2000s-53

Information Sharing and the Stability of Cooperation in Resarch Joint Ventures

Gamal Atallah

Série Scientifique
Scientific Series

CIRANO
Centre interuniversitaire de recherche en analyse des organisations

Montréal
Novembre 2000

ISSN 1198-8177

Information Sharing and the Stability of Cooperation in Research Joint Ventures*

Gamal Atallah†

Résumé / Abstract

Le partage d'information et la stabilité de la coopération dans les consortiums de recherche. Cet article examine le partage de technologie et la stabilité de la coopération dans les consortiums de recherche (RJVs) dont le but est la réduction des coûts de production. Dans un jeu à trois étapes, les firmes prennent des décisions quant à leur participation à la RJV, au partage d'information et aux dépenses en R&D, et à leur output. Une caractéristique importante du modèle est que le partage volontaire d'information au sein de la RJV augmente les fuites d'information vers les non-membres. On montre que les RJVs représentant une plus grande proportion des firmes dans l'industrie ont davantage tendance à partager l'information. Lorsqu'il n'en coûte rien de partager l'information, les firmes ne choisissent pas des niveaux intermédiaires de partage d'information: l'information est partagée au complet ou pas du tout. La taille de la RJV dépend de trois effets: un effet de coordination, un effet d'information et un effet de concurrence. Dépendamment de l'importance relative de ces trois effets, la taille de la RJV peut augmenter ou diminuer avec les externalités. Lorsque les fuites d'information vers les non-membres augmentent, les membres de la RJV réduisent leurs dépenses en R&D. De plus, soit qu'ils augmentent la taille de la RJV en maintenant le partage d'information (lorsque les externalités sont faibles), soit qu'ils réduisent la taille de la RJV et le partage d'information (lorsque les externalités sont élevées). L'effet du partage d'information sur la profitabilité des firmes ainsi que sur le bien-être est examiné.

The model studies information sharing and the stability of cooperation in cost reducing Research Joint Ventures (RJVs). In a three-stage game-theoretic framework, firms decide on participation in a RJV, information sharing along with R&D expenditures, and output. An important feature of the model is that voluntary information sharing

*This paper is based on the third chapter of my doctoral dissertation completed at the Université de Montréal. I would like to thank Gérard Gaudet, my thesis advisor, for insightful comments and suggestions. I would also like to thank Caroline Boivin, Marcel Boyer, Ngo Van Long, Michel Poitevin, and Jacques Robert for their comments, as well as participants to the 35th meeting of the Canadian Economics Association and the 28th Annual Conference of the European Association for Research in Industrial Economics.

† Department of Economics, University of Ottawa, Ontario, K1N 6N5, Canada. Email: gatallah@uottawa.ca

between cooperating firms increases information leakage from the RJV to outsiders. It is found that RJVs representing a larger portion of firms in the industry are more likely to share information. It is also found that when sharing information is costless, firms generally don't choose intermediate levels of information sharing: they share all the information or none at all. The size of the RJV is found to depend on three effects: a coordination effect, an information sharing effect, and a competition effect. Depending on the relative magnitudes of these effects, the size of the RJV may increase or decrease with spillovers. In response to an increase in leakages, RJV members reduce their R&D spending. In addition, they either increase the RJV size while maintaining information sharing unchanged (when leakages are low), or they reduce both information sharing and RJV size (when leakages are high). The effect of information sharing on the profitability of firms as well as on welfare is studied.

Mots clés : Externalités de recherche endogènes, Partage d'information, Coopération en R&D, Consortiums de recherche

Keywords: *Endogenous R&D spillovers, Information sharing, R&D cooperation, Research Joint Ventures*

JEL: L13, O32

1. Introduction

R&D cooperation incorporates three dimensions: the coordination of R&D expenditures, information sharing, and the stability of the cooperative venture. The coordination of R&D expenditures induces firms to internalize innovation externalities; information sharing increases R&D spillovers between cooperating firms; and the instability of cooperation arises because cartels are vulnerable to individual and coalitional deviations.

A large theoretical literature on R&D cooperation and competition now exists, starting with the seminal paper of d'Aspremont and Jacquemin (1988). Most of this literature has focussed on the coordination of R&D spending, with little attention being devoted to the information sharing dimension or to the stability of cooperation. Generally, information sharing and Research Joint Venture (RJV) formation have been analysed separately. Typically, the extent of information sharing has been assumed exogenously, and cooperation has been assumed to be industry-wide (the industry itself being often composed of a duopoly). However, important interactions between information sharing and RJV formation arise. The level of information sharing affects the attractiveness of the cooperative venture to outsiders, and also affects the willingness of cooperating firms to admit additional members. A thorough understanding of R&D cooperation requires the study of the interactions between information sharing and RJV formation. This paper attempts to remedy this gap by studying the endogenous determination of information sharing, together with endogenous RJV formation.

Two approaches coexist in the literature regarding information sharing. The first assumes that information sharing is not affected by cooperation, in which case cooperating firms simply coordinate R&D expenditures. The second assumes that cooperating firms share all of their research results. Both assumptions are arbitrary, and lack theoretical as well as empirical foundations. While it is reasonable to assume that information sharing is improved by cooperation, there is no foundation for the assumption of perfect information sharing.

Consider next the question of industry-wide cooperation. Studies have typically assumed that all industry members participate in the RJV. When the size of the RJV is endogenized, information sharing is generally exogenous. Only De Bondt and Wu (1997) and Katz (1986) have addressed jointly RJV stability and information sharing. De Bondt and Wu (1997) study an R&D cooperation model with insiders/outsiders. The effect of different levels of information sharing is addressed, although information sharing remains exogenous. They find that an industry-wide RJV quickly becomes stable for relatively low levels of information sharing. Katz (1986) is the only paper that simultaneously endogenizes information sharing and RJV formation. In his model, firms decide on their RJV membership, R&D cost sharing and information sharing rules, R&D expenditures, and output. The model shows that cooperation is beneficial when product market competition is low, when spillovers are important, and when cooperation improves information sharing. With industry-wide cooperation, full information sharing is adopted. The conditions for the emergence of industry-wide cooperation are characterized. However, the model focuses on polar cases: no exogenous spillovers, and either industry-wide or no cooperation.

In the model studied here both information sharing and participation in the RJV are endogenous. In a three-stage game-theoretic model, firms decide on participation in a RJV, information sharing along with R&D expenditures, and output. An important feature of the model is that voluntary information sharing between cooperating firms increases information leakage from the RJV to outsiders. The underlying argument is that sharing information increases the likelihood that this information leaks out to third parties. Also, firms may be allowed to cooperate in exchange for a greater diffusion of their findings.

Spillovers can be endogenous in two (non-exclusive) ways. First, by investing in learning and improving their absorptive capabilities, firms can increase the effective information they receive from other agents (Cohen and Levinthal, 1989; Adams, 2000). Second, by controlling how much information leaks out, firms can impact the level of outgoing spillovers. Ultimately, therefore, a flow of information is affected by the behaviour of both the source and the destination of the information. This paper focusses on the control of firms over outgoing spillovers through their information sharing decisions.

It is found that the likelihood of information sharing increases with the size of the RJV, because a larger RJV (for a given industry size) means that the benefits of information sharing are greater, and the losses from leakages to outsiders are smaller. This result shows the importance of the interaction between RJV size and information sharing. Moreover, when sharing information is costless information sharing does not take intermediate values (except for the critical leakage level separating sharing from no sharing): firms either share all the information or none at all. When leakages are sufficiently low, firms share information, because the benefits outweigh the losses due to leakages to outsiders. However, with high leakages, outsiders benefit sufficiently from information sharing that the competitive position of RJV members deteriorates. Therefore, the model predicts that the absence of information sharing is due to competitive impediments (leakage of information to non-RJV members), while intermediate levels of information sharing would arise as a result of other considerations: costs of sharing information, or limited compatibility of firms' technologies.

The size of the RJV is found to depend on three effects: a coordination effect, an information sharing effect, and a competition effect. Depending on the relative magnitudes of these effects, the size of the RJV may increase or decrease with spillovers. Paradoxically, the size of the RJV may increase with the leakage from the RJV to outsiders. The effect of information sharing on the profitability of firms as well as on welfare is studied.

In response to leakages on information sharing, firms have three dimensions on which they can adjust: R&D spending, information sharing, and the size of the RJV. It is always the case that an increase in leakages decreases R&D spending by RJV members. However, the adjustments on the two other dimensions are interrelated. When leakages are low or moderate, firms respond to increases in leakages by increasing the size of the RJV, in order to sustain information sharing (because larger RJVs have more tolerance for leakages). In that first case information sharing is not affected by the leakages. However, when leakages are very high, increases in leakages destroy the incentives for information sharing, and, by reducing the attractiveness of the RJV, reduce its size considerably.

Some studies have addressed information sharing and the size of the RJV, albeit separately. These studies are briefly discussed here, along with some empirical evidence showing that the assumptions of exogenous information sharing and of industry-wide cooperation are unsatisfactory.

A number of studies have addressed the issue of technology sharing between competitors, without taking into consideration the interactions between information sharing and the stability of cooperation, however. Kamien et al. (1992) study both the case where cooperation entails no information sharing and the case where it entails maximum information sharing. d'Aspremont et al. (1996) consider the problem of bargaining over the disclosure of interim research knowledge in a R&D race for a patentable innovation between two firms. Katsoulacos and Ulph (1998a, 1998b) endogenize R&D spillovers taking into account distinctions such as whether firms are in the same industry or not, product versus process innovations, technical substitutability or complementarity, and information sharing versus research coordination. Poyago-Theotoky (1999) allows duopolistic firms to choose the spillover level after R&D investments are undertaken; she finds that cooperating (non-cooperating) firms choose maximal (minimal) spillovers. Kamien and Zang (1998) allow firms to choose an "R&D approach" which determines how much the firm can benefit from other firms' R&D. Combs (1993) develops a model where R&D cooperation increases the probability of innovation by sharing information about research strategies and outcomes. De Fraja (1990, 1993) investigates whether firms have an incentive to disclose their research results or not. Rosenkranz (1998) studies firms' incentives to form RJVs in an incomplete information framework when technological know-how is private information; two firms first decide on cooperation and information revelation and then compete for a patent. Finally, Bhattacharya et al. (1990) develop a two-stage model where researchers may share endowments of productive knowledge in the first stage and choose R&D efforts independently in the second stage.

Some studies have focussed on the moral hazard dimension of technology sharing. Pérez-Castrillo and Sandonís (1997) study a model in which the disclosure of information makes the expected cost of the project lower. An RJV may fail to form because of the moral hazard problem arising from the difficulty of contracting upon the transfer of information. They find that penalties can alleviate the incentive problem and the individual rationality constraints. Bhattacharya et al. (1992) consider a three-stage model of R&D where firms can share knowledge prior to choosing unobservable R&D levels and competing in the product market. d'Aspremont et al. (1998) consider RJVs with adverse selection in knowledge sharing and moral hazard in private development efforts.

Empirically, R&D cooperation with and without information sharing is observed.[2] Branstetter and Sakakibara (1997) find evidence of increased knowledge spillovers within Japanese research consortia. They report that access to complementary knowledge of other RJV members is the most highly cited motive behind participation in research consortia by R&D managers. Mariti and Smiley (1983) studied 70 cooperative agreements between European firms that took place in 1980, and found that one way flows of information were behind 41% of agreements, while information sharing (two-ways flows of information) were behind 29% of agreements. Cassiman and Veugelers (1998), from the study of a sample of firms from the Belgian manufacturing industry, find that spillovers received by a firm tend to be higher when the firm engages in cooperative R&D, which is consistent with improved information sharing between cooperating firms. Adams (2000), from the study of a sample of R&D laboratories in the chemicals, machinery, electrical equipment, and transportation equipment industries, finds that learning expenditures increase in response to spillovers, which is an indication that spillovers are endogenous.

