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Incentives and forms of cooperation in research and development

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Abstract

The paper examines the main factors that affect the incentive to cooperate in R&D, inquiring into the effects of cooperation on incentives to innovate in both a complete and an incomplete contract framework. It considers several forms of cooperative agreements and studies the circumstances that make one type of cooperation, more likely than others, to emerge.

Theoretical considerations suggest that two of the main factors are uncertainty and spillovers. Further, the incentive to cooperate may be greater or less among symmetric than among asymmetric firms, depending on the source of the asymmetry.

When firms cooperate, in most cases they prefer a research joint venture, but because of transaction costs, moral hazard and adverse selection problems other forms of cooperation in R&D may occur. Uncertainty and spillovers also affect the size and the nature of coalitions, and in some circumstances competing research joint ventures may be formed.

Finally, the paper surveys the empirical evidence and discusses its consistency with the theoretical conclusions.

Keywords: Cooperation and competition in R&D; Research joint ventures; Cross-licensing agreements; Spillovers in R&D

0. Introduction

Technical progress certainly accounts for by far, the greatest part of the rise in living standards in the capitalist countries since the 18th century, but our understanding of the mechanism behind it is far inferior to its importance in everyday life. This may be because research and development is subject to all the main determinants of market failures.

First, there is uncertainty on the outcome of R&D activity, and as Arrow (1962, 1969) pointed out, the essence of this activity is the reduction of uncertainty about the nature of the R&D output.

Second, as Schumpeter (1961) was among the first to observe, innovative output is imperfectly appropriable, due to imitation or spillover of the knowledge developed. Both of these factors are likely to result in incentives to innovate that are lower than socially desirable.

Cooperation in R&D may mitigate the detrimental effects of market failures by eliminating uncertainty on the nature of the successful firm and duplication of effort and internalizing the externalities created by spillovers. However, there are also drawbacks. Cooperation lowers the costs not only for each firm but also for its associated competitors, making them more aggressive and thus penalizing cooperation in R&D. So in deciding whether to cooperate, firms must weigh the costs against the benefits.

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This paper addresses several related questions:

1. In what circumstances private firms have an incentive to cooperate in R&D?
2. What form of cooperation is likely to arise in the most common situations?
3. Does cooperation in R&D increase welfare?

The surveys on the incentive to cooperate in R&D (Veugelers, 1998; Hagedoorn et al., 2000; Caloghirou et al., 2003) tend to adopt a duopoly framework and thus cannot address issues relating to the size and the stability of the joint ventures; nor do they consider the forms and organizational aspects of the agreements.

This paper does encompass these last issues, considering the incentive to cooperate in oligopoly as well as duopoly R&D markets and dealing with the organizational form of the activity, its effects on the incentive to cooperate and on the performance of the agreement. In this more general framework, we consider the circumstances in which firms will cooperate in R&D and the type of agreement they are most likely to make. Finally, we compare theoretical conclusions and empirical evidence.

The survey is organized as follows. Section 1 discusses the main forms of cooperative agreements, and Sections 2 and 3 deal with the incentive to cooperate and innovate when firms are in a symmetric position in the R&D market. Section 4 considers cooperative agreements among asymmetric partners, and Section 5 explores the effects of incomplete contracts on the incentive for cooperation and the organization of the activity. Section 6 deals with the equilibrium and optimal size of joint ventures involving more than two firms, and Section 7 examines competing research joint ventures. Section 8 reports empirical evidence on the incentive to innovate and cooperate in R&D, and the last section summarizes the results and discusses directions for future research.

1. Forms of cooperation in the R&D market

We assume that contractual arrangements are not easily duplicated, so that only a few types of cooperative R&D agreements are available to firms. Accordingly we consider only the most stylized and common cases of R&D agreement. Cooperation in R&D may range from mere coordination of activities to joint ventures in which firms fully share information and costs. And cooperation may come at the R&D and/or the production stage.

The weakest form of cooperation is *coordination of R&D activity*. Under such an agreement, the firms decide the level of R&D investments by maximizing the expected joint profit function, but they conduct their R&D activities independently and remain competitors in the product market.

A more advanced form of cooperation involves R&D coordination plus the sharing of the results (*information sharing*). This increases the degree of spillovers with respect to a competitive R&D market. Spillovers become complete when firms fully share the knowledge acquired and their R&D results. A *cross-licensing agreement* is an example of information sharing, in which firms make a costless enforceable contract to share research results with their partners *ex post*. However, coordination of R&D activity and information sharing do not avoid the duplication of effort that may occur when firms conduct R&D separately, each in its own research lab.

More advanced still is a *research joint venture*, in which firms form a common lab, which not only allows information sharing but also avoids duplication of effort and saves on costs.

Beyond cooperating in the R&D market, firms would like to collude in the product market, which should reduce uncertainty on the outcome of R&D and increase the benefit from innovation but is detrimental to consumers.

We consider the incentive to undertake a cooperative agreement in relation to the degree of uncertainty and spillovers, as well as the specifics of the cooperative agreement. We posit that a cooperative agreement on R&D will be undertaken whenever the expected profit of each member firm is greater than it would be if the firm stood alone in R&D.

The first models of R&D cooperation are set in a complete contract framework, where investment or effort is accordingly contractible and enforceable. This implies that there are neither information problems nor transaction costs in the formation of the venture, and also that the outcome of the cooperative agreement is in some way contractible and measurable. However, very often in the formation of the cooperative agreement there are problems of knowledge disclosure, moral hazard and transaction costs Member firms may not have sufficient incentive to disclose all their information, and they may be unable to monitor the effort levels of their research partner.

There are some circumstances in which these assumptions are more likely to correspond to reality. In a duopoly, contractibility and enforceability are more likely to be effective than in other forms of oligopoly. And cooperation for the development of an aircraft or a computer will presumably engender less problems of moral hazard and

Table 1
The effects of spillovers and uncertainty on the incentive to cooperate

Prob. of success	Spillovers					
	0	Small	Intermediate	Large	1	Any
Low						
Intermediate	NC^{MC}					
High	C^{MC}					
1						C^{DJ}, RJV^{K}
Any		NC^{B}, CO^{MO}_{OS}		RJV^{B}, C^{C}	RJV^{MO}_{IS}	RJV^{SW}_{IS}

enforceability than for a vaccine, since it is easier to assess the contribution of each of the R&D partners.[1] Generally speaking, more narrowly focused research is characterized by a limited time horizon and allows each of the parties to go alone upon contract completion. In more generic research an incomplete contract is more likely, and a research joint venture (RJV) can be considered an efficient way to delimit the partners' risks.

In a complete contract framework, therefore, the crucial issue is how different forms of cooperation affect expected profit. By contrast, in the incomplete contract framework, there is the additional issue of which form of cooperation is most appropriate to motivate partners to share their knowledge and to induce optimal R&D effort, and in what circumstances. In this case the allocation of ownership rights in the venture may affect the efficiency of the investment decisions.

In what follows, first we survey models in a complete contract framework, then incomplete contract models.

2. Uncertainty, spillovers and the incentive to cooperate

Here we assume that firms make a complete contract covering their cooperation in R&D. This means that inputs and output of the activity are contractible, observable or verifiable, so that no problems of moral hazard or adverse selection arise in the formation of the venture.[2]

Most of the models that are set in this framework assume that R&D cooperation is industry-wide and concentrate on horizontal cooperation among rival firms. They take a world where R&D is imperfectly appropriable and results leak out involuntarily to rivals. Spillovers are non-firm-specific and symmetric: one firm's outgoing spillover is the other's incoming one. And they further posit that the partners are in a symmetric position in the R&D and the product markets.[3]

D'Aspremont and Jacquemin (1988), in a duopoly model with quadratic costs, compared R&D competition and coordination assuming spillovers but not uncertainty. In an analogous framework, Kamien et al. (1992) compared all the types of cooperative agreement we have mentioned. Marjit (1991) and Combs (1992), in a simplified model, studied only the effect of uncertainty on the incentive to cooperate.

