orientation of firms substantially increase their propensity to co-operate Interestingly, variables related to the various obstacles to innovate, including costs and risks, do not influence the propensity to co-operate.

The test also confirms results from previous empirical work discussed above, such as the positive influence of size and public funding. A high market share also stimulates co-operation on top of the size effect. So does belonging to a group, as suggested by Table 1.

3.3.2. *Choice of partners*

In order to examine the more specific determinants of co-operation with each type of partner, the sample is now restricted to firms that co-operate. Table 4 clearly shows that co-operation with different types of partners is driven by quite different factors.

Co-operation with rivals, which is relatively rare (Hypothesis 4a), is substantially more likely in high-tech sectors and, to a lesser extent, in mid-high-tech sectors (Hypothesis 4b). Conversely, vertical co-operation is relatively more frequent in low-tech sectors.[18] Vertical co-operation involves firms which consider that the lack of market information constitutes an obstacle to innovation and they might resort to co-operation with clients in particular to alleviate these problems. Firms that co-operate with rivals do not face similar obstacles. Rather, they cite R&D costs as an obstacle to innovation. This tends to confirm that rivals team up in order to exploit economies of scale and reduce individual costs of innovation in high-tech sectors, as argued above.

According to Table 4, permanent R&D does not significantly influence the relative propensity to co-operate with private partners. On the contrary, it strongly influences the propensity to co-operate with public institutions. Firms which co-operate with public institutions are not concentrated in R&D intensive sectors. They tend, however, to draw on close to science resources to innovate (Hypothesis 5). Consequently, they exhibit different features from firms that co-operate with rivals, which are concentrated in high-tech sectors but do not focus specifically on frontier R&D in their respective sectors. This may be related to another contrasting feature between the determinants of the two types of partnerships: firms co-operating with public institutions do not encounter cost obstacles to innovation (the cost variable has a significantly negative impact), while it is the case with firms which partner with rivals. On the contrary, firms that co-operate with public institutions consider that insufficient market information constitutes an obstacle to innovation. This may be because their R&D activities aim at more radical innovation for which markets are still uncertain. These firms may not devote much resources to marketing either.

Overall, these empirical tests strongly support our framework. In particular, they show that more *research oriented* firms are more likely to co-operate on R&D. Our results further suggest that conducting research close to science and exhibiting high R&D intensity are two different ways to be research oriented: each requires specific types of resources, which explains co-operation patterns. Using the above distinction (Section 2.2.1), we may say that co-operation with rivals aims at pooling *similar* resources to face high R&D costs, while co-operation with universities targets *complementary* resources to work at the technological frontier.

[18] The coefficient of mid-high-tech is negative and that of high-tech is non significant, which means that the sectors where vertical co-operation is relatively more frequent are low- and mid-low-tech.

Table 4
Determinants of R&D co-operation according to type of partner

Variable name	Coefficient ($P > \chi^2$)		
	Vertical co-operation	Co-operation with public institutions	Co-operation with rivals
Constant	−5.529 (0.000)	−6.907 (0.000)	−7.635 (0.000)
Size	0.898 (0.000)	0.748 (0.000)	0.727 (0.000)
Group	−0.358 (0.007)	−0.296 (0.100)	0.299 (0.344)
Public funding	0.158 (0.140)	0.585 (0.000)	0.583 (0.001)
Permanent R&D	−0.034 (0.810)	0.528 (0.034)	−0.037 (0.903)
High-tech	−0.135 (0.401)	−0.394 (0.039)	0.585 (0.012)
Mid-high-tech	−0.216 (0.050)	0.090 (0.410)	0.131 (0.498)
Science	0.008 (0.734)	0.342 (0.000)	0.005 (0.901)
Market share	0.068 (0.220)	0.094 (0.161)	0.060 (0.548)
Lack of technological information	0.032 (0.767)	0.049 (0.704)	0.108 (0.561)
High cost	0.048 (0.656)	−0.221 (0.091)	0.496 (0.008)
High risk	0.150 (0.164)	−0.075 (0.563)	0.065 (0.729)
Lack of market information	0.191 (0.059)	0.228 (0.066)	−0.042 (0.812)
McFadden R^2 (%)	20.80	29.95	21.39
log Likelihood	−1408.76	−975.64	−549.43
Probability (LR stat)	0.000	0.000	0.000

Sample: 1060 firms (weighted: 3300).