However, willingness to share some information does not mean that firms necessarily share all of their research results. Imperfect information sharing may arise because of technical difficulties,

[2]See Cassier and Foray (1999) for a discussion of the rules governing the sharing of research results in eight biotechnology research consortia.

differences in organizational culture, and strategic factors (De Bondt and Wu, 1997). The distinctive nature of the technologies of some firms may impose constraints on the extent of cooperation and information sharing with other firms (Uenhora, 1985). Firms also have discretion over how much information they effectively disclose. A firm can affect the spillover rate through the choice of the location of its laboratories, or by controlling the participation of its researchers in scientific conferences (De Fraja, 1990). Bhattacharya et al. (1992) report reluctancy on the part of some firms to send their best researchers to the RJV.

The regulation of information sharing can be found in the cooperative agreement itself. The US Department of Commerce estimates that one year is the minimum length of time required to reach agreement on the research agenda between cooperating firms (Link and Tancy, 1989). This shows the complexity of the negotiation mechanism behind research output sharing contracts. The European cooperative research programs Esprit and Race require cooperation and information sharing, while the program Eureka requires cooperation but not information sharing (Fölster, 1993).

Fransman (1990) addresses the issue of information sharing in terms of research facilities. He distinguishes between cooperative research where firms keep distinct research facilities -in which case the level of information sharing is low- and cooperative research where firms use joint research facilities -in which case we can expect higher levels of information sharing. Firms may want to maintain both types of cooperative agreements in parallel. In some cases, they may wish to share information more thoroughly with suppliers/distributors, and less with competitors. In Japan, separate research facilities between cooperating firms seem the norm, not the exception. There is evidence that the propensity to share knowledge is lower for commercializable devices, and when inter-firm competition is important (Fransman, 1990).

Consider now the second dimension, the stability of cooperation. De Bondt et al. (1992) study the stability of a RJV assuming that information sharing is not improved by cooperation, and that spillovers between the RJV and outsiders are symmetric. Poyago-Theotoky (1995) analyzes a model with spillovers where one RJV forms endogenously, assuming that cooperation entails maximal information sharing. Kamien and Zang (1993) study an industry where several competing RJVs form endogenously. Yi and Shin (2000) examine the endogenous formation of RJVs when many RJVs can form, and study the effects of exclusive membership versus open membership rules. Yi (1998) studies the stability of cost reducing joint ventures with exogenous cost reduction. Greenlee (1998) studies the stability of RJVs that share information but do not coordinate R&D expenditures; while information sharing in RJVs is imperfect, it remains exogenous. Röller et al. (2000) show that firms have an incentive to exclude other firms from RJV membership. In particular, large firms have an incentive not to form research consortia with small firms. Kesteloot and Veuglelers (1995) study the stability of R&D cooperation in a two-firms repeated game model. Eaton and Eswaran (1997) study the formation of technology-trading coalitions with an infinite horizon. However, in all of these studies, while the size of the cooperative venture(s) is endogenous, information sharing is exogenous.

The assumption of industry-wide cooperation (common in the literature) is at odds with empirical evidence. Most RJVs comprise only a subset of firms of a given industry. From the examination of 27 cooperative research agreements, Combs (1986) finds that in no case did the agreement include an entire industry. Industry-wide RJVs are generally directed at industry regulatory problems (Peck, 1986). Snyder and Vonortas (2000) find that many RJVs are constituted of a large number of firms; The MCC (Microelectronics and Computer Technology Corporation) research consortium included 21 participating firms. This makes the standard duopoly framework even less appropriate for the study of RJVs.

There are many reasons why one or more firms may decide not to participate in a RJV. Firms in an industry may take different technological paths, and may hence have more technological affinities with some firms than with others. Moreover, asymmetries between firms may lead some firms to opt out of the RJV. It may also be the case that the RJV is composed of more advanced firms in the industry, and that less advanced firms are not allowed in. In the same token, the RJV may be formed by technologically backward firms that are trying to catch up with the leaders, in which case the latter have no interest in participating in the RJV.[3] Firms may have different objectives and priorities with respect to the technological developments of their products. Some firms may prefer to stay out of the RJV and benefit from the research results of the RJV without sharing in the costs or providing information about its technology.[4] Antitrust authorities may pay more attention to cooperation between a large number of firms: an industry-wide RJV eliminates competition along the R&D dimension, which may lead to complacency in research efforts (Kamien and Zang, 1993; U.S. Department of Justice, 1985). Finally, some firms may be more secretive about their R&D results, and refuse to participate in

[3]Branstetter and Sakakibara (1997) report that in Japan technology leaders are more reluctant to participate in some research consortia.

[4]For instance, the research results of SEMATECH (the Semiconductor Manufacturing Technology Consortium) benefited members as well as non-members of the research consortium (Grindley et al., 1994).

RJVs. It is then not surprising that in the real world, most RJVs involve only a subset of firms in a given industry.

The paper is organized as follows. The four-stage model is presented in section 2. The results are taken up in section 3 in terms of output and R&D, information sharing, cartel stability, technological diffusion, and profits and welfare. Section 4 concludes.

2. The model

There are T identical firms selling a homogeneous output, whose inverse demand is given by $p=a-wY$, $Y=\sum_{i=1}^{T} y_i$, where Y is total output and y_i is firm i's output. The unit cost of firm i is

$$c_i(\Gamma_i) = r - x_i - \Gamma_i \qquad \textbf{(1)}$$

The parameter r is the production cost per unit before cost reductions attributable to R&D spending. The variable x_i is the R&D output of firm i. One unit of R&D reduces the production cost to its producer by one dollar. Γ_i represents the effect of voluntary information sharing on the cost of firm i. Note that Γ_i represents information received by, not information divulgated by, firm i. For simplicity it is assumed that there are no exogenous spillovers. Adding exogenous spillovers to the model would complicate the analysis without adding any new insights. The parameters are assumed to be such that $r>x_i+\Gamma_i$, so that costs are strictly positive.

The profit of firm i is

$$\pi_i = [p(Y)-c_i(\Gamma_i)]y_i - ux_i^2 \qquad \textbf{(2)}$$

where the dollar cost of x units of R&D is ux^2, $u>0$.

The game has three stages. In the first stage the size of the RJV, M, is determined endogenously. The number of firms outside the RJV is $N=T-M$. Only one RJV is allowed to form. In the second stage insiders decide on their R&D expenditures and on the level of information sharing within the RJV cooperatively; simultaneously, outsiders decide on their R&D expenditures. In the final stage firms compete noncooperatively à la Cournot.

The sequence of decisions is linked to the logical sequence of the formation of a real RJV. Before participating in the RJV, firms decide on its structure. Two important elements of this structure are the size of the RJV and the level of information sharing within the RJV. The former is likely to be agreed upon before the latter, for it will be only participants that decide on the level of information sharing.

The first stage is the determination of the size of the RJV. For simplicity's sake, the total size of the industry, T, is given. Players are ranked according to an exogenous rule of order. Because firms are identical, the profitability of the RJV depends only on its size, and not on the identity of its members. This is equivalent to an anonymity condition: each player's payoff depends only on the number of players who choose each strategy (insider/outsider).[5] It is assumed that insiders can block the entry of an additional firm if it reduces their profits.[6] An outsider will join the RJV only if this increases its profits, and is allowed by insiders. I define stability of the RJV as follows:

Definition. Let $\pi_i^m(z)$ represent the profit of an insider, and $\pi_i^n(z)$ represent the profit of an outsider when the RJV is of size z. Then a RJV of size M is stable iff, for $M \leq T$,

i) $\pi_i^m(M) \geq \pi_i^m(M\text{-}1)$, and

ii) $\pi_i^m(M) \geq \pi_i^n(M\text{-}1)$, and **(3)**

iii) $\pi_i^m(M) \geq \pi_i^m(M+1)$, or $\pi_i^n(M) \geq \pi_i^m(M+1)$, or both.

Condition *i* states that RJV members would not gain by eliminating a firm from the RJV. Condition *ii* states that no member wants to drop unilaterally from the RJV (internal stability). These two conditions take also care of the case of no RJV formation. Condition *iii* states that either no outsider wants to join the RJV (external stability), or insiders would lose by allowing an additional firm into the RJV, or both. When more than one RJV size satisfy (3), the RJV size yielding higher profits for insiders (given that they can block outsiders from becoming members) prevails. When more than one RJV size yield exactly the same profits for insiders and the same profits for outsiders (and that both satisfy (3)), the largest of these RJV sizes is assumed to prevail.

The stability conditions used here are close to those usually adopted in the cartel stability literature. De Bondt et al. (1992) and De Bondt and Wu (1997) use a Nash stability concept, based on d'Aspremont et al. (1983), which relies exclusively on internal and external stability, allowing for free entry into the cartel. Shaffer (1995) addresses the entry-blocking capacity of the cartel, but her stability concept incorporates only conditions *i* and *ii*. Poyago-Theotoky (1995) uses an entry-blocking cartel, but considers the condition $\pi_i^m(M) \geq \pi_i^m(M+1)$ as necessary, while here it is not. The concept used here

---

[5]A common weakness of this approach to cartel stability is that, while it informs us about the stability of the cartel, it tells us very little about the process behind the formation of the cartel, or about the identity of its members.

[6]For instance, Combs (1993) reports that members of the Microelectronics and Computer Technology Corporation vote to allow a firm to purchase shares in the venture.

incorporates internal and external stability, and goes further by allowing for entry-blocking by the cartel.[7]

We now turn to the second stage of the game, where all firms determine their R&D expenditures, and, in addition, insiders decide on information sharing. The cause to effect relationship between cooperation and spillovers is bidirectional: not only do spillovers affect the decision to cooperate, but also the decision to cooperate affects spillovers.[8] Let $g \in [0,1]$ represent the level of voluntary information sharing within the RJV.

There is an information leakage from the RJV to outsiders on voluntary information sharing within the RJV. From the moment a firm decides to share some of its private information with one or more other firms , the firm takes the risk that this information may leak to third parties.[9] By transmitting the information to other RJV members, the probability of leakage increases.[10] While an in-house research project may be run in total secrecy, the very formation of a RJV and the type of research being performed is common knowledge, for it usually requires the government's approval. A government may allow firms to form a RJV in exchange for a greater diffusion of their research findings or of the technology they share. When RJV members know that their information sharing will increase spillovers to outsiders, they may wish to choose less than perfect information sharing. And outsiders, knowing this, will act strategically so as to benefit from this link.[11] The dependence of spillovers from the RJV to outsiders on information sharing, which is endogenous, makes those spillovers themselves endogenous to the model.

Let $k \in [0,1]$ represent the leakage factor from the RJV to outsiders on voluntary information

---

[7]RJVs are generally short-lived. Kogut (1989) shows that joint ventures are highly unstable. This instability is often due, in his words, to "business failure or a fundamental instability in governance." He finds that the stability of a joint venture increases with its R&D intensity. Bureth et al. (1997) note that the knowledge produced by pre-competitive research agreements (such as the one studied here) is highly generic and abstract, which reduces the cost of breaking with the cartel, thereby increasing instability.

[8]Colombo and Garrone (1996), in their study of R&D and cooperation behaviour of 95 US, European, and Japanese firms, find that feedbacks between internal R&D and the participation in cooperative R&D agreements exist, and hence neither dimension can be considered exogenous with respect to the other.

[9]For instance, Mansfield (1985) finds that information on a new product or process is divulgated on average one year after its discovery.

[10]Cassiman and Veugelers (1998) find that cooperating firms have lower outgoing spillovers. However, that result is weakened by the fact that the data used gives information only on whether a given firm cooperates in R&D or not, without evidence on the extent of cooperation or on the nature of the cooperative agreement. Moreover, the data does not allow the separation of spillovers to and from partners versus non-partners. Also, they do not explain what mechanisms cooperating firms use to reduce outgoing spillovers, or why such mechanisms are not used by noncooperating firms.

[11]Even if the spillover on voluntary information sharing is high, outsiders may still suffer because of the lead time advantage of insiders. This advantage seems important, for instance, in the Microelectronics and Computer Technology Corporation RJV (Peck, 1986).

sharing. The total spillover level from the RJV to outsiders is kg. The following inequalities must hold: $0 \leq kg \leq g \leq 1$.