Choi (1993), Amir et al. (2003), and Silipo and Weiss (2005), in more general models, study the effects of both uncertainty and spillovers on incentives for innovation and R&D cooperation.

Table 1 summarizes the main results on incentives and forms of cooperation determined by the degree of uncertainty and spillovers. The first column in Table 1 shows the probability of success of the project, ranging from values near 0 to 1 (certainty on the results of R&D activity). The first row gives the degree of spillovers, ranging from 0 (no spillover) to 1 (full spillover of the results of the R&D activity). Each cell thus reports the combined effect of the two factors on the incentive to cooperate.

Models with uncertainty and no spillovers (Marjit, 1991; Combs, 1992) showed that cooperation (C^{MC}) is worthwhile for the firms only if the probability of success is relatively high; competition (NC^{MC}) is preferred when the probability of success of the project takes an intermediate value. By contrast, the models with spillovers and no

[1] For example, in cooperation on developing a new computer, the partners may assess the contribution of each member according to the particular component to develop. In a venture for a new vaccine it is harder to assess each member's know-how and contribution, so free-riding and incentive problems are more probable.

[2] This assumption allows us to investigate the incentive to cooperate consisting in greater expected profits independently of the other potentially relevant factors.

[3] In Section 4 we consider the effects of asymmetric positions in R&D; Section 5 considers incomplete contracts.

uncertainty found that coordination of R&D activity (C^{DJ}) is always preferred to competition (see D'Aspremont and Jacquemin (1988)). The logic behind this result is that since when there is cost sharing the firm can always choose the same level of investment that it would choose without cost sharing, their profits cannot fall below those without cost sharing. But this does not extend to models with both uncertainty and spillovers, in which cooperation (C^{C}) is chosen only if spillovers are large (see, Choi (1993)).[4]

These results can perhaps be best explained along the following lines. On the one hand, thanks to the coordination effect, with an RJV the firm's R&D cost per probability of success is lower than with competition, but on the other hand an RJV eliminates the competitive advantage of making the innovation. However, if spillovers are large the latter effect is weak, so firms expect to make similar profits even when they compete in R&D, and the RJV is preferred.

However, for overall social welfare the "coordination effect" and the "profit dissipation effect" of an RJV both work in the same direction (increasing welfare), which means the incentive to cooperate falls below the socially desirable level.

Kamien et al. (1992) compared various forms of cooperation (cost sharing, information sharing and RJVs), showing that an (RJV^{K}) is always preferred to other forms of R&D. Other researchers (Miyagiwa and Ohno, 2002; Silipo and Weiss, 2005), however, in a more general framework, have shown that this result may not hold when spillovers are small and when they decrease profits. In this case, firms prefer an R&D cartel (C^{OS}_{MO}) to an RJV. Nevertheless, the result of Kamien et al. (1992) still holds if spillovers increase industry profit (RJV^{SW}_{IS}) and when they are complete (RJV^{MO}_{IS}).

Another instance in which the RJV is not preferred is when it involves a vertical RJV (RJV^{I}), as this may not be the mode of vertical R&D organization that generates the greatest joint profit, since firms strategically overinvest when the spillover rate is low (Ishii, 2004).

From the foregoing discussion we can conclude that, in a complete contract setting, firms prefer cooperation to competition if spillovers eliminate the benefit of being first.[5] The most preferred form of cooperation is the RJV, although other forms also arise, but we should never find cross-licensing or information- and cost-sharing agreements.

Finally, a number of authors[6] have shown that the lower the degree of competition in the product market, the greater the incentive to cooperate and to invest in the cooperative agreement. This is reminiscent of the Schumpeterian hypothesis that in a market economy to achieve dynamic efficiency it is necessary to sacrifice some degree of static welfare.[7]

However, the welfare effects of cooperation in R&D are not clear-cut, and a case-by-case approach is more appropriate.[8]

3. Cooperation in R&D and the incentive to innovate

In this section we consider whether the circumstances in which firms elect to cooperate are also favourable to innovative activity. First, D'Aspremont and Jacquemin (1988), followed by many others (among them, Kamien et al. (1992), Motta (1992), Choi (1993) and Silipo and Weiss (2005)), proved in a complete contract framework, that firms always want to form an R&D cartel, but that when spillovers are small this reduces R&D expenditure (x^{DJ}_{C}) with respect to competition (x^{DJ}_{N}). When they are large, however, cooperation spurs innovation (see Table 2). However, Kamien et al. (1992) showed that when firms form an RJV the equilibrium effective R&D investment (x^{K}_{RJV}) is always greater than with other kinds of cooperation or with competition (x^{K}_{N}).

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4 In a similar framework, Beath et al. (1988) proved that firms prefer an RJV (RJV^{B}) to competition (NC^{B}) when imitation is easy and rivalry when imitation is difficult. Ease of imitation refers to the degree of perfection of an infinitely lived patent.

5 However, Belderbos et al. (2004) provide evidence that the incentive to cooperate is also related to the type of partner (e.g., competitors, suppliers, clients, universities), which suggests the need for a theoretical explanation of these phenomena.

6 Among many others, see D'Aspremont and Jacquemin (1988), Kamien et al. (1992), Choi (1993), Petit and Tolwinski (1999) and Silipo (2005).

7 This result explains the widespread advocacy of anti-trust exemption for this type of cooperation (Ordover and Willig, 1985; Grossman and Shapiro, 1986; Jacquemin, 1988; Shapiro and Willig, 1990), as implemented in the United States by the National Cooperative Research Act (1984) and the amended 1993 version.

8 Opposing results are obtained by Baumol (2001), on the one hand, and by Chen and Ross (2003), Martin (1995) and Cabral (2000) on the other. De Fraja and Silipo (2002) used simulations to demonstrate that all the types of R&D activity (competition; simple coordination of R&D investments; joint venture where any patent obtained is licensed to the participants; and a full-fledged cartel or merger) can be welfare-improving for appropriate choices of degree of spillover and product differentiation. Finally, Stenbacka and Tombak (1998) proved that also technology policy affects the investment incentives of firms in various forms of cooperation.

Table 2
Cooperation and the incentive to innovate

Prob. of success	Spillovers					
	0	Small	Intermediate	Large	1	Any
Low						x_{IS}^{SW}
Intermediate						
High						x_{OS}^{SW}
1		x_N^{DJ}		x_C^{DJ}		x_{RJV}^{K}
Any		x_N^{MO}		x_C^{MO}	x_{RJV}^{SW}	x_{JV}^{MO}

However, according to Silipo and Weiss (2005) and Miyagiwa and Ohno (2002), in more general models the latter conclusion may not hold. Specifically, an R&D cartel performs better than an RJV if spillovers are large (x_C^{MO}) and reduce industry profits,[9] or if the probability of success is high (x_{OS}^{SW}). Finally, competition (x_N^{MO}) results in the largest R&D investment if spillovers are small.[10] Nevertheless, the conclusions of Kamien et al. (1992) still hold when spillovers increase industry profits.[11]

But, De Bondt and Veugelers's (1991), in a more general framework including process and product innovation, found that substitution among products reduces the incentive to invest in R&D when firms undertake a cooperative agreement, and complementarity among goods increases the co-operative level of R&D. In general, therefore, there is no instance in which we can state conclusively that the RJV produces more research than the other forms of cooperation in R&D or than competition. But an examination of Tables 1 and 2 reveals that in most cases when cooperation occurs, it also increases the incentive to innovate.