3.3.3. *International R&D co-operation*

Table 2 clearly showed that French firms co-operate first and foremost with French partners. It also suggested that the more distant the partner, the less likely the co-operation. All firms exhibit these patterns, but the largest ones and firms from high-tech sectors co-operate relatively more with distant foreign partners from the US and Japan. Table 5 further shows that firms which co-operate with geographically distant partners also co-operate with French and European partners.

This observation may be related to the above discussion to say that domestic and European partnerships are easier to strike and that partnerships with American or Japanese firms are entered into only when the stakes are high enough. There would thus be a hierarchy of R&D co-operation. The following results about Hypotheses 6a–6c tend to confirm this prediction.

Table 5
Geographical hierarchy in R&D partnerships

Firms that co-operate with	Firms that also co-operate with			No. of firms
	France	UE	US	
UE	88%	–	–	330
US	89%	69%	–	171
Japan	90%	71%	65%	71

Table 6 gives the results of the equations on the determinants of R&D co-operation with US partners on the one hand and EU partners on the other hand. As explained above, the sample is reduced to French firms that co-operate with EU and/or US partners.[19]

Results strongly support Hypothesis 6a as the technological and comparative advantage variables have a sizeable positive impact on the propensity to co-operate with American partners. Firms co-operating with American allies are concentrated in high- and mid-high-tech sectors. Moreover, they belong to sectors in which the US exhibits a comparative advantage. Hypothesis 6b is also strongly supported. Actually, "science" has not been included as an independent variable because nearly all firms that co-operate with the US use external sources of innovation close to science. Accordingly, firms that co-operate with the US may be considered as working closer to the technological frontier than other firms, including those that co-operate with European partners. On the contrary, firms co-operating with

[19] Tests have not been conducted for partnerships with Japanese firms because very few cases are left once subsidiaries of Japanese groups in France are eliminated.

Table 6
Determinants of R&D co-operation with US vs. EU partners

Variable name	Coefficient ($P > \chi^2$)	
	Co-operation with US partners	Co-operation with EU partners
Constant	−9.268 (0.000)	−5.938 (0.000)
Size	0.759 (0.000)	0.666 (0.000)
Group	1.496 (0.050)	0.565 (0.040)
Public funding	0.741 (0.012)	0.496 (0.008)
High-tech	1.225 (0.003)	0.050 (0.867)
Mid-high-tech	1.064 (0.002)	0.400 (0.063)
US comparative advantage	0.303 (0.057)	0.012 (0.929)
Lack of technological information	0.761 (0.013)	−0.124 (0.544)
High cost	−0.441 (0.179)	0.435 (0.032)
High risk	−0.354 (0.276)	0.081 (0.692)
Lack of market information	0.464 (0.136)	0.105 (0.596)
Market share	0.282 (0.084)	0.319 (0.001)
McFadden R^2 (%)	36.71	27.88
log Likelihood	−174.458	−403.648
Probability (LR stat)	0.000	0.000

Sample: 422 firms (weighted: 1565).

US or EU partners all tend to have an internal R&D capability.

The French firms, which choose to co-operate with American partners, tend to consider that lack of technological information constitutes an obstacle to innovation. This observation, along with the other technological variables, strongly suggests that they are seeking access to crucial complementary R&D resources through their transatlantic partnerships. On the contrary, they do not consider that they face cost obstacles to innovate. This is in stark contrast to the French firms that concentrate on intra-European co-operation since the latter mention cost rather than technological obstacles. This supports Hypothesis 6c, according to which French firms resort to intra-European partnerships in order to share costs rather than access specific R&D resources. This conclusion is reinforced by the fact that intra-European co-operations are not concentrated in high-tech sectors but rather in mid-high-tech industries, in which a number of European countries hold traditional comparative advantages.