Let M be the number of RJV members (to be determined endogenously in the first stage), and let N be the number of outsiders, $M+N=T$. Without loss of generality assume that the first M firms join the RJV, while the other N firms remain outsiders. The following notation will be used to represent R&D output:

$$X^m \equiv \sum_{i=1}^{M} x_i^m \qquad \text{(Total R\&D output of the RJV)}$$
$$X_{-i}^m \equiv X^m - x_i^m$$
$$X^n \equiv \sum_{i=M+1}^{T} x_i^n \qquad \text{(Total R\&D output of outsiders)}$$
$$X_{-i}^n \equiv X^n - x_i^n$$
$$X \equiv X^m + X^n \qquad \text{(Total R\&D output)}$$
$$X_{-i} \equiv X - x_i$$

We now define Γ_i. The information received by firm i, Γ_i, can take two values, depending on whether the firm is an insider or an outsider.

$$\Gamma_i^m \equiv gX_{-i}^m, \qquad i=1,\dots,M$$
$$\Gamma_j^n \equiv kgX^m, \qquad j=M+1,\dots,T$$

Insiders benefit the most from voluntary information sharing if they receive more information than outsiders, that is, if $\Gamma_i^m > \Gamma_j^n$. It is useful to examine under what circumstances this inequality holds. Assume for this purpose that $x_{M+1}^n = \dots = x_T^n$, $x_1^m = \dots = x_M^m$ (this will be shown to hold in equilibrium). Then it is immediate that $\Gamma_i^m > \Gamma_j^n$ if and only if $M > 1/(1-k)$. We see that insiders are more likely to benefit from information sharing (by insiders) more than outsiders the larger the RJV, and the lower k is. The relation does not depend on g. Also, it is neither sufficient nor necessary for insiders to spend more on R&D in order to benefit more from voluntary information sharing.

On substituting Γ_i^m and Γ_j^n into (1) we obtain the unit costs of outsiders and insiders:

$$\begin{aligned} c_i^m &= r - x_i^m - gX_{-i}^m, \qquad i=1,\dots,M \\ c_j^n &= r - x_j^n - kgX^m, \qquad j=M+1,\dots,T \end{aligned} \tag{4}$$

In the second stage firms decide on R&D expenditures and information sharing. Insiders choose their R&D expenditures and information sharing to maximize their joint profits, while each outsider chooses its R&D to maximize its own profits. Let $x^n \equiv \{x_{M+1}^n, \dots, x_T^n\}$, and $x^m \equiv \{x_1^m, \dots, x_M^m\}$. Outsider i solves the following problem

$$\max_{x_i^n} \quad \pi_i^n = [p(Y(x^n, x^m, g)) - c_i^n(x^n, x^m, g)]y_i^n(x^n, x^m, g) - u[x_i^n]^2 \qquad i=M+1,\dots,T \tag{5}$$

and insiders solve, jointly

$$\max_{g\,,\,x_1^m,\ldots,\,x_M^m} \quad \Sigma_{i=1}^{M} \quad \pi_i^m \;=\; [p(Y(x^n,x^m,g))-c_i^{\,m}(x^n,x^m,g)]y_i^{\,m}(x^n,x^m,g)-u[x_i^{\,m}]^2 \qquad \textbf{(6)}$$
$$s.t. \quad g\in[0,1]$$

In the final stage (the output stage) firm *i* solves the following problem

$$\max_{y_i} \quad \pi_i \;=\; [p(Y)-c_i(\Gamma_i)]y_i-ux_i^2 \qquad i=1,\ldots,T \qquad \textbf{(7)}$$

Note that output is chosen noncooperatively.

3. Results

We solve the model starting from the last stage to ensure subgame perfectness. Solving the output stage (7) yields each firm's output as a function of R&D expenditures of all firms and of spillovers:

$$y_i \;=\; \frac{a-r+Tx_i+T\Gamma_i-X_{-i}-\Sigma_{j\neq i}^{T}\Gamma_j}{T+1} \qquad i=1,\ldots,T \qquad \textbf{(8)}$$

Substituting Γ_i^m and Γ_i^n into (8) yields each outsider's output y_i^n and each insider's output y_i^m.

$$y_i^{\,n} \;=\; \frac{a-r+Tx_i^{\,n}-X_{-i}^{\,n}+[-1+g(1+k-M(1-k))]X^m}{T+1} \qquad i=M+1,\ldots,T$$
$$y_i^{\,m} \;=\; \frac{a-r+(g+M(1-g)+N(1-kg))x_i^{\,m}+(-1+g(2+N(1-k)))X_{-i}^{\,m}-X^n}{T+1} \qquad i=1,\ldots,M \qquad \textbf{(9)}$$

We now turn to the second stage, the determination of R&D expenditures and information sharing. Consider first information sharing.

Proposition 1. *For a given RJV size $M\in\{2,\ldots,T\}$, there exists a critical leakage level*

$$k_c \;=\; \frac{MN+M-N-1}{MN} \qquad \textbf{(10)}$$

such that:

a) For all $k<k_c$ maximal information sharing is chosen ($g=1$).

b) *For all* $k>k_c$ *no information is shared* ($g=0$).

c) For $k=k_c$ *information sharing is indeterminate* ($g\in[0,1]$).

d) k_c *increases with the number of insiders, and decreases with the number of outsiders.*

Proposition 1 (all proofs are in the appendix) says that for a given RJV size, firms will choose maximal information sharing if k is smaller than a certain threshold, and will choose zero information sharing if k is higher than that threshold. The threshold k_c is decreasing in N and increasing in M. Information sharing is found to be either maximal or minimal, it never takes intermediate values, except when $k=k_c$, where it can take any value between 0 and 1.

Note that $k_c>0$. This means that whenever there is no leakage to outsiders, insiders share information. When $k=0$ voluntary information sharing within the RJV reinforces its competitive position relative to outsiders, without yielding any advantage to outsiders; hence insiders always choose maximal information sharing in this case. With $k>0$, some information leaks out, hence information sharing by insiders benefits both insiders and outsiders. Insiders choose maximal information sharing when k is sufficiently low so that the benefits leaking to outsiders are not too important. When $k<k_c$, insiders' profits are increasing in information sharing, and they set $g=1$. For large k, insiders do not share information, since outsiders benefit from it significantly at no cost. When $k>k_c$, insiders' profits are decreasing in information sharing, and they set $g=0$. When $k=k_c$, we have an interior solution for g. In that case the optimal choice of g is indeterminate: all levels of g yield the same level of profits for insiders. This is so because at $k=k_c$ the benefits from information sharing are exactly outweighed by the leakage to outsiders, therefore insiders are indifferent as to the level of information sharing (but outsiders are not necessarily indifferent).

k affects the decision of whether to share information, but has no effect on the level of information sharing. However, while the level of information sharing is independent of k, the amount of information effectively shared is affected by k, since k affects R&D. Clearly, for a given level of R&D, it is socially optimal that firms share all their research results. Hence a weak protection of cooperative research (i.e. a high k) will lead to suboptimal information sharing.

k_c depends on the size of the RJV relative to the size of the industry because it is ultimately this ratio which determines the benefits from information sharing and the losses from leakages to outsiders. The threshold k_c increases with M because as M increases the benefits of internal information sharing increase (because there are more insiders). Similarly, it decreases with N because as the number of outsiders increases, the impact of information leakage on outsiders becomes more important. As k

increases, a larger RJV (relative to the industry) becomes necessary to make information sharing in the RJV beneficial to insiders. This suggests that RJVs constrained in size (by regulation, for instance) are less likely to share information than non-constrained RJVs, because of the benefits such sharing provides to outsiders.

To get some sense of the magnitudes of k_c, the following table presents values of k_c for a range of RJV and industry sizes. The cases where $k_c>1$ represent cases where insiders always share information, irrespective of k. From (10) we see that this occurs when $M>N+1$: when the number of insiders exceeds the number of outsiders by at least 1. Even though all the information shared leaks out to outsiders, insiders benefit sufficiently from information sharing to decide to share it. Thus, as long as the size of the RJV exceeds the number of outsiders by at least one, insiders share all information, irrespective of leakages to outsiders.

Moreover, the table illustrates that even very small RJVs may share information in the presence of substantial leakages. For instance, an RJV composed of 2 firms facing 10 outsiders would share information as long as $k\leq 0.55$; and the same RJV in a (almost) perfectly competitive market would share information as long as $k\leq 0.5$. The threshold $k_c=0.5$ constitutes a lower bound on k_c. Even small (relative to the industry) RJVs have a surprisingly high degree of tolerance for leakage (50%) to outsiders. Whereas an RJV whose size is large (infinite) relative to the rest of the industry would always share information.

Table 1 - Critical threshold of leakage (k_c)

		N									
		1	2	3	4	5	6	7	8	9	10
	2	1.000	0.750	0.667	0.625	0.600	0.583	0.571	0.563	0.556	0.550
	3	1.333	1.000	0.889	0.833	0.800	0.778	0.762	0.750	0.741	0.733
	4	1.500	1.125	1.000	0.938	0.900	0.875	0.857	0.844	0.833	0.825
M	5	1.600	1.200	1.067	1.000	0.960	0.933	0.914	0.900	0.889	0.880
	6	1.667	1.250	1.111	1.042	1.000	0.972	0.952	0.938	0.926	0.917
	7	1.714	1.286	1.143	1.071	1.029	1.000	0.980	0.964	0.952	0.943
	8	1.750	1.313	1.167	1.094	1.050	1.021	1.000	0.984	0.972	0.963
	9	1.778	1.333	1.185	1.111	1.067	1.037	1.016	1.000	0.988	0.978
	10	1.800	1.350	1.200	1.125	1.080	1.050	1.029	1.013	1.000	0.990

The leakage on voluntary information sharing represents a competitive impediment to information sharing. It is shown that this competitive impediment leads to extreme levels of information sharing. There exist other factors which may also affect information sharing. Technological impediments represent one such factor: the cost of sharing information, or imperfect compatibility of firms' technologies, can lead to intermediate levels of information sharing. The model predicts that the absence of information sharing is due to competitive impediments, while intermediate levels of information sharing are due to technological impediments.

The finding that firms choose extreme levels of information sharing (in the absence of technological impediments) is recurrent in the literature. Amir and Wooders (1999) analyse a research consortium composed of two firms which choose R&D and the spillover rate. However the spillover is one-directional: it flows only from one firm to the other firm. They find that firms choose extreme levels of information sharing. The rationale is that firms choose maximal information sharing when the efficiency effect -which pushes for cost minimization- dominates, while they choose no spillovers when the asymmetry effect -which pushes for maximum cost differentiation in order to maximize joint profits- dominates. Poyago-Theotoky (1999) allows firms to choose the spillover level after R&D investments are undertaken in a duopoly; she finds that cooperating (non-cooperating) firms choose maximal (minimal) spillovers.

Because small RJVs are less likely to share information, they need more protection than larger RJVs. Moreover, RJVs in markets where appropriability problems are important need more protection. Hence, it is sufficient to induce either a low k or a large M: either cooperative research is protected, which will induce larger RJVs, or incentives for larger RJVs are provided, in which case less protection is needed. This recommendation underlines a paradox when viewed from a dynamic point of view, however. Small RJVs need more protection. As this protection is provided, the size of the RJV is likely to increase. As the RJV becomes larger, the level of protection of the RJV necessary to induce its members to share information decreases. However, the temporary nature of most R&D agreements mitigates the importance of this dynamic inconsistency problem.

Above we saw that outsiders benefit more than insiders (in terms of information flows) if $k>1-1/M$. Let k_b (b for benefit) denote the level of k such that this relation holds with equality. Comparing k_b with k_c shows that

$$k_b - k_c = \frac{1}{MN} - \frac{1}{N} < 0, \qquad \textbf{(11)}$$

hence $k_b<k_c$. Remember that $k>k_b$ means that outsiders are benefiting more from information sharing, and $k>k_c$ means that insiders share a positive level of information. Thus this inequality means that there are situations where outsiders receive more cost reduction from voluntary information sharing (between insiders) than insiders, but where insiders still choose to share that information. In that case, even though outsiders benefit more (in terms of technological flows), insiders still increase their profits by sharing information. When $k>k_c$, the information outsiders receive is so much higher than what insiders receive that information sharing would reduce insiders' profits, therefore insiders refrain from sharing information.