4. Cooperative agreements among asymmetric partners

The theoretical models of R&D cooperation discussed above ignore some important motivations, such as synergies from exploiting asset complementarities, as well as the explicit sharing of costs and risks, even though R&D costs are lowered by avoiding wasteful duplication. Finally, these models do not consider asymmetric positions of the firms in the R&D market.

First, let us notice that there exist situations in which firms that begin with a symmetric position in the R&D market may adopt asymmetric strategies in a cooperative R&D agreement. Salant and Shaffer (1998) showed that in a cooperative R&D agreement the partners may increase total joint profit by making unequal R&D investments, enabling one firm to cut its production costs more than the other.[12] Rosenkranz (1995) obtains similar qualitative results in a model of product innovation.

Another example of ex post asymmetry is suggested by Amir et al. (2003): in a model in which firms decide R&D expenditure and the spillover rate jointly,[13] firms form an RJV with two possible outcomes — either they share the costs of R&D equally and set the spillover rate at 1, or else they keep the spillover rate at the minimum and only one of the firms conducts R&D. So there are cases in which the cooperative equilibrium may be asymmetric, even though firms are symmetric ex ante.[14]

Firms may be also in an asymmetric position ex ante — differing in size, say, or assets, productive efficiency, R&D efficiency and/or absorptive capabilities, or acquired knowledge. Such asymmetry may affect the costs and benefits

9 To be precise, Miyagiwa and Ohno (2002) posit that spillovers may be either fast or slow to diffuse innovation from firm to firm. On the effects of spillovers on joint profits see also Marjit (1990), Levin et al. (1987) and Levin and Reiss (1988).

10 Vonortas (1994) reaches similar conclusions, demonstrating that when the R&D activities of the firms are strategic substitutes, competition spurs innovation but when they are strategic complements, an RJV performs better.

11 In Table 2, this case is denoted by x_{IS}^{SW} for Silipo and Weiss and by X_{JV}^{MO} for Miyagiwa and Ohno. In Silipo and Weiss (2005) there is the additional condition that the probability of success must be lower than 1/2.

12 Although this strategy may raise the costs of innovation, it increases profits in the production stage, by increasing concentration in the product market.

13 One of the first papers in which spillover is made endogenous is De Fraja (1993).

14 Leahy and Neary (2005) established the conditions for a symmetric ex post equilibrium, which is related to how changes in R&D expenditure by one firm affect another one's marginal contribution to industry profits.

of cooperation significantly. If firms have complementary assets, an RJV can exploit these synergies, and we should expect a greater incentive for cooperation among asymmetric than symmetric partners (Sinha and Cusumano, 1991). By contrast, where firms differ in cost or technology, they should want to cooperate only if the asymmetry is not too great (see, Chaudhuri (1995) and Roller et al. (1997)).[15]

Another potential source of asymmetry is spillovers.[16] In a situation of symmetry, all the partners have the same degree of spillover. Actually, however, partners very often generate more outgoing spillover than receive incoming, or vice versa. For instance, this occurs in alliances between firms and universities, or between firms that are related vertically or horizontally, or between leaders and followers. For this latter case, Cohen and Levinthal (1989) pointed out that firms invest in R&D in order to increase their absorptive capacity, which is greater for leaders than followers, thus giving the former a greater incentive to cooperate.[17] However, there are cases in which the opposite result holds, because the follower may learn more from the leader (see De Bondt and Henriques (1995)).

Finally, theoretical inquiry (Doz, 1988; Banerjee and Lin, 2001) and empirical findings (Kogut, 1988; Harrigan, 1988; Hagedoorn et al., 2000) suggest that differences between partners can make cooperative agreements unstable or unfeasible even when they provide a great mutual advantage.[18]

Thus the incentive to cooperate may be either greater or smaller among asymmetric than among symmetric partners, depending on the source of the asymmetry. If it depends on complementarity of assets, the incentive to cooperate is greater among asymmetric firms. But if firms are equal apart from their level of knowledge, it is greater among symmetric partners. Miotti and Sachwald (2003) suggested a unified framework to explain different types of cooperative R&D agreement. If partners aim to reduce costs and risks through economies of scale and rationalized innovation processes, they will pool similar resources in the alliance. But if the aim is to manage technological convergence or interdependence among innovation processes, they will confer complementary resources. A related issue that literature has not investigated is whether asymmetry among firms affects not only the incentive to cooperate but also the form of the agreement.

5. Incentives and forms of cooperation under incomplete contracts

So far we have assumed that cooperative R&D agreements between firms involve a complete contract. Commonly, however, there are problems of knowledge disclosure, moral hazard e transaction costs, so that an incomplete contract framework is more appropriate for the analysis of the joint venture.

First, cooperation poses problems of ex ante evaluation of the specific knowledge that will be contributed by several participants. The resources supplied to a joint venture are not easily measurable or observable. For example, assessing the value of the human capital embodied in the research staff assigned to the venture or the quality of the information that the parties elect to share is often an impossible task.

Second, often it is difficult, in advance, to define the exact nature of the innovation being developed. As a result, it becomes impossible to conclude a contract for the delivery of a specific innovation. And the non-verifiability of inputs and output may lead to enforceability problems.

In addition, cooperation requires firms to combine their specific know-how and to share their research results with other firms, with which they may be competitors in the downstream product market. In this case, full disclosure may damage a firm's competitive position,[19] as some firms may want to join the venture not in order to contribute to the project but only to appropriate the partners' know-how.

15 Similarly, Silipo (2005) compared the incentive to cooperate in a two-firm patent race model when firms are in symmetric and asymmetric positions in terms of acquired knowledge, showing that the incentive to cooperate is less greater under asymmetry, because by cooperating the leader loses his advantage in the race.

16 An excellent survey of models with symmetric and asymmetric firms and spillovers is De Bondt (1996).

17 However, Veugelers and Kesteloot (1997) have shown that better-positioned firms (in terms of productive efficiency, R&D efficiency and/or absorptive capacity) have an incentive to undertake a cooperative agreement with disadvantaged firms only when their advantage is reflected in a larger share of the benefits of the alliance.

18 As an example, Banerjee and Lin (2001) examined the incentive to form an RJV between an input supplier and downstream users that use the new technology to produce a final good. They show that although this vertical joint venture is beneficial to all the partners, the interests of the upstream and downstream conflict, which undermines the possibility of actually forming the venture: the former prefers the coalition to be as large as possible, the latter as small as possible.

19 More precisely, when firms are rivals in the product market or in future R&D races, they face a trade-off: the firm that discloses its valuable know-how to the venture improves the project's probability of success and expected profit, but such behavior may not be reciprocal, so that the partner/rival may improve its competitive position. Only disclosure in an RJV see also Katsoulacos and Ulph (1998) and Poyago-Theotoky (1999).

Apart from these moral hazard problems of knowledge transfer, there are those relating to the impossibility of monitoring researchers' effort. Member firms may thus have an incentive for free riding by making insufficient effort. Finally, there may also be adverse selection problems. The firms may be unable to determine the most appropriate partners for the type of project undertaken. All this foregoing discussion suggests that R&D cooperation contracts are not easy to draw up and enforce, and are therefore incomplete.