Since large firms co-operate relatively more with American partners, a similar test has been run on the sample of French firms with more than 500 employees that co-operate with European and/or US partners (not reproduced here). The equation not as significant as the one in Table 6,[20] but the results on the determinants of co-operation with US partners are similar. In particular, the lack of technological information has a significant positive impact, as well as US comparative advantage. One difference for the large firms is that belonging to mid-high-tech sectors increases the probability to co-operate with US partners, while the high-tech variable is positive but not significant.

In conclusion, French firms co-operate relatively little with American firms, but do so to access high quality complementary R&D resources close to the technological frontier in high- and mid-high-tech sectors. These resources should thus be particularly efficient to enhance the innovative capabilities of French firms.

4. Efficiency of R&D co-operation with different partners

As a complement to the analysis of the determinants of co-operation with different partners, we now explore the relative efficiency of co-operation with different partners. The dependent variables are two

[20] *Group* and *permanent R&D* variables have not been included because nearly all large firms belong to groups and have permanent R&D.

Table 7
Determinants of patenting and product innovation

Variable name	Coefficient ($P > \chi^2$)	
	Patenting	Share of innovative products in turnover
Constant	−7.538 (0.000)	−6.837 (0.000)
Size	0.914 (0.000)	0.987 (0.000)
Group	−0.062 (0.572)	−0.080 (0.433)
Public funding	0.449 (0.000)	0.010 (0.917)
Permanent R&D	1.279 (0.000)	0.497 (0.000)
Science	0.484 (0.000)	−0.075 (0.592)
High-tech	−0.190 (0.189)	0.274 (0.038)
Mid-high-tech	0.016 (0.858)	0.061 (0.482)
Co-operation	0.213 (0.012)	0.191 (0.018)
Market share	0.201 (0.000)	0.231 (0.000)
McFadden R^2 (%)	30.13	30.12
log Likelihood	−2275.98	−2528.68
Probability (LR stat)	0.000	0.000

Sample: 2378 firms (weighted: 9832).

different indicators of innovation, patenting and the share of innovative products in turnover.[21] These two types of results are quite different and require different resources, which may have an impact on the role assigned to co-operation in the innovation process. Patenting requires substantial R&D efforts close to the technological frontier, while introducing successful new products rather requires efficient interactions between R&D and other functions, such as production and marketing.

This analysis builds on the general framework and independent variables are the same as in the equations above, except for the indicators of obstacles to innovation. New independent variables are introduced to take co-operation into consideration. They are dummy variables that take the value of 1 if the firm co-operates in order to innovate, or if it co-operates with a specific type of partner. The distinctions between partners are the same as above: clients or suppliers, rivals, public institutions, American and European firms.

4.1. R&D co-operation is efficient

Following the same research design as for the determinants of co-operation, we first estimate the impact of R&D co-operation on innovation, whatever the type of partner. The estimates in Table 7 will thus serve as a sort of baseline, as did those in Table 3 in the case of the determinants of co-operation.

Equations have very good overall explanatory power and variables have the expected impact on innovation. Size, market share, permanent R&D and public funding all tend to increase the probability to patent. Although public funding does not influence the share of innovative products in turnover, belonging to a high-tech sector does. Sectoral variables do not influence the propensity to patent, which may be due to the fact that the dependent variable is the probability to patent, rather than the number of patents. Interestingly though, the proximity to science has a positive impact on patenting, while it does not influence the share of innovative products in turnover.

In both equations, R&D co-operation exhibits a significant positive impact on the propensity to innovate. R&D co-operation thus appears to be efficient in terms of innovation. In order to follow on the distinction between partners, the issue is now to examine whether co-operation with different types of partners influences the propensity to innovate, or the types of innovative results.

4.2. Different partners contribute different resources to the partnership

The exploration of the choice of partners above shows that it corresponds to the specific profile of firms and to their specific needs. According to our framework of analysis, co-operation with different partners should thus yield different results in terms of innovation. In particular, vertical co-operation may be rather efficient in terms of new products, while it may not be helpful for conducting research at the technological frontier and for generating patents. Co-operation with public institutions should on the contrary give access to close to science research capabilities and should thus increase the ability of a firm to come up with patents.

Hypothesis 7a. Vertical co-operation positively influences the propensity of firms to introduce new products.