Information sharing within the RJV is socially desirable. Firms may in some circumstances choose suboptimal levels of information sharing. There is a well-known tradeoff between increasing the pace of innovation and inducing a high diffusion of the innovation.[12] The model points to a related effect of the lack of protection of cooperative innovations (high k): it may prevent firms from sharing information, hence reducing the diffusion of existing innovations. There is a tradeoff between the (voluntary) diffusion of the innovation to the immediate partners of the firm, and the (involuntary) diffusion of the innovation to other agents in the economy.

Consider now the determination of R&D expenditures (which is decided upon simultaneously to information sharing). For that we substitute the optimal value of g into the T f.o.c. for R&D expenditures. When $k<k_c(M,N)$:

$$x_i^m = \frac{-M((k-1)N-1)(-M-N+u(1+M+N))(a-r)}{u^2(1+M+N)^3-M^2(M+N)(-1+(-1+k)N)-u(1+M+N)(N+M(1+N)+M^2(2-2(-1+k)N+(-1+k)^2N^2))} \quad \textbf{(12)}$$

$$x_i^n = \frac{-(M+N)(-(u(1+M+N))+(-1+k)M(-1+(-1+k)N))(a-r)}{u^2(1+M+N)^3-M^2(M+N)(-1+(-1+k)N)-u(1+M+N)(N+M(1+N)+M^2(2-2(-1+k)N+(-1+k)^2N^2))} \quad \textbf{(13)}$$

When, on the other hand, $k>k_c(M,N)$:

$$x_i^m = \frac{(1+N)(-M-N+u(1+M+N))(a-r)}{(1+N)(M+N)+u^2(1+M+N)^3-u(1+M^3+4N+4N^2+N^3+2M^2(1+N)+M(2+5N+2N^2))} \quad \textbf{(14)}$$

---

[12] This result does not always hold empirically, however. As Baumol (1997) notes, innovation spillovers are higher in the Japanese economy than in the American economy, with no observable negative effects on Japanese innovation.

$$x_i^n = \frac{(M+N)(-1-N+u(1+M+N))(a-r)}{(1+N)(M+N)+u^2(1+M+N)^3-u(1+M^3+4N+4N^2+N^3+2M^2(1+N)+M(2+5N+2N^2))} \quad \textbf{(15)}$$

Given that M is endogenous and depends on k, there is not much to be learned form analysing these expressions directly through comparative statics. Rather, to better focus on the equilibrium values of R&D, we delay the analysis of R&D expenditures until we have determined the endogenous size of the RJV.

3.3 RJV size

The first stage of the game is the determination of the size of the RJV according to (3). The previous section was concerned with the question: how does information sharing depend on the size of the RJV and on leakages? This section addresses the related question: how does the size of the RJV depend on information sharing and on leakages?

The size of the RJV is determined by three effects: a coordination effect, an information sharing effect, and a competition effect. The coordination effect comes from the fact that an additional member increases the externalities internalized by the RJV: this encourages increases in the size of the RJV. The information sharing effect comes from the possibility of improved information sharing among RJV members, discounted by any leakage of part or all of this information to outsiders; the competition effect too encourages increases in the size of the RJV. The competition effect comes from the fact that the newcomer is now a fiercer competitor on the output market; it discourages insiders from accepting additional members.[13] Moreover, there is an indirect link between the information sharing effect and the competition effect: because information sharing reinforces the competitive position of RJV members relative to outsiders, it reinforces the competition effect. From the point of view of an outsider considering whether to join the RJV or not, all three effects reinforce the profitability of joining the RJV.

The importance of each of these effects varies with k and M. Consider first the effect of k. k reduces the coordination effect by reducing R&D (it is easily checked from (12) that $\partial x_i^m/\partial k<0$) and by potentially eliminating information sharing, which further depresses R&D. Furthermore, with

[13] Röller et al. (2000) show that firms have an incentive to exclude other firms from RJV membership. In particular, large firms have an incentive not to form research consortia with small firms. In other words, their model suggests that the competition effect is stronger when insiders are large and outsiders are small.

information sharing coordination increases R&D, and the benefits of this increase decline with *k*. The information sharing effect becomes less important as *k* increases because higher leakage on voluntary information sharing reduces the value of additional information sharing to the RJV. The competition effect becomes less important with *k*, because the relative disadvantage of outsiders diminishes with *k*.

The importance of the three effects varies also with the size of the RJV. The coordination effect and the information sharing effect become negligible as *M* increases, because the marginal gain compared to existing coordination and information levels decreases. Regarding the competition effect, Bloch (1995) notes that it becomes more important as the size of the RJV increases: the cost reduction advantage of the RJV tends to increase with its size. The larger the RJV, the more inefficient is the newcomer, the more it gains from joining the RJV, and hence the stronger is the competition effect.

For tractability, this first stage is solved using an industry size T=10. Moreover, the solution is studied at $k=\{0,0.1,...,1\}$.

Proposition 2. *Let* $T=10$ *and* $k\in\{0,0.1,...,1\}$. *The endogenous RJV size increases and then decreases with k, and is given by the second row of table* 2.

From table 2 we see that overall there is an inverted U relationship between M^* and *k*: M^* increases and then decreases with *k*. In most cases, the RJV comprises more than half the industry, and when *k* takes intermediate values (*k*=0.8 or *k*=0.9), M*=T. Moreover, there is no case where no RJV is formed.

Table 2 - RJV size and information sharing in equilibrium

Leakage (*k*)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Endogenous RJV size (*M*)	6	6	6	6	6	7	7	8	10	10	2
Socially optimal RJV size (M_w)	8/9	8/9	8/9	8/9	9	9	9	9	10	10	10
Information sharing (*g*)	1	1	1	1	1	1	1	1	1	1	0

To understand the relationship between M^* and *k*, note that the size of the RJV can be less than the whole industry for two reasons: external stability, or blocking by insiders. When *k* is low ($k\leq 0.7$), the size of the RJV is constrained by blocking by insiders: some outsiders would like to join the RJV, but they are rejected by insiders. All three effects (coordination, information sharing, and competition) contribute to this outcome: as additional members join the RJV, the marginal coordination and information sharing effects diminish, and the competition effect becomes stronger: hence the gains to the RJV of expanding are reduced, and the costs (fiercer competition) are increased. On the other hand, when k is large (k=1), the size of the RJV is limited by the fact that outsiders are not interested in joining the RJV: they can benefit fully from information sharing by RJV members without sharing their own information.

Consider now the relationship between M^* and k. When k increases, the coordination effect and the competition effect become less important; this should reduce the size of the RJV. Moreover, the competition effect becomes less important; this should increase the size of the RJV. The fact that whenever the size of the RJV is limited by blocking by insiders (when $k \leq 0.7$) M^* increases with k means that the competition effect always dominates the (sum of the) coordination and information sharing effects: the fact that outsiders are anyway fiercer competitors (because of higher leakages), which induces the RJV to admit them, dominates the effect that the contribution of the newcomers in terms of coordination and information sharing is less important (also because of higher leakages).

In fact, firms respond to increases in the leakage from the RJV by increasing its size. An increase in the leakage makes the RJV less profitable for a given level of information sharing but, more importantly, this increase can eliminate the incentives for information sharing. By increasing the size of the RJV, firms ensure that they will continue to share information in spite of the increase of the leakage, since larger RJVs have more tolerance for leakages. From that perspective, an additional member can be seen as a substitute for better appropriability, since both an increase in M and a decline in k increase the net benefits of information sharing. For a given RJV size, a higher k reduces the likelihood of information sharing. Whereas, when the size of the RJV is allowed to adjust to the leakage, the increase in k can in fact increase the amount of information effectively shared (in terms of effective cost reduction), since firms continue to share all the information they can share and, in addition, there are more insiders to benefit from information sharing (due to the increase in M) and outsiders benefit more from that information sharing (through the increase in M and k).

On the other hand, when k is sufficiently high (specifically, when k=1) that firms do not share information, the size of the RJV is constrained by external stability: most firms prefer to stay outside the RJV, which loses from its attractiveness without information sharing. Even though insiders would gain by attracting more members into the RJV, so as to make information sharing profitable, outsiders prefer not to join; as explained earlier, the attractiveness of the RJV to outsiders decreases with k. The decline in RJV size with k is due partly to the destruction of the incentives for information sharing when k=1, and partly to the free riding behaviour of outsiders when leakages are high. Hence the decline of M^* for high values of k.[14]

For intermediate values of k (k=0.8 or k=0.9), neither internal stability nor external stability limit the size of the RJV, therefore the RJV encompasses all industry members.

We now compare this endogenous RJV size to the socially optimal size, M_w. The following proposition characterises M_w.

Proposition 3. *Let T=10 and $k \in \{0, 0.1, ..., 1\}$. The socially optimal size of the RJV, M_w, is nondecreasing in k, and is given by the third row of table 2. When $k \leq 0.3$, M_w is not unique (specifically, it has 2 possible values), as it depends on u.*

M_w is nondecreasing in k because the benefit of the internalization of externalities increases with these externalities. By comparing M^* and M_w we see that in most cases the RJV is too small compared with the social optimum.[15] $M^*=M_w$ only in very special cases.

Row 3 in table 2 shows that for $k \leq 0.7$, $M_w < T$ (remember that T=10). This means that welfare increases and then decreases with the size of the RJV in that parameter range. This reduction in welfare is linked to R&D spending. When spillovers are low R&D by each insider increases and then decreases with the size of the RJV. To see that, we differentiate x_i^m from (12) at k=0 (assuming information sharing):

$$\frac{\partial x_i^m}{\partial M} = \frac{\gamma}{-1331M^2+10(-11+M)M^2+11u(10+10M+121M^2-22M^3+M^4))^2} \qquad \textbf{(16)}$$

where

$$\gamma = -(-100(-11+M)^2M^2+14641u^3(-11+2M)-220u(55-10M-731M^2+253M^3-28M^4+M^5) \\ +121u^2(1320-240M-1341M^2+484M^3-55M^4+2M^5))(a-r) \qquad \textbf{(17)}$$

---

[14]Further analysis reveals that, more generally, the size of the RJV is limited by internal stability when $k<k_b$ and by external stability when $k>k_b$; that is, the outcome depends on who benefits more from information sharing, insiders or outsiders).

[15]While the model suggests that in many cases industry-wide RJVs are socially optimal, the potential for output collusion qualifies this result. The presence of outsiders limits the benefit to insiders from output collusion, and maintains a competitive pressure in the industry.

The denominator is positive, and it is easy to check that the numerator is positive when M is low (M=2, for instance) and negative when M is high (M=8 for instance). The explanation is as follows. An increase in the size of the RJV induces two effects on R&D spending by insiders: an R&D-coordination effect, and an R&D-information sharing effect.[16] The R&D-coordination effect comes from the internalization of more externalities. It is negative when spillovers are low, and positive when spillovers are high (this is a standard result in the literature; see De Bondt, 1996). The R&D-information sharing effect comes from the increased value of R&D to insiders, given that they can share more information. The R&D-information sharing effect encourages R&D, for all levels of spillovers. With low spillovers the R&D-coordination effect induces less R&D, while the R&D-information sharing effect induces more R&D spending. As the size of the RJV increases, the (negative) R&D-coordination effect becomes more important (because more externalities are being internalized) relative to the R&D-information sharing effect, and R&D decreases. On the other hand, with high spillovers the two effects have a positive impact on R&D, x_i^m increases steadily with M, hence an industry-wide RJV is desirable. The benefits of information sharing explain why a RJV is socially desirable even when spillovers are low. The reduction in R&D when spillovers are low explains why the socially optimal size of the RJV is smaller than the industry.[17]

The response of RJV members to increases in leakages is complex. In all cases, they reduce their R&D spending, given that approapriability is weakened (this will be established later). In addition, they also adjust their information sharing and RJV size in an interrelated fashion. One response, which is observed when k is not too high (k<1), is for RJV members to accept more members into the RJV, while maintaining the level of information sharing unchanged. Because larger RJVs have more tolerance for leakages, this allows the RJV to maintain high levels of information sharing. However, when k is very high, this is not feasible, because outsiders are not interested in joining the RJV. In that case the response is for information sharing to be reduced (to zero) and for the size of the RJV to shrink. These responses can be summarized as follows.