First, we review models that deal with evaluation of research inputs and knowledge disclosure in the formation of the venture. Then we consider moral hazard and transaction costs. As benchmark, Choi (1992) showed that when the amount of research inputs that should be supplied by each firm is contractible, the first-best solution is attained when each firm agrees to supply the cost-minimizing amount of inputs to achieve probability of success p^0. Beath et al. (1998), Marjit (1990) and Combs (1992, 1993) proved that, even in this context, the performance of the cooperative agreement is related to the allocation of R&D resources among research labs. But if inputs are not contractible, not observable and/or not verifiable, (such as the effort levels or the abilities of the researchers assigned), in equilibrium there will be under-provision of non-contractible inputs, and a sub-optimal amount of R&D. Moreover, profitable RJVs may not start when the disclosure of know-how is not contractible Perez Castrillo and Sandonís (1996).

A related question is thus the form of cooperation most appropriate to motivate all the partners to share their knowledge and to induce the optimal level of R&D effort.[20]

In a different context, Grossman and Hart (1986) show that if contracts are incomplete the distribution of the property rights affects the efficiency of investment decisions. Others, applying contract theory[21] to this case, have shown that ownership structure affects also know-how disclosure (see Rosenkranz and Schmitz (1999)). If there is full disclosure of know-how by both parties, then joint ownership with no veto power over the other's use of the innovation is optimal; but if firms need incentives to disclose knowledge, then this is the worst scenario. Instead, the optimal ownership structure would be a joint ownership with veto power on use. Yet this leads to less than optimal R&D effort.[22]

Aghion and Tirole (1994) also studied the efficient allocation of ownership rights, but in a different context. They considered allocation between a research unit and customers, i.e. the parties that directly benefit from the innovation. They inquired whether it is more efficient for customers to own and freely use the innovation (integration), or for the research unit to own it and bargain with the customers over the license fee (non-integration). They concluded that research will more likely be conducted in an integrated structure if (a) capital inputs are more important than intellectual inputs and (b) the customer has more bargaining power ex ante, for example because there is intense competition among research teams. Otherwise, the non-integrated solution is more likely.

However, when there are multiple users it may be more efficient to split the property rights between the customer and the research unit, each retaining the rights to those activities in which it has a comparative advantage in creating value.[23]

While Aghion and Tirole (1994) studied the allocation of ownership rights in a vertical RJV, Tao and Wu (1997) investigated ownership arrangements of jointly developed innovations in horizontal RJVs,[24] focusing on the organization of cooperative R&D between different businesses, each engaging in both R&D and production. In a context of incomplete contract, they considered two possible arrangements governing ownership of the future

[20] In this regard, Katz and Ordover (1990) report on the VLSI consortium in Japan. The participating firms feared the loss of the proprietary knowledge they had prior to the project. The solution was to rank the R&D projects in terms of their "distance" from commercial applications. The most pre-competitive research would be conducted jointly in one of the new VLSI Cooperative laboratories, more nearly commercial R&D would be performed in the two existing joint laboratories of the co-venturers, and actual product development would be undertaken by individual firms on their own pilot production lines.

[21] Milestones of this theory are Grossman and Hart (1986), Hart and Moore (1990) and Hart (1995).

[22] See Rosenkranz and Schmitz (2003) for the proof of these results and an analysis of the optimal allocation of ownership rights in dynamic R&D alliances.

[23] These conclusions are relevant to understanding the relative advantages of integrated structures vis-à-vis vertical RJVs. The latter involve joint ownership by independent researchers (or inventors) and manufacturing firms (developers), the former contributing their knowledge and the latter capital or other productive inputs. It is logical to conclude but in the case of a single user of the innovation it is optimal to allocate ownership rights to one of party (either the research unit or the customer); but where more than one customer may use the innovation, a vertical RJV among the research unit and the customer may be more appropriate, because it is more likely that more than one owner will have a comparative advantage in creating value from the innovation.

[24] In a "horizontal" RJV several customers, competing or not in a product market, join forces to finance research.

innovations. First, firm 1 and firm 2 may form an equity RJV, which owns the future innovation, and the participating firms need to pay royalty fees for the use of innovations. The second is non-equity co-development, in which all the participating firms own and have free access to the innovations.[25] Tao and Wu explore the conditions that affect the choice, showing that when firms use the new technology to engage in different downstream business, they could choose either of the organizational forms, depending on the division of the payoff upon success. But if they compete in the same downstream business, they will choose an equity RJV.[26]

A major problem of the agreement under incomplete contracts is thus designing the organization of the joint venture and writing contracts that induce full disclosure of the participants' private information, both ex ante and ex post, and prompt the efficient effort level.

Bhattacharya et al. (1992) were among the first to design rules to motivate the sharing of productive knowledge among an RJV's members, knowing that they will later compete both in R&D to reduce production costs and eventually in the product market. In their model, N firms have the opportunity to share their private knowledge in the first stage, which enhances R&D abilities in the second stage. In this stage, firms employ knowledge independently, in an attempt to achieve an innovation of known social value, V. In the third stage firms compete à la Bertrand in the product market. The authors consider two mechanisms: restricted licensing (RL), in that the licensed firm must pay a licensing fee rV if it earns at least V in the final-stage product market competition. Otherwise, the licensed firm, like all other lagging firms, pays no fee. An alternative mechanism is unrestricted licensing (UL), in which lagging firms that wish to enter the second stage R&D competition pay a uniform entry fee (E) to the leading firm, independently of realized profit. UL motivates both efficient sharing of knowledge and subsequent independent R&D effort if the leader can control entry into the R&D market. RL too can produce a first-best outcome in some settings (when the probability of success is sufficiently high), but not in others (when superior knowledge is rare and valuable).

Gandal and Scotchmer (1993) suggested another mechanism to obtain full disclosure of knowledge: remunerating each team member according to the date of discovery and the identity of discoverer: both are ex post signals of the ability and the effort made ex ante by each firm.

Notice that some forms of cooperative organization are more appropriate for promoting disclosure than others. Pastor and Sandonis (2002) have compared research joint ventures (RJV) and cross-licensing agreements (CLA) in terms of incentives for disclosure and for the efficient level of effort. An RJV allows the firms to capture synergies and to exert a given effort at a lower expected cost than a CLA, but it reveals valuable know-how to the partners. By contrast, in a CLA each firm develops a line of research in its own laboratory, preventing the dissemination of its own know-how to the partners. The authors show that if the patent value is high enough, firms disclose their know-how in an RJV. But if the value of the innovation is low, no firm discloses its know-how. In this case, the CLA is superior to the RJV because the greater effort offsets the more valuable information. However, the less acute the competition rivalry in the downstream product market, the greater the incentive to disclose know-how.

Another factor that may shape cooperative R&D agreements is transaction costs. Morasch (1995) compared RJVs and CLAs assuming that RJVs entail higher transaction costs and require far more complex contracts and getting a different result: a CLA is preferable if it includes an optimal royalty scheme to induce full disclosure. These contrasting conclusions may be due to the different roles played by the RJV. Monasch posits that the RJV engenders higher transaction costs, although R&D effort is more observable, while Pastor and Sandonis highlight the greater efficiency of the RJV in conducting R&D activity.[27]

Notice that firms do not always lack incentive to transmit their specific know-how. If the partners have complementary technologies, the value of each firm's knowledge depends on the possibility of acquiring that of the firms, and full disclosure will be chosen. A similar result arises when firms are in complementary markets. In any case, the literature lacks a comprehensive analysis of cooperation versus competition under incomplete R&D contracts.

[25] It should be pointed out that, when contracts are relatively complete, ownership structure does not matter: i.e., RJV and co-development could become equivalent.