Hypothesis 7b. Co-operation with public institutions increases the capability of firms to con-

[21] Both are taken from the CIS survey.

duct research at the technological frontier and to patent.

Our results above suggest that co-operation with rivals is rare and mostly motivated by the need to share costs. It should thus stimulate costly research. The latter may generate both new products and patents and it seems difficult to distinguish them a priori, so no hypothesis is made on the specific impact of co-operation with rivals.

The results in Table 8 are similar to those of Table 7, and we focus our comments on the distinctive influence of co-operation with different partners. The equations clearly support both Hypotheses 7a and 7b. Patenting is positively influenced by co-operation with public institutions, but not by other types of co-operation. Conversely, the share of innovative products in turnover is only increased by vertical co-operation.

Co-operation with rivals shows no significant influence on innovation. The correlation table[22] nevertheless indicates a slight correlation (12%) between co-operation with rivals and both indicators of innovation. This correlation is smaller than between innovation and other types of co-operation; besides, there is a slight correlation between co-operation with rivals and with public institutions. Co-operation with rivals may thus play an important role, but it is difficult to disentangle its specific contribution, especially as it is relatively rare. Results from this paper as well as what we know from case studies suggest that co-operation with rivals focuses on pre-competitive projects, which often also involve public funding and co-operation with public research institutions. This is the case in particular with the EU-sponsored research consortia, to which French firms actively participate (Mustar and Larédo, 2002).

4.3. Transatlantic co-operation is more efficient

Our results on the determinants of co-operation suggests that French firms resort to transatlantic R&D alliances in order to access complementary resources in high-tech sectors where American firms tend to have strong competitive advantages. They further indicate that French firms seek transatlantic rather than European partners whenever they conduct research at the technological frontier. As a consequence, our framework predicts that transatlantic co-operation will particularly influence the ability of firms to patent, which should not be the case with intra-European co-operation.

Hypothesis 8. Transatlantic R&D co-operation positively influences the propensity of firms to patent.

In order to test this hypothesis, new independent variables are introduced. Three types of alliances are distinguished with dummy variables: co-operation with French partners only, co-operation with European partners, and co-operation with American partners—which, tends to come on top of European co-operation (Table 5).

Results clearly support Hypothesis 8 as only transatlantic R&D co-operation has a significantly positive impact on the propensity to patent. Both transatlantic and intra-European co-operation have a positive influence on the share of innovating products in turnover. On the contrary, co-operation with French firms only does not significantly influence innovation, whatever the indicator.

Combining the results of the different tests on the determinants of co-operation and on its influence on innovation indicates that there does exist a hierarchy of co-operation, as suggested in the discussion of Table 5 above. Co-operation with American firms, which is relatively rare, is motivated by the need to access specific R&D resources, and indeed serves knowledge transfer, including close to the technological frontier. In contradistinction, co-operation with European firms is motivated by cost economising and only promotes product innovation, albeit not as much as transatlantic co-operation.

This conclusion is quite complementary to that of Giarratana and Torrisi (2002), who have conducted an analysis of the influence of co-operative agreements on patenting by 15 European electronic firms over the period 1984–1997. They do not measure any significant impact of EU-sponsored co-operative agreements, or of private only intra-EU agreements on the share of these firms in world patents.[23] On the con-

[22] Not reproduced here.

[23] Patents filed by the 15 firms are classified into 14 categories and the performance measure is the yearly increase in the world share of each firm's patents in each category.

Table 8
Distinctive influence of different types of co-operation on innovation

Variable name	Coefficient ($P > \chi^2$)	
	Patenting	Share of innovative products in turnover
Constant	−7.455 (0.000)	−6.785 (0.000)
Size	0.903 (0.000)	0.978 (0.000)
Group	−0.038 (0.723)	−0.066 (0.511)
Public funding	0.429 (0.000)	0.023 (0.813)
Permanent R&D	1.261 (0.000)	0.484 (0.000)
High-tech	−0.1658 (0.248)	0.263 (0.046)
Mid-high-tech	−0.001 (0.076)	0.067 (0.446)
Co-operation with public institutions	0.389 (0.000)	0.042 (0.689)
Vertical co-operation	0.094 (0.311)	0.200 (0.024)
Co-operation with rivals	0.119 (0.433)	0.163 (0.282)
Market share	0.198 (0.000)	0.232 (0.000)
McFadden R^2 (%)	30.59	30.17
log Likelihood	−2275.945	−2526.997
Probability (LR stat)	0.000	0.000