---

[16]We use the prefix R&D to distinguish these effects from those affecting the size of the RJV.

[17]De Bondt and Wu (1997) obtain a similar result. They find that, when information sharing is allowed, with high spillovers full cooperation is desirable, while with low spillovers welfare increases, and then decreases, with the size of the RJV. And they note: "As the size of the RJV increases, the tendency for research cartel members to restrict output begins to dominate incentives to expand resulting from better information-sharing". Poyago-Theotoky (1995), in a model where information sharing is limited by exogenous spillovers, finds that an industry-wide RJV is always socially optimal. However, she defines social welfare as industry profits, while here I consider the sum of industry profits and consumer surplus. The U.S. Department of Justice (1985) views that RJVs raise competitive concerns when the RJV is "overinclusive", so that too few firms are left outside the RJV to perform R&D.

Proposition 4. *In response to an increase in leakages (k), RJV members reduce their R&D spending. In addition, they either increase the RJV size while maintaining information sharing unchanged (when k is low), or they reduce both information sharing and RJV size (when k is high).*

We can see how information sharing determines the nature of the equilibrium. When it is profitable for RJV members to share information, the equilibrium is characterised by large RJVs, higher R&D spending by insiders, and significant diffusion of technology to outsiders. When, on the other hand, information sharing is not profitable (because of high leakages), the RJV is small, insiders spend less on R&D than outsiders, and there is no technological diffusion.

3.4 R&D, profits, and welfare

Having determined RJV size and information sharing, we now analyze R&D and profits.

Proposition 5. *An increase in the leakage k:*

a) decreases each insider's R&D;

b) increases each outsider's R&D;

c) does not increase, and generally decreases, each insider's profits;

d) increases each outsider's profits;

e) has an ambiguous effect on welfare.

As expected, x_i^m decreases with k. The increase in leakage has a net negative effect on per firm R&D, even when firms increase the size of the RJV to compensate for that increased leakage, and in spite of the increased amount of shared information (because of the increase in the number of members) generally associated with increases in k. Therefore the main response of firms to increases in leakages, is not to share less information, neither to reduce the size of the RJV, but rather to reduce their R&D spending.

Not surprisingly, outsiders behave in an opposite fashion: they increase their R&D in response to an increase in leakages. A higher k, by reducing the production costs of outsiders before they engage in R&D, increases the value of cost reduction to outsiders, increasing their R&D. And this is in spite of the decline in insiders' R&D due to the increase in k. Remember that the amount of information received by outsiders is $\Gamma_j^n \equiv kgMx_i^m$. An increase in k often increases M and always decreases x_i^m, therefore the net effect on Γ_j^n can be positive. Information transfer from the RJV is a complement, not a substitute, for outsiders' R&D.

We now consider how leakages affect profits. Insiders' profits decline with *k* because the net benefit of information sharing diminishes with *k*. In response, RJV members spend less each on R&D, which results in higher production costs, ceteris paribus. And the increase in the size of the RJV (which, as explained above, is one of the consequences of the increases in leakages) is not sufficient to compensate for that reduction in R&D.

In contrast, outsiders' profits increase with *k*. As explained above, although insiders reduce their R&D spending, the size of the RJV increases and this, along with the increase in *k*, has a positive effect on the information flows received from the RJV. This increases the value of cost reduction to outsiders, inducing them to increase their R&D and to improve their competitive position. Paradoxically, outsiders' profits increase, and insiders' profits decrease, with the size of the RJV when this increase in size is due to an increase in leakages.

The last part of proposition 5 concerns the effect of leakages on welfare. Welfare does not vary monotonically with *k*, and one cannot even establish a clear nonlinear relationship between the two constructs. As *k* changes, the R&D expenditures of insiders and outsiders change in opposite directions, along with changes in information sharing and RJV size. The net effect on welfare depends on the net effect on production costs (effective cost reduction) of increases and decreases in R&D, changes in RJV size, changes in diffusion, and changes in information sharing. No clear relationship between the sum of these effects and *k* emerges.

Welfare is highest when k=0.8 and 0.9. It is in those cases that $M^*=T=10$: the RJV encompasses all the industry. Those combinations yield the same level of total welfare even though *k* changes because there are no outsiders. The social benefits in this case come not from the increase in R&D by insiders (remember that x_i^m decreases with *k*), but due to the improved diffusion of technology.

Having asserted the effects of leakages on R&D, profits, and welfare, we now turn to the comparison of R&D and profits between insiders and outsiders.

Proposition 6. *Insiders spend more each on R&D and make more profits than each outsider when* k<1. *This result is reversed when* k=1.

When *k* is low, insiders value R&D more, because they enjoy (the possibility of) improved information sharing, and internalize the externalities of their R&D on other insiders.[18] When k is high, it is possible that $x_i^m < x_j^n$.

Intuitively, one could think that outsiders have an incentive to free-ride on the R&D performed by insiders, given the leakage on information sharing. These results allow us to refine the notion of free-riding by non-RJV members, according to whether we consider a given level of leakages, or changes in the level of leakages. For a given level of k, outsiders can be said to free-ride on the R&D of insiders when $x_i^m > x_j^n$, and this occurs when $k<1$. However, it is still the case that $x_i^m > x_j^n$ even when k=0. This suggests that there is more than free-riding here: outsiders may be simply choosing their R&D according to the value of cost reduction. This value is higher for insiders when k is low, because they benefit more from technological diffusion. When $k=1$, we have that $x_i^m < x_j^n$, and hence it cannot be said that outsiders free-ride. The free-riding argument seems most plausible when $k \in (0,1)$ (although it is not the whole story), but does not hold when $k=0$ or $k=1$.

On the other hand, because insiders decrease and outsiders increase their R&D expenditures in response to increases in leakages, it can be said that any free-riding behaviour by outsiders is in fact mitigated by increases in leakages. In such a context it cannot be said, as is often asserted, that outsiders free ride on the information received from the RJV. Rather, it is the opposite: the leakage of the RJV information encourages the innovative activities of non-members.

Because insiders' profits decrease with k, while outsiders' profits increase with k, insiders' profits dominate when k is low and outsiders' profits dominate when $k=1$. With low leakages, insiders spend more on R&D, and a small portion of this R&D leaks out to competitors. Moreover, they choose to share information, and only a small portion of this additional information sharing leaks out to outsiders. When $k=1$, insiders spend less on R&D, refrain from sharing information, and, moreover, the size of the RJV is only $M^*=2$. We know that with low spillovers (due to the absence of information sharing) R&D coordination reduces R&D expenditures. This combination of low R&D spending and small RJV size results in lower profits for insiders.

Combining the results obtained here with those obtained on the sources of limitation to RJV size (section 3.3), we observe that when the size of the RJV is limited by external stability (outsiders refuse to join the RJV), insiders do not share information, and make less profits and spend less on R&D than

[18] Empirical evidence suggests that participation in research consortia has a positive impact on R&D expenditures (e.g. Branstetter and Sakakibara, 1997).

outsiders. In contrast, when the size of the RJV is limited because of blockage by insiders, these relationships are reversed.

3.5 Technological diffusion

Proposition 1 explained how information sharing is determined for a given RJV size. Now that the size of the RJV has been endogenized in section 3.3, we analyze information sharing in equilibrium. Table 2 shows g given that $M=M^*$. In equilibrium maximal information sharing is chosen except when k=1. There is a dynamic interaction between the choices of M and g: the level of g to be chosen in the second stage has a direct impact on the choice of M in the first stage. Because the likelihood of information sharing increases with M, firms tend to choose the size of the RJV so as to make maximal information sharing an equilibrium. This explains why firms almost always choose maximal information sharing. A higher level of information sharing increases the benefits from cooperation to insiders, and increases the attractiveness of the RJV to outsiders, thereby increasing the size of the RJV. And a larger RJV is more likely to share information. Hence information sharing and the endogenization of M reinforce each other and lead to larger RJVs and more information sharing.[19] The information sharing problem, and the leakage of information to outsiders, are partly resolved when firms can adjust the size of the RJV.[20]

What matters for social welfare is ultimately effective cost reduction, which is defined as the total cost reduction enjoyed by all firms due to R&D activities. Here effective cost reduction can be decomposed into three components: the own cost effect, voluntary sharing, and leakages, which are defined as follows:

Own cost effect $= X$

Voluntary information sharing $= g(M^*\text{-}1)X^m$

Leakage from the RJV on voluntary information sharing $= kgNX^m$

Total effective cost reduction, Q, is given by $Q = X+X^m g(M^*\text{-}1+kN)$. In order to get a sense of the evolution of effective cost reduction and the relative importance of its components with k, we use numerical simulation based on the following parameter values: a=1000, r=50, and u=60. Figure 1

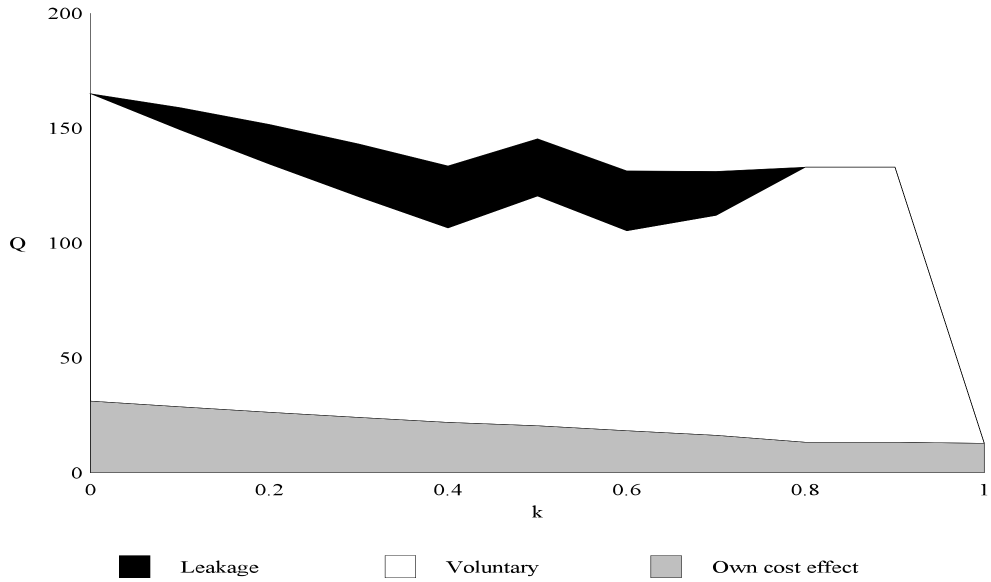
---

[19]Kesteloot and Veuglelers (1995) obtain a similar result in a two-firms repeated game model.

[20]De Bondt et al. (1992) conjecture that "If cooperation on R&D is accompanied with perfect spillovers, ... one would expect stability to be less problematic". Here it is shown that stability problems do not vanish when information sharing is allowed.

shows the decomposition of Q into its three components.

Fig. 1 Decomposition of cost reduction



As the figure shows, voluntary sharing is the most important source of cost reduction The own cost effect is less important, and diminishes further with spillovers. However, the own cost effect is the only source of cost reduction that is strictly positive for all levels of spillovers. Nonetheless, most cost reduction is due to diffusion, rather than to the use of the technology by the innovating firm. Finally, the cost reduction accruing to outsiders from the leakage from the RJV is negligible. However, this negligible leakage has the non-negligible effect of reducing voluntary information sharing (as well as the own cost effect for insiders). Looking at total effective cost reduction (the upper bound of the graph), we see that even when accounting for diffusion, spillovers reduce total cost reduction: the disincentives of diffusion on innovators dominate the positive effects of diffusion on receivers.