[26] This is because the RJV facilitates collusion in the downstream business and gives firms appropriate incentives for cooperative R&D.

[27] Similar conclusions apply to the question of the best form of cooperation to deal with asymmetry of information and moral hazard. An RJV is more suitable to solve the moral hazard problem than other forms of cooperation, by making the R&D effort more observable. But the transaction costs for forming the venture are high, a CLA may be appropriate. The CLA is also more suitable for inducing disclosure of knowledge when firms compete in the product market, whereas if they operate in different markets the RJV is more efficient.

6. Equilibrium and optimal size of the joint venture

Most of the papers reviewed are set in a duopoly framework and so are unable to study the incentive to cooperate and the nature of the equilibrium when there are more than two firms. This is the case we now take up.

Let us assume there are N identical firms involved in R&D activity, denoting by x_i, $i = 1, \dots, N$, the level of firm i's R&D effort. If there are spillovers of knowledge, firm i's effective level of R&D (z_i) is the sum of its own R&D expenditure plus that of its competitors that spills over to it:

$$z_i = x_i + \underline{\alpha} \sum_{j \in N-\{i\}} x_j$$

where $0 \le \underline{\alpha} \le 1$ is the degree of R&D spillover when firms compete. If firm i forms a cooperative agreement with other $K - 1$ firms, $K \le N$, in which firms share the results of R&D, its effective level of R&D becomes

$$z_i = x_i + \overline{\alpha} \sum_{j \in K-\{i\}} x_j + \underline{\alpha} \sum_{h \in N-K} x_h$$

with $\overline{\alpha}$ denoting the degree of spillover among the members, $\underline{\alpha} \le \overline{\alpha} \le 1$.

Let us denote by Π_i^N the expected profit of firm i, $i = 1, \dots, N$, when firm i competes with other $N - 1$ firms for a cost-reducing innovation, and by Π_i^{CJ} its expected profit if it is a member of a coalition with other $K - 1$ firms, in which they coordinate R&D and share their results. Two possible rules for the formation of the coalition discussed in the literature are open and exclusive membership. Open membership means an outsider can join an existing RJV without the consent of the current members; exclusive membership requires their consent to join. In formal terms, the equilibrium size of the coalition under open membership is determined by the condition $\Pi_i^{CJ}(k) > \Pi_i^N(k-1)$ (internal stability) and $\Pi_i^{CJ}(k+1) < \Pi_i^N(k)$ (external stability), with k denoting the number of firms in the coalition. Under exclusive membership the equilibrium size is determined by the conditions $\Pi_i^{CJ}(k) > \Pi_i^{CJ}(k-1)$ and $\Pi_i^{CJ}(k+1) < \Pi_i^{CJ}(k)$.

In other words, with open membership the decision whether to join the venture depends on the expected profits of each firm in the two regimes, while with exclusive membership the size of the RJV depends on the expected profit of the coalition, and members will not allow new firms to join when the profit is already maximized.

What is the incentive to cooperate in these circumstances? How is the size of the R&D coalition affected by the membership rule and by spillovers?

In a model with exclusive membership, Poyago-Theotoky (1995) shows that if the spillover parameter is sufficiently low, the equilibrium size of the RJV is smaller than the optimal, which is industry-wide. But when spillover is large, the equilibrium and the optimal size tend to coincide. This is because if the degree of informational spillover is small, R&D expenditure by the RJV is a strategic substitute for the non-RJV group, and an increase in the R&D effort of the RJV will increase the cost gap between the two groups. It follows that an additional partner joining the RJV means that the present members share the market with a less efficient partner and their average profit decreases. By contrast, when spillover is large, R&D expenditure by the RJV becomes a strategic complement for the non-RJV group, so letting one additional firm join will not jeopardize the profits of the current members.

Open membership models lead to opposite conclusions.[28] If firms can enter the joint venture freely, with low spillover rates and high information sharing, everyone wants to join. But with large spillover, free riding becomes an important incentive, and the firm's benefit is increased by staying out, so the RJV will be small.[29]

Finally, the size of the coalition is affected by the degree of competition in the eventual product market. In a similar framework,[30] Combs (1993) found that intense product rivalry induces firms to form a coalition that is smaller than one that would maximize welfare, because even though an RJV increases the chance of successful innovation, as membership expands competition in the product market becomes fiercer. This competition is welfare-improving but reduces the incentive to enlarge the joint venture.

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28 See De Bondt and Wu (1997) and Katz (1986).

29 It is worth noting that the results for both the open and exclusive membership cases are based on numerical simulations.

30 But assuming uncertainty in the R&D process, in addition to free entry into the RJV.

The results in this section, let us recall, are based on the assumption that only one RJV is going to be formed and that the RJV members compete with all firms outside the coalition. Actually, of course, more than one coalition may form, and this is the case we next investigate.

7. Competing research joint ventures

When some firms within an industry have formed an RJV, the others may respond with competing ventures. This adds new motivations for cooperative agreements, as some firms attempt to get a strategic edge over others involved in R&D activity.

In this framework, the interesting questions are:

1. How many research joint ventures are going to be formed within an R&D market?
2. What are the circumstances that allow one of the competing RJVs to gain leadership in the patent race? and
3. How does competition among RJVs affect the incentive to innovate?

In this approach, that is, the number of research coalitions is endogenous[31] and these questions are studied in a game-theoretical framework. The problem is to define the conditions under which stable coalition structures exist.[32] According to the Coalition-Proof Nash Equilibrium concept introduced by Bernheim et al. (1987a), a coalition structure is an equilibrium and is also stable if no member of an RJV can gain by changing its membership.

Models adopting the Coalition-Proof Nash Equilibrium concept (Bloch, 1995; Yi, 1997; Yi and Shin, 2000), have shown that: (a) the coalition structure is more concentrated if membership is open than if it is exclusive[33]; (b) as the spillover rate increases, a more concentrated RJV structure emerges, under both open and exclusive membership; and (c) the grand coalition, which is the socially efficient solution, is rarely an equilibrium outcome under both membership rules,[34] due to the free-riding problem that arises from positive R&D spillover externalities. This finding reflects the fact that larger spillover aggravates underinvestment in the absence of R&D cooperation and so increases the private incentive to form RJVs.

Moreover, if there is asymmetry in the coalition formation, since coalitions are formed in sequence,[35] the equilibrium coalition structure too is characterized by two asymmetric coalitions, with the dominant coalition comprising three-quarters of the firms in the industry (see Bloch (1996)). This is because if there is no collusion in the product market, the admission of new members to the R&D coalition has contrasting effects. By reducing a firm's own marginal cost, it increases its profit, but at the same time, by reducing its competitors' costs it triggers more aggressive behavior on their part and lowers profit. Hence, there is a critical size of the coalition above which the admission of new members has an adverse effect on the firms' profits. This explains why an industry-wide agreement, though socially desirable, does not form. In any case, the first coalition admits more members as a means of decreasing the size and increasing the costs of the rival coalitions.

This conclusion depends on the hypothesis that firms compete for a homogeneous product. If, however, they produce differentiated products, competition between them in the ex post markets is weak and the size of the dominant coalition increases. In the extreme case in which firms produce complementary goods, they benefit from the lower marginal costs of their competitors and thus have an incentive to form the grand coalition.

Does competition between research joint ventures spur innovation?

Both exogenous and endogenous models of competing RJVs[36] show that in most circumstances competition has beneficial effects on the incentive to innovate. Specifically, for low values of the spillover parameter, competing RJVs

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[31] Endogenous formation of coalitions has been extensively studied in other contexts (not that of innovation). Among many others, see Bernheim et al. (1987b), Belleflamme (2000) and Kim and Shin (2002).