Sample: 1060 firms (weighted: 3300).

trary, R&D co-operation with extra-EU entities, which means mostly US partners, positively influences the patenting performance of the European electronics companies. Their interpretation is that this stark difference is due to the complementarity of the resources of extra-EU partners with those of European firms. This interpretation is very much in line with the argument developed in Section 2 above and with our results, which underscore the cost-economising rationale for intra-EU co-operations. They further note that EU co-operation tends to focus on incremental innovation along firms' trajectories, especially when they are sponsored by EU research funds. Such co-operation makes it possible to share costs and introduce new products rather than explore new trajectories, which also dovetails with our own results related to the distinction between the different types of innovation performance. Table 9 shows that co-operation with

Table 9
The specific influence of transatlantic R&D co-operation

Variable name	Coefficient ($P > \chi^2$)	
	Patenting	Share of innovative products in turnover
Constant	−7.017 (0.000)	−6.130 (0.000)
Size	0.857 (0.000)	0.835 (0.000)
Group	−0.082 (0.503)	−0.005 (0.966)
Public funding	0.597 (0.000)	0.006 (0.963)
Permanent R&D	1.130 (0.000)	0.527 (0.000)
High-tech	−0.167 (0.356)	0.227 (0.163)
Mid-high-tech	0.042 (0.719)	0.062 (0.585)
Co-operation with French partners only	0.065 (0.618)	−0.163 (0.210)
Co-operation with European partners	0.230 (0.132)	0.280 (0.059)
Co-operation with American partners	0.362 (0.041)	0.366 (0.035)
Market share	0.250 (0.000)	0.246 (0.000)
McFadden R^2 (%)	29.23	25.82
log Likelihood	−1577.64	−1770.99
Probability (LR stat)	0.000	0.000

Sample: 1645 (weighted: 7721).

American partners is relatively more efficient in terms of innovation, especially for more radical innovation.

5. Conclusion

The empirical results above strongly support the *why–who framework*, which relates the objectives firms assign to R&D co-operation, the profile of partners they choose to team up with and the benefits in terms of innovation. In other words, the very reasons that explain why firms co-operate, simultaneously determine with whom they co-operate. In conclusion, we compare these results with those of previous studies before discussing their theoretical and policy implications.

5.1. Technology seeking and choice of partners

The empirical test of our framework has consisted in a thorough examination of the interactions between the reasons for co-operation and the profile of R&D partners. It has focused on the technological profile of firms, with a detailed treatment of the R&D indicators at both the sectoral and firm levels.

Overall, technology seeking emerges as a major motivation for R&D co-operation. Bayona et al. (2001), who have studied the case of Spanish firms based on a similar large survey, have also underscored the importance of technology access, rather than market access as a determinant of R&D co-operation. This result may seem quite logical since such co-operation focuses on research capabilities. It is very much in line with the literature on technological co-operation and in particular with a number of case studies and sectoral analyses. It has nevertheless been somewhat blurred in more general studies of co-operation. Indeed, another major rationale for co-operation is market access, especially in foreign countries. In such cases, co-operation typically does not focus on R&D, even if it may involve technology transfer or product development, such as in numerous international joint ventures.

Our framework nevertheless suggests that technology seeking is not the main objective of all R&D co-operations. In vertical R&D co-operation with suppliers or clients, the objective is to pool complementary resources and access more market information, presumably to better target innovation efforts. This confirms the perception that vertical R&D co-operation has become an important aspect of the incremental, day-to-day innovative process. Consequently, vertical co-operation is not more frequent in high-tech sectors and does not involve firms working at the technological frontier. Conversely, co-operation with public institutions involves firms that draw heavily on close to science external R&D sources. Moreover, such R&D co-operation has a positive impact on patenting, while vertical co-operation only impacts the introduction of new products to the market. Co-operation with rivals, which is quite rare, seems to be mostly used to share R&D costs in high-tech sectors—and not to work at the technological frontier.