An implicit assumption in the model is that there are no spillovers applicable to the R&D performed by firms if there is no information sharing: leakages concern only voluntary information sharing. It is straightforward, but cumbersome and not particularly useful, to incorporate "general" spillovers into the model. This has been done by the author; the results are essentially the same, except that they are derived based on numerical simulations, due to the complexity of the model. One important insight that comes out from the model with general spillovers, though, is that when general spillovers are high, the scope for information sharing is reduced, because the maximum amount of information firms can share is that which has not already leaked out through the parameter k. Hence, for high levels of general spillovers, the benefits from information sharing are reduced.[21]

This result has implications for the regulation of R&D cooperation, in view of the standard finding in the strategic investment literature that without information sharing, R&D coordination reduces R&D expenditures when general spillovers are low. Baumol (1992) argues that "The use of a technology cartel to collude on ... total R&D expenditures is likely to be damaging to public welfare." He is more open to technology cooperative agreements involving improved information sharing. A similar position is held by De Fraja (1990).[22] Our model gives mixed recommendations regarding the regulation of R&D cooperation. Contrarily to RJVs that coordinate R&D expenditures only, which are beneficial only when spillovers are high, and RJVs that share information only, which are beneficial only when spillovers are low (Hinloopen, 1994; Greenlee, 1998), RJVs that coordinate R&D expenditures and (may) share information improve welfare for all levels of spillovers. When spillovers are low, R&D coordination by itself reduces R&D, but this is more than compensated for by the increase in R&D due to information sharing. When spillovers are high, there is little scope for information sharing, but R&D coordination increases R&D. R&D coordination is beneficial if spillovers are high and/or firms share information. Also, combined with the results of Hinloopen (1994) and Greenlee (1998), the model suggests that information sharing is beneficial when spillovers are low (when spillovers are high information sharing is only marginally beneficial) and/or firms coordinate R&D expenditures.

4. Conclusions

At the outset of the strategic investment literature the question was whether R&D cooperation is socially beneficial or not. Empirical and theoretical studies show that R&D cooperation is generally beneficial. Thus the question has now shifted to: what types of cooperation are superior, and which are

---

[21]Another result which comes out from the model with general spillovers is that it is the leakage from the RJV to outsiders which determines the decision of insiders whether to share information, while it is the general spillover rate which determines the level of information sharing within the RJV.

[22]Fölster (1995) studies the effects of different types of R&D subsidies on R&D cooperation and spending for a sample of Swedish industrial firms. Some R&D subsidies require cooperation but allow firms to choose the mode and extent of information sharing (e.g. Eureka). Other R&D subsidies require cooperation and information sharing between participating firms (e.g. Esprit, Race). Fölster finds that subsidy programs requiring only cooperation have no effect on the likelihood of cooperation but have a positive effect on R&D incentives. On the other hand, subsidy programs requiring both cooperation and information sharing increase the likelihood of cooperation, but decrease R&D incentives. He interprets the potential negative effect on R&D as a socially desirable elimination of duplication in research. Our model shows that this decline in R&D following cooperation can be due to at least two other factors: collusion between firms, and the desire to limit the amount of information leaking to competitors.

likely to arise in a decentralized market? R&D cooperative ventures are complex multidimensional agreements. In this paper the focus was on RJV stability, information sharing, and leakage on voluntary information sharing.

The model studied information sharing and the stability of cooperation in cost reducing Research Joint Ventures (RJVs). In a three-stage game-theoretic framework, firms decided on participation in a RJV, information sharing along with R&D expenditures, and output. An important feature of the model was that voluntary information sharing between cooperating firms increased information leakage from the RJV to outsiders. It was found that RJVs representing a larger portion of the industry are more likely to share information: large RJVs suffer less from leakages, and are less likely to stop sharing information because of them. It was also found that firms generally don't choose intermediate levels of information sharing: they share all the information or none at all. The model predicts that the absence of information sharing is due to competitive impediments (leakage of information to non-RJV members), while intermediate levels of information sharing would arise because of other considerations: costs of sharing information, or limited compatibility of firms' technologies. The size of the RJV was found to depend on three effects: a coordination effect, an information sharing effect, and a competition effect. Depending on the relative magnitudes of these effects, the size of the RJV may increase or decrease with spillovers. The effect of information sharing on the profitability of firms as well as on welfare was studied.

An important question addressed by the mode is how the RJV responded to increases in leakages. In the model firms have three dimensions on which they can adjust: R&D spending, information sharing, and the size of the RJV. It is always the case that an increase in leakages decreases R&D spending by RJV members. However, the adjustments on the two other dimensions are interrelated. When leakages are low or moderate, firms respond to increases in leakages by increasing the size of the RJV, in order to sustain information sharing (because larger RJVs have more tolerance for leakages). In that first case information sharing is not affected by the leakages. However, when leakages are very high, increases in leakages destroy the incentives for information sharing, and, by reducing the attractiveness of the RJV, reduce its size considerably. This suggests that a policy of requiring cooperating firms to diffuse more of their private information to outsiders can have one of two effects. When the additional diffusion requirement is low or moderate, it will be beneficial, for firms will respond by increasing the size of the RJV as well as their R&D expenditures, which will increase information sharing and ultimately diffusion. When, however, the additional diffusion requirement is excessive, firms will respond by reducing the size of the RJV, reducing R&D expenditures, reducing information sharing, and hence diffusion.

However, a problem with a lax patent policy aiming at inducing firms to cooperate is that firms may get the wrong message: instead of cooperating on R&D to internalize externalities and share information, firms may find it easier to move their research facilities to legislations (in a context where competition between legislations for R&D activities exists) providing a stricter protection for innovations, albeit with less R&D cooperation.

The finding that firms share information when leakages are low and may not share it when leakages are high indicates that the imposition of no or maximal information sharing -both approaches are common in the literature- hides important assumptions. Studies that assume that cooperation firms do not share information implicitly assume that k is high, making information sharing unprofitable. Studies that assume maximal information sharing between firms implicitly assume that k is low.

The scope for information sharing may be higher with newer technologies. Cooperation in industries with older, more mature technologies is likely to rely mainly on the coordination of R&D expenditures. This suggests that governments should favour RJVs in high-tech sectors. MITI (the Japanese Ministry of International Trade and Industry) seems to be following this path, with its focus on emerging technologies. In contrast, the British government funds cooperative research in mature declining industries.[23]

In this paper k was interpreted as a leakage parameter on information sharing. The mechanism behind this leakage was not specified. k can also be seen as a moral hazard parameter: once a firm has received information from other RJV members, it may have an incentive to trade part or all of that information with outsiders. While insiders may benefit from committing not to give information to third parties, such a commitment would not be credible. k can therefore represent the degree to which firms violate the secrecy of the RJV. In that respect, the results of the model suggest that firms may share information even in the presence of substantial moral hazard problems.

The model has many possible extensions. An interesting issue to explore is how information sharing is affected by product differentiation. Firms selling differentiated goods face less fierce competition on the product market, and may be more willing to share information. This intuition is confirmed by the observation that industry-wide joint ventures are observed more in countries where

[23]The reference for this insight is unfortunately lost.

exports have a relatively greater importance than the domestic market (De Fraja, 1990). However, as product differentiation increases the information each firm possesses (or develops) may become less relevant to other firms.

The role of information leakage, k, could be explored further. k can depend on the size of the RJV: a larger RJV may leak out more information to outsiders than a smaller one. For instance, Link and Bauer (1989) find an inverse relation between appropriability of research results and the number of participants in research cooperative agreements.

In this paper firms were found to choose relatively high levels of information sharing. Many factors can make it difficult for firms to achieve such a high rate of diffusion of innovations. Information sharing may require the use of common research facilities, which brings into play diseconomies of scale. Increasing production costs would reduce the value of output expansion and hence of cost reduction. The high transaction costs of innovation may imply that RJVs are smaller than the model suggests, or that less information is shared because of opportunism. There may be a cost to sharing information, and that cost may rise with the size of the RJV; this would limit both RJV size and information sharing. When discoveries are made at different points in time, information exchange becomes more difficult; information sharing between firms could be made dependent on past experiences of information sharing. Differences in compatibility and communication, absorptive capacities, and organizational culture impose further limits on the levels (De Bondt et al., 1992) and the symmetry of information sharing.

Perhaps the main limit of this study is that firms can form only one RJV. Kamien and Zang study multiple RJV formation, with RJVs of identical sizes, although in their model information sharing is imposed upon firms. A more complete model of R&D cooperation would consider both endogenous information sharing and multiple RJV (of different sizes) formation. The socially optimal number of RJVs with endogenous information sharing is likely to be smaller than the socially optimal number of RJVs with exogenous perfect information sharing because, as our model shows, smaller RJVs are less likely to share information.

Appendix

Proof of proposition 1.

Solving the programs (7) and (8) yields T+1 first-order conditions, T of them relating to the optimal choice of R&D expenditures and 1 relating to information sharing. Let f_i denote the f.o.c. relating to x_i, i=1,...,T, and let f_{T+1} denote the f.o.c. relating to g. Optimality requires that f_i=0 for i=1,...,T. However, because of the constraint in (8), the sign of f_{T+1} is unkown. For each f.o.c. f_i, we solve for x_i to obtain $x_i(a,M,N,r,u,g,k)$. The ex ante symmetry of firms implies that $x^n_{M+1}=\ldots=x^n_T$, $x^m_1=\ldots=x^m_M$.[24] We substitute the T first f.o.c. into f_{T+1}, to obtain

$$f_{T+1} = \frac{2uM[M+N-u(1+M+N)]^2(1+N+Z)[g(1+N+Z)-1-N](a-r)^2}{[[1+g(M-1)](M+N)[g(1+N+Z)-1-N]-[u^2(1+M+N)^3]+u(1+M+N)R]^2} \qquad \textbf{(18)}$$

where $Z \equiv M((k\text{-}1)\text{–}1)$ and $R \equiv 1+M+M^2+3N+MN+N^2-2g(1+N)(1+N+Z)+g^2(1+N+Z)^2$

The level of information sharing depends on the sign of this derivative. If $f_{T+1}>0$ for all g, then insiders' profits are increasing in information sharing, and they will choose g=1. If $f_{T+1}<0$ for all g, then insiders' profits are decreasing in information sharing, and they will choose g=0. If f_{T+1}=0, then we have an internal solution.

We now analyze the sign of this expression. The denominator is positive. The first two terms and the last term in the numerator are positive, therefore what's left is to determine the signs of $(1+N+Z)$ and of $[g(1+N+Z)-1-N]$. Substituting Z into this last term yields

$$(g-1)(N+1)+gMN(k-1)-gM$$

All of these terms are negative or nil, and they cannot be all nil simultaneously. Therefore this term is negative. Hence the sign of f_{T+1} is equal to the sign of $-(1+N+Z)$. Substituting Z into this last term yields $M+MN-N-1-kMN$. Setting this expression equal to zero and solving for k yields k_c.

When $k=k_c$, f_{T+1}=0 irrespective of g. Therefore in this case the level of information sharing is indeterminate, i.e. insiders are indifferent between all levels of information sharing.

What's left is to show the effect of M and N on k_c. From the solution to k_c we have that

[24] The Salant and Shaffer (1998) critique of the use of symmetric R&D strategies does not apply here, because there are no side payments and there is only one output market. Moreover, the very idea of side payments goes counter to the pre-competitive nature of R&D collaboration.

$$\frac{\partial k_c}{\partial M} = \frac{N+1}{M^2 N} > 0 \qquad \textit{and} \qquad \frac{\partial k_c}{\partial N} = \frac{1-M}{MN^2} < 0 \tag{19}$$

Consider what happens as M grows very large. Taking the limit of k_c yields

$\lim_{M\to\infty} k_c = 1 + 1/N \geq 1.$

Similarly, the limit of k_c as N grows very large is

$\lim_{N\to\infty} k_c = 1 - 1/M \geq 0.5.$ ■

Proof of proposition 2.

Recall that $M^*=M$ only if the following three conditions are satisfied:

i) $\pi_i^m(M) \geq \pi_i^m(M\text{-}1)$ and

ii) $\pi_i^m(M) \geq \pi_i^n(M\text{-}1)$ and

iii) $\pi_i^m(M) \geq \pi_i^m(M+1)$, or $\pi_i^n(M) \geq \pi_i^m(M+1)$, or both.

For each level of k, these conditions must be evaluated for all $M \in \{1,3,...,10\}$. In general there will be a unique M satisfying all conditions. When more than one RJV size satisfy these conditions, the RJV size yielding higher profits for insiders (given that they can block outsiders from becoming members) prevails. When, in addition, more than one RJV size yield exactly the same profits for insiders and the same profits for outsiders, the largest of these RJV sizes is assumed to prevail.