[32] A research coalition C_i is a subset of the N firms, and a coalition structure $C = \{C_1, C_2, \ldots, C_m\}$ is a partition of the set of firms $F = \{F_1, F_2, \ldots, F_N\}$ such that $C_i \cap C_j = \varnothing, \forall C_i, C_j \in C, i \neq j$ and $\cup_{i=1}^{N} C_i = F$. This implies that players form non-overlapping coalitions.

[33] Intuitively, one coalition structure is more concentrated than another when the former has larger (hence, fewer) coalitions than the latter.

[34] However, since R&D investment increases with concentration, it follows that the exclusive membership rule leads to a lower industry-wide R&D investment than open membership.

[35] More precisely, one firm (the initiator) proposes the coalition; each prospective member responds in turn; the first to refuse is the initiator of a new round. When a firm agrees to join, it is bound to remain in the coalition and the coalition cannot accept new members at later stages. The game proceeds in a similar way until all offers are accepted. The horizon is infinite.

[36] For an example of the former see Kamien and Zang (1993), for the latter, Yi and Shin (2000). Similar qualitative results are obtained also by Morasch (2000).

make more R&D investment than one grand RJV cartel. In this case, the highest level of effective industry-wide research activity comes when the firms are divided into exactly two RJV cartels.[37] But if the exogenous spillover effect among competing coalitions is substantial, the decline in R&D activity from free riding becomes so severe that it can only be internalized by the grand RJV cartel. This is because each coalition has an incentive to imitate the innovation of the others.

Finally, Yi (1999) and Eerola and Määttänen (2004) pointed out that another motivation for firms to make strategic alliances is to gain access to a market, and this enhances competition because it diminishes the market power of the incumbent. By contrast, Zhang and Zhang (2006) demonstrate that an alliance that arises strictly because the threat of entry may reduce welfare. Instead, intra-alliance complementarities and cross-alliance substitutability are welfare-enhancing.

The conclusions are the following:

(a) When more than two firms are involved in R&D, the equilibrium outcome is very often competing RJVs.
(b) Open membership leads to more concentrated coalition structures than exclusive membership.
(c) The greater the degree of product differentiation, the more concentrated the coalition structure. Firms form the grand coalition in the extreme case of complementary goods.
(d) Asymmetric positions in the R&D market lead to uneven coalitions, with the larger coalition more advantaged in the race.
(e) There exists a degree of spillover below which competing RJVs maximize R&D investments and above which R&D expenditure is maximized by an industry-wide cooperative agreement.

However, it is worth pointing out that all the papers reviewed adopt a static framework. In reality, though, RJVs are formed and break down during the discovery process, as a result of dynamic interaction between firms in the race. However, very few papers analyze these dynamic interactions. Silipo (2005) considered the formation and breakdown of coalitions in a duopolistic patent race model, demonstrating that cooperation at the outset is followed by breakdown if firms are competitors in the downstream product market, while there will be joint discovery when firms are even in the race and can collude in the ex post market.[38] However, there are no theoretical and empirical explanations of the evolution of cooperation when more than two firms are in the race.

8. Empirical findings on cooperation in R&D

In a complete contract framework, theoretical models of R&D indicate that cooperation is more likely among firms in symmetric than in asymmetric positions in the R&D market. Even asymmetrically situated firms may have an incentive to cooperate, however, if they have complementary assets. The research joint venture is the preferred form of cooperation. However, due to moral hazard, asymmetric information and transaction costs, the outcome can also be other forms of cooperation or no cooperation at all. Thus a cross-licensing agreement is more likely when intense competition in the product market reduces the value of innovation or when there are high transaction costs for the formation of the RJV. Finally, spillovers affect the incentive to cooperate and also the form of cooperation in R&D. In the next section we consider the extent to which the theoretical conclusions set forth above are supported by empirical evidence.

8.1. The incentive to cooperate

The empirical literature on the main theoretical issues discussed above suffers from the lack of a general and "official" source of information. So it relies on case studies or databases that overlap only partially, and they draw on different primary sources of information. Nevertheless, these empirical studies do lead to some conclusions concerning the foregoing theoretical predictions.

[37] As the number of competing RJVs declines, total R&D investment is stimulated by two effects: (1) each coalition faces a more formidable rival because its membership is increased; and (2) the scope over which an RJV innovation applies is broadened. The maximum industry-wide research activity is obtained when there are precisely two RJV cartels.

[38] This result was supported by both theoretical and experimental evidence. Most interestingly, Roy Chowdhury and Roy Chowdhury (2001), though in a different context (joint production venture formation and breakdown between a foreign multinational and a domestic company), found similar results. A stable joint venture forms if demand is very high, for intermediate levels of demand there is joint venture followed by breakdown, and for low levels of demand, there is Cournot competition in both the periods.

There has been a proliferation of research joint ventures in recent decades entailing the formation of a separate company. Research on the MERIT-CATI database, reporting worldwide trends in technology partnership, reveals that the annual number of new partnerships rose from 30 or 40 in the early 1970s to over 600 in the 1980s and 1990s. They were concentrated in United States, Japan and Europe. This growth can be ascribed to alliances in high-tech industries, while over the same period the number of alliances in medium- and low-tech industries decreased. The prevalent area for partnership has been information technology, followed by biotechnology and new materials (see Caloghirou et al. (2003)).

Using US Department of Commerce data on RJVs from 1985 to 1994, Roller et al. (1997) tested the hypotheses that RJVs will tend to be formed:

(i) when R&D spillovers create free-riding problems,
(ii) when duplication of R&D effort creates opportunities for cost sharing,
(iii) by firms producing complementary products, and
(iv) among firms of similar size.

The results suggest that in R&D at firm level whether cost sharing or free riding (case (i) or (ii)) dominates depends on the industry and the size of the RJV. With respect to point (iii), the evidence is that firms producing complementary products are more likely to form RJVs than those producing substitute products, although complementarities were not significant in all the industry-pairs considered. In vertically related industries, however, complementarities do increase RJV formation significantly. Narula (2002) also finds that access to complementary technology is the leading motive for R&D cooperation among European ICT firms. In short, the empirical findings support the thesis that the incentive for an RJV is greater when the interests of firms are less in conflict.

Finally, with respect to case (iv) above, Roller et al. (1997) support the view that RJVs tend to be formed among firms of similar size, and in particular that large firms do not want to form RJVs together with smaller ones.[39] This result is consistent with the theoretical consideration that cooperation is more likely between firms in symmetric than asymmetric positions. But Veugelers (1993) provided massive evidence of asymmetries between partners.

Siebert (1997), studying 314 RJVs registered in the United States from 1985 to 1992, concluded that the incentive to cooperate is greater among larger firms.[40] By contrast, Kleinknecht and van Reijnen (1992) analyze a large sample of firms representative of all manufacturing and service industries in the Netherlands and conclude that neither firm size nor market concentration nor type of R&D (product or process innovation) significantly affects the probability of cooperation. They conclude, instead, that the causal variable is having an own R&D department. This positive effect has been confirmed in other contexts, among many others, by Hagedoorn and Schakenraad (1994), Colombo and Garrone (1996), and Veugelers (1997).[41] However, Fritsch and Lukas (2001), for a sample of 1800 German manufacturing enterprises, find that both variables are significant: the enterprises that maintain R&D cooperation tend to be relatively large and tend to have their own R&D units.