Similarly, technology seeking only partly explains the geographical pattern of R&D co-operation. French firms in high- and mid-high-tech sectors that need complementary technological resources tend to team up with American partners, especially in sectors where the US enjoys a comparative advantage. The French firms that choose European partners exhibit quite a different profile. They tend to belong to mid-high-tech and not to sectors where the US has a comparative advantage. Moreover, they consider that costs, rather than technological information, constitute an obstacle to innovation. These results combined suggest that firms which co-operate with EU partners tend to belong to mid-high-tech sectors, where a number of European countries traditionally enjoy a comparative advantage, such as chemicals or automobiles,[24] and where they can pool similar R&D resources. Intra-EU co-operation is also active in some high-tech sectors where European firms are quite competitive, such as telecommunications, but even in these sectors, transatlantic co-operation has been very dynamic.[25]

5.2. A resource-based perspective

Results support the *why–who framework*, which is founded on a resource-based perspective. Firms

[24] As also suggested by other studies on alliances, including technological partnerships, such as Sachwald (1994) or Veugelers (1995).

[25] These sectoral details have been tested but results are not reproduced. They match earlier studies such as Duysters and Hagedoorn (1996) or EU (1997).

engage in R&D co-operation in order to complement their internal resources and accordingly team up with partners who control the relevant complementary resources—which are not necessarily frontier technologies. This resource-based perspective has been extended to interpret the geographical pattern of R&D co-operation. Firms tend to draw on their home country-specific resources in order to build up their competitive advantages. As a result, firms may view R&D co-operation with foreign partners as a way to access indigenous resources from the latter's home country. We indeed found that the comparative advantage in high-tech sectors embedded in American firms is an important determinant of transatlantic R&D co-operation. When viewed from this perspective, cross-border R&D co-operative agreements constitute one important aspect of the internationalization of R&D, which is increasingly driven by technology seeking.

The resource-based perspective also accounts for the matching condition in partnerships. Firms that engage the most in R&D co-operation, including with rivals or distant partners, are *high-profile innovators*. These firms invest heavily in R&D and resort to various types of transactions in order to access and use the relevant R&D resources. In particular, they have permanent internal R&D facilities and use close to science sources of information in their innovative process. Our results on this point corroborate previous studies, which found positive interactions between internal R&D, technology acquisition and co-operation (Arora and Gambardella, 1990; Veugelers, 1997; Bayona et al., 2001; Fritsch and Lukas, 2001). These results also match other studies, which emphasize the need for firms to possess technological resources in order to acquire high-quality complementary resources. Studies on patenting strategies have emphasised in particular the need to build up a strong patent portfolio in order to be able to engage in extensive cross-licensing in some high-tech sectors such as semiconductors (Grindley and Teece, 1997; Hall and Ham, 1999). More generally, "firms must have resources to get resources" (Eisenhardt and Schoonhoven, 1996). High-profile innovators are thus logically the most active R&D partners: they possess a wide array of high-quality R&D resources, which both makes them attractive partners and enables them to draw and absorb the most from co-operation.

5.3. *Policy implications*

Our results on the determinants and results of international co-operation suggest that these firms' characteristics are more important than public incentives which aim at promoting a specific pattern of co-operation. This has clearly surfaced in the above discussion of the choice of American partners by French firms. According to this discussion and our results, transatlantic co-operation is more efficient in terms of innovation than intra-European co-operation. This should be considered as part of the assessment EU programs, which have promoted co-operative research among European firms in sectors where catching up with American or Japanese competitors was considered as an important objective. In the 1980s and early 1990s, it has been the case in particular in information technologies, and more particularly in microelectronics. The above results suggest that these co-operations may have mainly served at sharing fixed R&D costs and avoiding duplication by pooling resources. From this perspective, they would be similar to the Japanese R&D consortia of the 1970s, when government policy emphasised large-scale projects (Sakakibara, 2001a,b). When firms rather need to access specific complementary resources to innovate in new technological areas, our results show that they tend to team with extra-European partners.

Uncited references

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