The evaluation of any of the conditions *i* through *iii* entails the comparison of a pair of profits. It turns out that such comparisons yield one of three types of expressions, which we call A, B, and C. By being able to sign those expressions, all the comparisons can be performed in a straightforward manner. To illustrate, we perform here three comparisons of profits, each yielding a different type of expression (A, B, and C, respectively).

Consider condition *i* evaluated at $M^*=3$ and $k=0.6$. Notice that the comparison of profits has to make use of the results derived in the second stage regarding the effect of leakages and market structure on information sharing. Hence in this case $\pi_i^m(3)$ is evaluated at $g=1$ (because $k_c(3)>0.6$), whereas $\pi_i^m(2)$ is evaluated at $g=0$ (because $k_c(2)<0.6$). That is, when a RJV of 3 firms considers the elimination of a member (condition *i*), it does so knowing that if only 2 firms are left, those 2 firms will stop sharing information, because $k=0.6$ is higher than the tolerance of such an RJV for leakages, which is $k_c(2)=0.56$. Taking the difference between profits yields

$$\pi_i^m(3)-\pi_i^m(2) = A = \frac{A_1}{(-1.19+u)^4(-0.84+u)^2(-0.08+u)^2(0.05-0.43u+u^2)^2} \quad \textbf{(20)}$$

where

$$A_1=1.49x10^{-21}u(-1.11+u)(-0.91+u)(-0.91+u)(-0.22+u)^2(-0.15+u)(1.41-2.38u+u^2)(0.41-1.23u+u^2)3.17(a^2-2ar+r^2)$$

The denominator is positive. It is easy to check from the solution for output (equation 9) that $y_i^m>0$ requires $u>1.18842$ (evaluated at $M^*=3$, $k=0.6$, $g=1$). Therefore the numerator A_1 is also positive, and $\pi_i^m(3)>\pi_i^m(2)$ at $k=0.6$. This means that a RJV composed of 3 firms would not gain by eliminating one member when $k=0.6$. All profit comparisons yielding an expression having the same structure as A in (18) are performed in the same fashion.

Consider now the case where profit comparisons yield an expression of type B. The evaluation of condition *ii* for $M^*=4$, $k=0.3$, $g=1$ yields

$$\pi_i^m(4)-\pi_i^n(3) = B = \frac{B_1(a-r)^2}{(14.63-7.65u+u^2)^2(7.71-5.55u+u^2)^2(0.03-0.33u+u^2)^2(0.02-0.29u+u^2)^2} \quad \textbf{(21)}$$

where

$$\begin{aligned} B_1 = {} & 2.18x10^{-35}+0.002u-0.07u^2+1.23u^3-12.21u^4+74.28u^5-283.56u^6+678.1u^7 \\ & -1005.53u^8+938.29u^9-565.76u^{10}+223.95u^{11}-57.91u^{12}+9.43u^{13}-0.88u^{14}+0.04u^{15} \end{aligned}$$

The denominator of B is positive, and the numerator B_1 is positive if $u>3.8254$, which is required for the positivity of x_i^m. Therefore we conclude that $\pi_i^m(4)>\pi_i^n(3)$ at $k=0.3$. This means that when $k=0.3$ a member of a RJV of size 4 would not gain by leaving the RJV (internal stability). All profit comparisons yielding an expression having the same structure as B in (21) are performed in the same fashion.

Finally, consider the case where the comparison of profits yield an expression of type C. We evaluate the first part of condition *iii* at $M^*=3$, $k=0.9$, $g=0$.

$$\pi_i^m(3)-\pi_i^m(4) = C = \frac{-55(10-11u)^2u^2(-11036+173844u-331419u^2+161051u^3)(a-r)^2}{(80-1144u+1331u^2)^2(70-1089u+1331u^2)^2} \quad \textbf{(22)}$$

The denominator is positive, and the numerator is positive if $u>1.80602$, which is required for the positivity of c_i^n when evaluated at $M^*=4$ and $g=1$. Therefore we conclude that $\pi_i^m(3)<\pi_i^m(4)$ at $k=0.9$.

This means that in a RJV of size 3 insiders gain by admitting an additional firm into the RJV. All profit comparisons yielding expressions having the same structure as C are performed in the same manner. Having shown how profits are compared, we now proceed to apply the stability conditions (3) for a specific value of k=0.6. The following table shows which conditions are satisfied for all values of M.

Table 3 - Stability analysis with k=0.6

		Conditions			
		i	***ii***	***iii* (1st part)**	***iii* (2nd part)**
		$\pi_i^m(M) \geq \pi_i^m(M-1)$	$\pi_i^n(M) \geq \pi_i^n(M-1)$	$\pi_i^m(M) \geq \pi_i^n(M+1)$	$\pi_i^n(M) \geq \pi_i^m(M+1)$
	1			No	No
	2	Yes	Yes	No	No
	3	Yes	Yes	No	No
	4	Yes	Yes	No	No
M	5	Yes	Yes	No	No
	6	Yes	Yes	No	No
	7	**Yes**	**Yes**	**Yes**	**No**
	8	No	Yes	Yes	No
	9	No	Yes	Yes	No
	10	No	Yes		

We see from the table that the only RJV size satisfying conditions i and ii and either part of condition *iii* is M^*=7, and therefore with k=0.6, M^*=7. Note how this table relates to the profit comparisons performed above. Above it was shown that $\pi_i^m(3)>\pi_i^n(2)$ at k=0.6. This establishes simultaneously that condition *i* is satisfied at M^*=3, and that the 1st part of condition *iii* is not satisfied at M^*=2.
Reproducing this table for k={0,0.1,...,1} yields Proposition 2. ■

Proof of proposition 3.

Let W represent total welfare. We have that

$$W=M\,\pi_i^m + N\,\pi_i^n + 0.5(a-p)[M\,y_i^m + N\,y_i^n]$$

where the last term represents consumer surplus. We cannot find M_w using the first order approach, because changes in M can entail changes in information sharing. Rather, we have to compare the levels of W for different values of M.

To illustrate, hereafter we compare welfare with M^*=8 and M^*=9 when k=0.2.

$$W(9)-W(8)=\frac{\alpha(a-r)^2}{(16.06-8.01u+u^2)^2(6.6-5.14u+u^2)^2(0.18-0.85u+u^2)^2(0.1-0.62u+u^2)^2} \quad \textbf{(23)}$$

where

$$\begin{aligned}\alpha \;=\; & -1.02x10^{-31}+2.3u-45.28u^2+391.04u^3-1949.57u^4+6215.56u^5-13281.6u^6+19430.8u^7 \\ & -19597.5u^8+13591.8u^9-6409.27u^{10}+2008.39u^{11}-400.26u^{12}+46.44u^{13}-2.54u^{14}+0.03u^{15}\end{aligned} \quad \textbf{(24)}$$

This expression can be positive or negative depending on u. Hence with k=0.2, either M_w=8 or M_w=9. Comparing welfare levels for different RJV sizes and for all values of k establishes proposition 3. ■

Proof of proposition 4.

Proposition 4 is a summarization of propositions 1, 2, and 5. ■

Proof of proposition 5.

a) We compare x_i^m(k=0.4, M^*=6) with x_i^m(k=0.5, M^*=7). In both cases g=1 in equilibrium.

$$x_i^m(k=0.4)-x_i^m(k=0.5) \;=\; \frac{0.02(-0.91+u)(0.93+1.79u+u^2)(a-r)}{(-3.77+u)(-2.87+u)(-0.32+u)(-0.24+u)} \quad \textbf{(25)}$$

This expression is positive if u>3.77419, which is required for the positivity of x_i^n evaluated at k=0.5, M^*=7.

b) We evaluate the change in outsiders' R&D when k goes from 0.3 to 0.2 (in both cases M^*=6):

$$x_i^n(k=0.3)-x_i^n(k=0.2) \;=\; \frac{0.11(-1.16+u)(-0.91+u)(a-r)}{(-5.63+u)(-4.65+u)(-0.22+u)(-0.20+u)} \quad \textbf{(26)}$$

This expression is positive if u>5.62482, which is required for the positivity of x_i^n.

c) We illustrate that π_i^m decreases with k by comparing profits when k=0.6 (M^*=7) with profits when k=0.7 (M^*=8). In both cases g=1.

$$\pi_i^m(k=0.6)-\pi_i^m(k=0.7) \;=\; \frac{E_1(a-r)^2}{(5.12-4.53u+u^2)^2(2.64-3.25u+u^2)^2(0.22-0.95u+u^2)^2(0.13-0.72u+u^2)^2} \quad \textbf{(27)}$$

where

$$E_1 = 2x10^{-34} - 0.0007u + 0.01u^2 - 0.08u^3 + 0.29u^4 - 0.6u^5 + 0.45u^6 + 0.91u^7 - 3.3u^8 + 5.05u^9 - 4.78u^{10} + 3.01u^{11} - 1.26u^{12} + 0.34u^{13} - 0.05u^{14} + 0.004u^{15} \quad \textbf{(28)}$$

This expression is positive if u>2.26331, which is required for the positivity of x_i^n.

π_i^m is not strictly decreasing in k because for k=0.8 and k=0.9, M*=10, and hence k has no impact on the equilibrium, because there are no outsiders to benefit from leakages.

d) We illustrate the increase in π_i^n by comparing outsiders' profits at k=0.3 and at k=0.4 (in both cases M*=6 and g=1).

$$\pi_i^n(k{=}0.4) - \pi_i^n(k{=}0.3) = \frac{F_1(a-r)^2}{(21.66-9.31u+u^2)^2(14.25-7.55u+u^2)^2(0.06-0.49u+u^2)^2(0.05-0.44u+u^2)^2} \quad \textbf{(29)}$$

where

$$F_1 = 1.98x10^{-32} + 0.1u - 2.71u^2 + 30.41u^3 - 191.31u^4 + 743.19u^5 - 1856.53u^6 + 3035.02u^7 - 3275.14u^8 + 2341.26u^9 - 1108.89u^{10} + 346.70u^{11} - 70.41u^{12} + 8.90u^{13} - 0.63u^{14} + 0.02u^{15} \quad \textbf{(30)}$$

This expression is positive if u>7.81338, which is required for the positivity of c_i^m.

e) Given that this is a negative result, a numerical example will suffice. Evaluating welfare at a=1000, r=50, u=60, it is straightforward to compute that

$W(k{=}0)$=457327

$W(k{=}0.3)$=457416

$W(k{=}1)$=447740. ■

Proof of proposition 6.

$$x_i^m(k{=}1) - x_i^n(k{=}1) = \frac{11u(a-r)}{-90+1221u-1331u^2} < 0 \quad \textbf{(31)}$$

We illustrate the dominance of x_i^m when k is low by comparing insiders' and outsiders' R&D when k=0.1

$$x_i^m(k{=}0.1) - x_i^n(k{=}0.1) = \frac{0.15(-6.69+u)(-0.19+u)(6.27+u)(a-r)}{(44.73-13.38u+u^2)(0.04-0.37u+u^2)} > 0 \quad \textbf{(32)}$$

Consider now profits with k=0.5.

$$\pi_i^m(k=0.5)-\pi_i^n(k=0.5) \; = \; \frac{0.06(a-r)^2(-3.74+u)(-2.87+u)(-2.87+u)(-0.83+u)u(0.1-0.64u+u^2)}{(-0.32+u)^2(-0.32+u)^2(8.25-5.74u+u^2)^2} \quad \textbf{(33)}$$

This expression is positive if u>3.7422, which is required for the positivity of x_i^n.

And profits with k=1:

$$\pi_i^m(k=1)-\pi_i^n(k=1) \; = \; \frac{11(a-r)u^2(29-33u)}{(90-1221u+1331u^2)^2} < 0. \; \blacksquare \quad \textbf{(34)}$$

Bibliography

Adams, J.D., 2000, *Endogenous R&D Spillovers and Industrial Research Productivity*, Working Paper 7484, NBER.

Amir, R., and Wooders, J., 1999, 'Effects of One-way Spillovers on Market Shares, Industry Prices, Welfare, and R&D Cooperation', *Journal of Economics and Management Strategy*, 8(2):223-49.