Similarly, Hernan et al. (2003), using a large database of European RJVs covering the period 1986–96, have shown that the probability of joining an RJV is positively related to industry concentration and past participation in RJVs. A more concentrated industry makes it easier to identify the appropriate partners, while past experience with cooperation increases the probability of success. These findings support the absorptive capacity thesis, which stresses that for a firm to benefit optimally from R&D cooperation it needs to have its own in-house technological capacity.

At the same time, Roller et al. (1997), Siebert (1997) and Tyler and Steensma[42] (1995) have shown that cost sharing is another important incentive to cooperate. Vonortas (1997) and Scott (1996) provided evidence that cooperation fosters new research that would not have been initiated otherwise. However, if cost sharing spurs cooperation, transaction costs for the formation of the venture may work in the opposite direction. Desai et al. (2004), based on the activities of American multinationals abroad from 1982 through 1997, reported that the high transaction costs of

[39] Similarly, Harrigan (1988) found that ventures last longer between partners of similar culture, size (measured by assets) and venturing experience.

[40] Other early empirical studies Berg et al. (1982) also found a positive correlation between firm size and R&D cooperation.

[41] Hagedoorn and Schakenraad (1994), and Colombo and Garrone (1996) rely on a sample of major US, European and Japanese firms in semiconductors, data processing and telecommunications between 1980 and 1986, Veugelers (1997) surveyed about 290 Flemish companies on their R&D expenditures during 1992–1993.

[42] The conclusions of the last authors are based on a random sample of 130 executives from the large Midwestern university in the US in companies participating in industries where technological development is a consideration (manufacturing, utilities, and software development, two-digit SIC codes 20–39, 49, and 73).

running overseas operations as joint ventures decreased shared ownership over a period of two decades and increased the number of wholly owned operations. Joint ventures, it is argued, cannot fully exploit certain fixed assets developed by parent firms or the opportunities to coordinate worldwide operations through financial and other exchanges.

In the end, which effect prevails (cost sharing or transaction cost) in determining the propensity to cooperate is an empirical question, and it depends on the nature and form of the cooperative agreement.

One of the most extensive, recent surveys on RJVs in Europe (Caloghirou et al., 2003) finds that the main objectives of the firms for engaging in collaborative R&D were:

– Access to complementary resources and skills;
– Keeping up with major technological developments;
– Technological learning;
– R&D cost sharing.

That is, the previous empirical findings stand confirmed. Although the main reasons for RJVs are reported to be cost sharing, elimination of duplication, risk sharing, access to complementary resources and skills, and technological learning, there is also evidence that firms use RJVs to coordinate their interests in product markets, both current and arising from the innovation (Scott, 1993), (Vonortas, 2000). So RJVs may be formed for anti-competitive reasons.[43]

But the opposite may also occur. One firm may enter an RJV just to catch up with the leader. Rosegger (1989) argued that the leapfrog competition over international rivals was the strategic motive for cooperation in research by US automobile manufacturers throughout the 1980s. This supports the competing research joint venture models reported above.

The competitive threat may also explain whether firms choose vertical or horizontal R&D cooperation agreements. Link and Bauer (1989) and Link (1990) found that firms facing market threats from foreign competition were using partnerships as a vehicle for horizontal diversification, while those not subject to such pressures used them to increase their market share by becoming vertically integrated.

Given that a joint venture has been formed, the next question that arises is with regard to its stability and duration, but there is very little empirical work on this topic. One of the very few papers is Nakamura et al. (1996), who investigated the dynamics of joint ventures, hypothesizing that those that result in the partners' competitive capabilities becoming similar break down earlier than those in which intangible competitive capabilities become more dissimilar but remain complementary. Their cross-sectional data from US–Japanese joint ventures in Japan offer empirical support.

Broadly speaking the available evidence, though fragmentary, supports most of our theoretical conclusions. First, there is empirical evidence that the incentive to cooperate is greater among symmetric than asymmetric partners. Cost and risk sharing, as well as complementarities, also appear to create an incentive to cooperate. By contrast, there is evidence that transaction costs for the formation of the venture may impede R&D cooperation agreements. Finally, depending on the number of firms in the innovation race, R&D cooperation may be motivated by either competitive or anti-competitive considerations.

8.2. Spillovers and the incentive to cooperate in R&D

Most of the theoretical models of the relationship between spillovers and R&D cooperation predict that firms will be more likely to cooperate when the appropriation regime is loose. There are two ways to capture the effects of spillovers on the incentive to cooperate: comparing the incentive to cooperate between firms with a basic research orientation and those oriented to applied research; and comparing industries that differ in the degree of R&D spillover. We should expect spillovers and cooperation to be greater for firms oriented to basic than to applied research.

Another approach is to evaluate whether the incentive to cooperate is greater in sectors where spillover is larger (Jaffe, 1986). Large-spillover industries, typically, are telecommunications, semiconductors, instruments, chemicals and electronics. The most typical medium-spillover industry is motor vehicles. Examples of small-spillover industries include food and beverages.[44]

[43] Vonortas (1997) pointed out that "a likely implication of such 'concentration' would be that the RJVs in question operate as exclusive clubs for the big and wealthy, limiting entry to particular industries/technologies and, eventually, slowing down the rate of innovation".

[44] For intra-industry and inter-industry spillovers, see Bernstein (1988), Bernstein and Nadiri (1988) and Levin and Reiss (1988).

Veugelers and de Bond (1992) find significantly more joint ventures in large- and medium-spillover industries. Vonortas (1997) reported that telecommunications and computer software ranked first both in number of RJVs and in membership. The empirical evidence, that is to say, appears to support our theoretical conclusion: the larger spillovers, the greater the incentive for R&D cooperation.

However, spillovers may be of different kinds: incremental and offsetting, for instance, or incoming and outgoing. Incoming spillovers are information flows from outside that improve a firm's innovation process. Outgoing spillovers are information flows that transfer part of the benefits of innovation to other firms.[45]

While the papers cited assume that incoming and outgoing spillovers are equal and symmetric, Cassiman and Veugelers (2002) assume that firms seek to minimize outgoing and maximize incoming spillover. In this view, cooperation is likely to be found among firms for which incoming spillovers are substantial and for those that are effective in appropriating the results of innovation.[46] Empirical inquiries in Belgium support both these predictions.

The nature of spillovers (incoming or outgoing), may affect not only the incentive to cooperate but also the type of agreement (with suppliers or customers, or with research institutions). Cassiman and Veugelers (2002), using Belgian data, and Belderbos et al. (2004), drawing on two Dutch Community Innovation Surveys in 1996 and 1998, found that incoming spillover from one type of partner stimulates cooperation by that type of partner, while incoming spillover from universities and research institutes stimulates all types of cooperation. This suggests that more generic or basic knowledge may enhance the technological opportunities and general effectiveness of a firm's R&D activities. However, the positive effect of incoming spillover is less for horizontal than for other forms of cooperation. By contrast, outgoing spillover has a negative impact on horizontal but a positive effect on vertical cooperation (both with suppliers and customers) and on institutional cooperation (with universities and research centres). López (2008), using Spanish data on manufacturing firms, has now confirmed that larger incoming spillover and more effective strategic methods of appropriating the returns from innovation make R&D cooperation more probable.

Thus we can perceive some general tendencies, but these last results nevertheless confirm that to evaluate the effects of spillovers on R&D cooperation, a case-by-case approach is best.