Baumol, W.J., 1992, 'Horizontal Collusion and Innovation', *Economic Journal*, 102:129-37.

Baumol, W.J., 1997, *Pareto Optimal Sizes of Innovation Spillovers*, Research Report # 97-42, The C.V. Starr Centre for Applied Economics, Department of Economics, New York University.

Bhattacharya, S., Glazer, J., and Sappington, D.E.M., 1990, 'Sharing Productive Knowledge in Internally Financed R&D Contests', *Journal of Industrial Economics*, 39(2):187-208.

Bhattacharya, S., Glazer, J., and Sappington, D.E.M., 1992, 'Licensing and the Sharing of Knowledge in Research Joint Ventures', *Journal of Economic Theory*, 56:43-69.

Bloch, F., 1995, 'Endogenous structures of association in oligopolies', *RAND Journal of Economics*, 26(3):537-56.

Branstetter, L., and Sakakibara, M., 1997, *Japanese Research Consortia: a Microeconometric Analysis of Industrial Policy*, Working Paper 6066, NBER.

Bureth, A., Wolff, S., and Zanfei, A., 1997, 'The two faces of learning by cooperating: The evolution and stability of inter-firm agreements in the European electronics industry', *Journal of Economic Behavior & Organization*, 32:519-37.

Cassier, M., and Foray, D., 1999, 'La régulation de la propriété intellectuelle dans les consortiums de recherche: les types de solutions élaborées par les chercheurs', *Economie Appliquée*, 52(2):155-82.

Cassiman, B., and Veugelers, R., 1998, *R&D Cooperation and Spillovers: Some Empirical Evidence*, Working paper, Universitat Pompeu Fabra/Katholieke Universiteit Leuven.

Cohen and Levinthal, 1989, 'Innovation and Learning: The Two Faces of R&D', *The Economic Journal*, 99:569-96.

Colombo, M.G., and Garrone, P., 1996, 'Technological cooperative agreements and firm's R&D intensity. A note on causality relations', *Research Policy*, 25(6):923-32.

Combs, K.L., 1986, *A Summary of Research Joint Ventures Filed with the Justice Department*, unpublished mimeograph.

Combs, K.L., 1993, 'The role of information sharing in cooperative research and development', *International Journal of Industrial Organization*, 11:535-51.

d'Aspremont, C., and Jacquemin, A, 1983, 'On the stability of collusive price leadership', *Canadian Journal of Economics*, 16(1):17-25.

d'Aspremont, C., and Jacquemin, A., 1988, 'Cooperative and noncooperative R&D in duopoly with spillovers', *AER*, 78:1133-37.

d'Aspremont, C., Bhattacharya, S., and Gérard-Varet, L.A., 1996, *Bargaining and Sharing Knowledge*, Discussion Paper No. TE/96/293, Suntory and Toyota International Centres for Economics and Related Disciplines, London School of Economics and Political Science.

De Bondt, R., 1996, 'Spillovers and innovative activities', *International Journal of Industrial Organization*, 15:1-28.

De Bondt, R., Wu, C., and Lievens, D., 1992, *Stable Strategic R&D Cartels*, Onderzoeksrapport NR. 9204, Departement Toegepaste Economische Wetenschappen, Katholieke Universiteit Leuven.

De Bondt, R., and Wu, C., 1997, 'Research Joint Venture Cartels and Welfare', in Poyago-Theotoky (ed.), *Competition, Cooperation, Research and Development*, MacMillan, London.

De Fraja, G., 1990, *Strategic Disclosure of R&D Knowledge and Research Joint Ventures*, Discussion Paper No. 90/278, University of Bristol.

De Fraja, G., 1993, 'Strategic spillovers in patent races', *International Journal of Industrial Organization*, 11:139-46.

Delbono, F., and Denicolo, V., 1990, 'R&D Investment in a Symmetric and Homogeneous Oligopoly: Bertrand vs Cournot', *International Journal of Industrial Organization*, 8(2):297-313.

Eaton, B.C., and Eswaran, M., 1997, 'Technology-trading coalitions in supergames', *RAND Journal of Economics*, 28(1):135-49.

Fölster, S., 1995, 'Do subsidies to cooperative R&D actually stimulate R&D investment and cooperation?', *Research Policy*, 24:403-17.

Fransman, M., 1990, *The market and beyond: Cooperation and competition in information technology development in the Japanese System*, Cambridge University Press, Cambridge.

Greenlee, P., 1998, *Endogenous Formation of Competitive Research Sharing Joint Ventures*, Working Paper, U.S. Department of Justice.

Grindley, P., Mowery, D., and Silverman, B., 1994, 'SEMATECH and collaborative research: lessons for the Design of High Technology Consortia', *Journal of policy analysis and management*, 35:723-58.

Hinloopen, J., 1994, *Subsidising Cooperative and Non-Cooperative R&D in Duopoly with Spillovers*, European University Institute Working Paper ECO No. 94/25.

Katz, M.L., 1986, 'An analysis of cooperative research and development', *RAND Journal of Economics*, 17(4):527-43.

Kamien, M.I., Muller, E., and Zang, I., 1992, 'Research Joint Ventures and R&D Cartels', *AER*, 82(5):1293-1306.

Kamien, M.I., and Zang, I., 1993, 'Competing Research Joint Ventures', *Journal of Economics and Management Strategy*, 2(1):23-40.

Kamien, M.I., and Zang, I., 1998, *Meet Me Halfway: Research Joint Ventures and Absorptive Capacity*, Mimeo, Department of Managerial Economics and Decision Sciences, J.L. Kellogg Graduate School of Management, Northwester University.

Katsoulacos, Y., and Ulph, D., 1998a, 'Endogenous Spillovers and the Performance of Research Joint Ventures', *Journal of Industrial Economics*, 46(3):333-57.

Katsoulacos, Y., and Ulph, D., 1998b, 'Innovation Spillovers and Technology Policy', *Annales d'Economie et de Statistique*, 40-50:589-607.

Kesteloot, K., and Veugelers, R., 1995, 'Stable R&D Cooperation with Spillovers', *Journal of Economics & Management Strategy*, 4(4):651-72.

Kogut, B., 1989, 'The Stability of Joint Ventures: Reciprocity and Competitive Rivalry', *Journal of Industrial Economics*, 38(2):183-98.

Link, A.N., and Bauer, L.L., 1989, *Cooperative Research in U.S. Manufacturing: Assessing Policy Initiatives and Corporate Strategies*, Lexington Books, Lexington, MA.

Link, A., and Tancy, 1989, Lost reference.

Mansfield, E., 1985, 'How Rapidly does New Industrial Technology Leak Out?', *Journal of Industrial Economics*, 34:217-23.

Mariti, P., and Smiley, R.H., 1983, 'Co-operative Agreements and the Organization of Industry', *Journal of Industrial Economics*, 31(4):437-51.

Peck, M.J., 1986, 'Joint R&D: The case of Microelectronics and Computer Technology Corporation', *Research Policy*, 15:219-31.

Pérez-Castrillo, J.D., and Sandonís, J., 1997, 'Disclosure of know-how in research joint ventures',

International Journal of Industrial Organization, 15(1):51-75.
Poyago-Theotoky, J., 1995, 'Equilibrium and Optimal Size of a Research Joint Venture in an Oligopoly with Spillovers', *Journal of Industrial Economics*, 43(2):209-25.
Poyago-Theotoky, J., 1999, 'A Note on Endogenous Spillovers in a Non-Tournament R&D Duopoly', *Review of Industrial Organization*, 15:253-62.
Röller, L., Siebert, R., and Tombak, M. M., 2000, *Strategic Choice of Partners: Research Joint Ventures and Market Power*, Manuscript, Wissenschaftszentrum Berlin, December.
Rosen, R.J., 1991, 'Research and Development with Asymmetric Firm Sizes', *RAND Journal of Economics*, 22:411-29.
Rosenkranz, S., 1998, *To Reveal or Not to Reveal: The Case of Research Joint Ventures with Two-Sided Incomplete Information*, CEPR Discussion Paper No. 1985, Wissensschaftszentrum Berlin.
Salant, S.W., and Shaffer, G., 1998, 'Optimal Asymmetric Strategies in Research Joint Ventures', *International Journal of Industrial Organization*, 16(2):195-208.
Shaffer, S., 1995, 'Stable Cartels with a Cournot Fringe', *Southern Economic Journal*, 61(3):744-54.
Snyder, C., and Vonortas, N., 2000, *Multimarket and Multiproject Contact in Research Joint Ventures*, Paper presented at the *AEA* 2000 Meetings.
Uenhora, M., 1985, 'Increased reliance of modern industrial technology on scientific outcomes', in Bartocha, B., and Okamura, S., *Transforming Scientific Ideas into Innovations*, Japan Society for the Promotion of Science, Tokyo.
U.S. Department of Justice, 1985, News Release with accompanying letter by Charles F. Rule, Acting Assistant Attorney General, June 26.
Veugelers, R., and De Bondt, R., 1992, 'Cooperative Innovative Activities', in Antonelli, C. (ed.), *The Economics of Information Networks*, North-Holland, Amsterdam.
Yi, S.S., 1998, *Endogenous formation of joint ventures with efficiency gains*, Working paper, Dartmouth College.
Yi, S.S., and Shin, H., 2000, 'Endogenous Formation of Research Coalitions', *International Journal of Industrial Organisation*, 18(2):29-56.

Liste des publications au CIRANO *

Cahiers CIRANO / *CIRANO Papers* (ISSN 1198-8169)

99c-1 Les Expos, l'OSM, les universités, les hôpitaux : Le coût d'un déficit de 400 000 emplois au Québec — Expos, Montréal Symphony Orchestra, Universities, Hospitals: The Cost of a 400,000-Job Shortfall in Québec / Marcel Boyer

96c-1 Peut-on créer des emplois en réglementant le temps de travail? / Robert Lacroix

95c-2 Anomalies de marché et sélection des titres au Canada / Richard Guay, Jean-François L'Her et Jean-Marc Suret

95c-1 La réglementation incitative / Marcel Boyer

94c-3 L'importance relative des gouvernements : causes, conséquences et organisations alternative / Claude Montmarquette

94c-2 Commercial Bankruptcy and Financial Reorganization in Canada / Jocelyn Martel

94c-1 Faire ou faire faire : La perspective de l'économie des organisations / Michel Patry

Série Scientifique / *Scientific Series* (ISSN 1198-8177)

2000s-52 A Theory of Routines as Mindsavers / Bernard Sinclair-Desgagné et Antoine Soubeyran

2000s-51 Can Financial Intermediation Induce Economic Fluctuations? / Sanjay Banerji et Ngo Van Long

2000s-50 Information Technology Sophistication in Hospitals: A Field Study in Quebec / Guy Paré et Claude Sicotte

2000s-49 Does Comparable Worth Work in a Decentralized Labor Market? / Michael Baker et Nicole M. Fortin

2000s-48 Occupational Gender Composition and Wages in Canada: 1987-1988 / Michael Baker et Nicole M. Fortin

2000s-47 Économétrie, théorie des tests et philosophie des sciences / Jean-Marie Dufour

2000s-46 Factor Analysis and Independent Component Analysis in Presence of High Idiosyncratic Risks / Thierry Vessereau

2000s-45 Aspects non linéaires du marché des actions français / Thierry Vessereau

2000s-44 Étude du modèle d'évaluation par arbitrage sur le marché des actions suisses / Thierry Vessereau

2000s-43 Habit Formation with Recursive Preferences / Aylin Seckin

2000s-42 Habit Formation: A Kind of Prudence? / Aylin Seckin

2000s-41 Consumption with Liquidity Constraints and Habit Formation / Aylin Seckin

2000s-40 Consumption-Leisure Choice with Habit Formation / Aylin Seckin

2000s-39 Consumption with Habit Formation / Aylin Seckin

2000s-38 Consumption with Durability / Aylin Seckin

* Vous pouvez consulter la liste complète des publications du CIRANO et les publications elles-mêmes sur notre site Internet à l'adresse suivante :

http://www.cirano.umontreal.ca/publication/documents.html