8.3. Empirical findings on the forms of cooperation

Our theoretical results predict that the preferred form of cooperation will most often be the research joint venture. Let us now look at the empirical evidence on this point. Research using the MERIT-CATI database has found that in the early 1970s some 80% were equity joint ventures, but that by the mid-1990s not even 5% of technology partnerships still involved equity investments. Veugelers and Kesteloot (1994) found that 62% of the 668 alliances reported in the Belgian and international press between 1986 and 1992 were joint ventures, whereas of the 8674 cooperative R&D agreements from 1971 to 1989 classified by Hagedoorn and Schakenraad (1994), 19% were RJVs and 22% were non-equity co-developments (COD). Hagedoorn and Schakenraad found that the choice of RJV rather than COD is related to the degree of competition in the downstream business: R&D cooperation between firms in the same industry and same country was conducted exclusively in the form of RJVs, whereas when firms expect to use the new technology developed in different downstream businesses, they may choose either an RJV or a COD. Tao and Wu (1997) reach similar conclusions for a sample of 105 major cooperative R&D projects reported in the *Wall Street Journal* from 1985 to 1992.

There is very little empirical work on the relative importance, to technological performance, of consortium design and level of R&D input. Branstetter and Sakakibara (2002), using data on large firms in research consortia in Japan, did find that the design of the consortium is more important than the amount of input. One of the very few other papers on this topic (Okamuro, 2007) concludes that the organizational and contractual characteristics of the R&D enterprise, such as membership structure, partner relationships, external support, and rules for cost and result sharing, are relevant not only for large firms but also for cooperation among SMEs. However, more empirical evidence is necessary to get a better understanding of choices concerning the form and organization of R&D cooperation.

Let us now turn to the empirical evidence on how R&D cooperation affects the incentive to innovate. On theoretical grounds we should expect a diminution of R&D effort when cooperation is motivated by eliminating duplication of

[45] Incremental and offsetting spillovers may be considered as two kinds of outgoing spillovers.

[46] It should be noted that this last prediction contrasts with those set forth earlier, namely that firms have an higher incentive to cooperate when spillovers are high.

effort or by anti-competitive purposes. Cooperative agreements to share costs or to exploit complementarities among firms, on the other hand, should spur innovation.

Roller et al. (1997) confirmed these predictions. They reported negative correlation between R&D expenditure and cooperation when the motivation is cost-cutting, but a positive correlation when it is to exploit synergies and complementarities. Okamuro (2004) demonstrates that R&D cooperation among Japanese SMEs has a positive impact on patent awards, confirming that cost- and risk-sharing motivations tend to increase the incentive to innovate. Becker and Dietz (2004) find that in Germany cooperation increases both R&D input and output.

Notice that the causal relation between cooperation and R&D effort may also be reversed. On French data, Miotti and Sachwald (2003) found that the propensity to cooperate on R&D is higher for firms that are more R&D-intensive and have stronger absorptive capacity, typically those in high-tech sectors. The positive influence of R&D intensity on the propensity to cooperate has also been confirmed for large cross-sectional samples of German and Spanish firms by Fritsch and Lukas (2001) and by Bayona et al. (2001). Thus the quantity and quality of firms' R&D resources influence their propensity to cooperate in general and the propensity to cooperate with specific partners. On this question, too, however, more extensive and robust empirical evidence is necessary.

Finally, the results reported above suggest that when firms do undertake a cooperative agreement, spillovers may either increase or decrease the incentive to innovate, depending on their size and nature. However, to date there have been virtually no empirical studies on the relationship between cooperative and competitive R&D efforts in industries characterized by different degrees of spillover.

9. Conclusion

We have discussed the main factors affecting the incentive for firms to cooperate in R&D and the effects of cooperation on the incentive to innovate. Theoretical models in a complete contract framework postulate that uncertainty and spillovers are crucial parameters affecting the incentive to cooperate. Low uncertainty (high probability of project success) and large spillover of the results enhance the incentive to cooperate. Under most circumstances the preferred form of cooperation is the research joint venture, in which firms share costs and results and eliminate duplication of effort.

However, problems of asymmetric information, moral hazard and transaction costs explain why in some cases firms may prefer cross-licensing agreements or why cooperation may not be realized even when it would be profitable. Moreover, the incentive to cooperate may be either greater or lesser among asymmetric than symmetric partners, depending on the source of the asymmetry. If it derives from complementarity of assets, the incentive is greater among asymmetric firms, but if firms are equal except for the level of knowledge, it is stronger among symmetric partners. And in any case cooperative agreements among asymmetric firms are more unstable.

If more than two firms are involved, the equilibrium outcome very often is a set of competing RJVs. However, the less competitive the ex post product market, the more concentrated the coalition structure; and in the extreme case of complementary goods, firms will form a single grand coalition. Spillovers have similar effects: the larger they are, the larger the R&D coalition will be. Finally, uneven coalitions may arise as a result of asymmetric positions in the R&D market.

The empirical evidence on cooperation in R&D is scanty, consisting mostly of case studies, but it does support most of our theoretical predictions. Thus there is evidence that the incentive to cooperate in R&D is greater among symmetric than asymmetric partners, and case studies show that cost and risk sharing and complementarities among firms heighten the incentive to cooperate. But there is also evidence that transaction costs may prevent the establishment of a cooperative R&D venture. The absorptive capacity motivation for R&D is supported by a number of empirical papers. And finally, there is evidence that leapfrog competition over rivals has also spurred cooperation but that agreements may also have anti-competitive motivations.

Empirical findings show that spillovers increase the incentive to cooperate and also affect the type of agreement (i.e., the nature of the partners). In line with the theoretical predictions, the empirical evidence is that the most commonly preferred form of cooperation is the RJV, but other forms may arise, depending on the nature of competition in the downstream markets.

Finally, theoretical considerations indicate that the effects of R&D cooperation on the incentive to innovate depend on underlying motivations. The empirical evidence supports this thesis, finding a negative correlation between R&D expenditure and cooperation when the reason is the reduction of R&D expenses and a positive correlation when exploiting synergies and complementarities. Competing research joint ventures enhance the incentive to innovate with respect to a competitive R&D market.

The general purport of the literature reviewed is that in evaluating the incentives and effects of cooperation in research and development, a case-by-case approach will be most fruitful. This is needed to assess how the characteristics of the R&D activity, the assets of the partners, and the purposes of the agreement interact to determine the technological and commercial success of the R&D agreement, which also depends on the characteristics of the R&D market and the product market arising from the innovation.

So anti-trust analysis of the incentive to cooperate in R&D must be based on a detailed understanding of the circumstances in which cooperation occurs. As an example, authorities tend to view cooperation between firms with suspicion. They fear that while cooperation in the research stage increases the probability of discovery, it could easily turn into collusion in the production stage. However, some types of cooperation are more conducive to collusion than others. Thus, for instance, when engaged in a joint venture members of the different firms spend much time and effort working together, which may create particularly fertile ground for discussions and decision-making in other realms (such as price setting). Information sharing, on the other hand, does not require such an intimate setting and so may be preferred by anti-trust authorities. Thus we can see information-sharing agreements flourish despite their inferiority. At the same time, however, there are instances where permissive anti-trust policy on cooperation in R&D is more appropriate, if static welfare losses prompt innovation.

In any event, considerably greater effort will have to be made to improve our understanding of the determinants and effects of cooperation in R&D. To mention only a few of the issues that need to be addressed, the organizational and contractual characteristics of cooperative agreements, and their effects on technological and commercial success, are largely unexplored. And there is practically no empirical or theoretical literature on the evolution of cooperation. Other unexplored questions are what is the incentive to cooperate and to innovate when firms take account of both current and future innovations; whether, in addition to the incentive to innovate, cooperative agreements also affect the nature of R&D projects and the direction of innovation (process or product); and how industries evolve when the outcome is joint discovery rather than a single winner. These issues are likely to shape the direction of future research.

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