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R&D organization: Cooperation or Cross-Licensing?

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Abstract

Under the Cross-Licensing system (CL) firms are allowed to trade non cooperatively the results of R&D efforts while competing in the innovation and production stages. The paper proposes first a simple modeling of this system. Second a relevant comparison is made with the Cartelized Research Joint Venture (RJV), a form of R&D cooperation recognized to be the best one. We prove that the Cross-Licensing system may be socially better than the Cartelized RJV. In terms of antitrust policy, the conclusion is more subtle. For firms the most favorable collusion mode is Joint Exploitation and firms are equally tempted by this mode whether they are under CL or under Cartelized RJV. The temptation to move to Monopoly is also the same under both modes except on a narrow range of R&D costs.

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Keywords : R&D cooperation, Cartelized Research Joint Venture, Cross-Licensing, R&D spillovers, Antitrust policy.

JEL Classification : C72, L24, D23.

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1 Introduction

The question of the best organization mode of R&D has been of great interest to economists and deciders, as production and diffusion of technological knowledge have proved to be crucial to ensure economic growth (Aghion and Howitt, 1998). Regarding Cross-Licensing and cooperative R&D, on the one hand the "Antitrust guidelines for licensing of intellectual property" of the U.S. Department of Justice and Federal Trade Commission (1995) states: "When cross-licensing involves horizontal competitors, the Agencies will consider whether the effect of the settlement is to diminish competition among entities that would have been actual or likely potential competitors in a relevant market in the absence of the cross-license. In the absence of offsetting efficiencies, such settlements may be challenged as unlawful restraints of trade." On the other hand the U.S. Congress explicitly acknowledged the social value of cooperative R&D in 1984 by passing the National Cooperative Research Act (NCRA).

This article proposes a theoretical framework to check whether the mistrust against Cross-Licensing and the preference of antitrust authorities for cooperative R&D are founded. Mainly the Cross-Licensing system in which firms can trade the results of their R&D efforts, is modeled and compared with the Cartelized Research Joint Venture, the best cooperative R&D organization mode. The comparison is made in terms of the usual efficiency criterion and in terms of antitrust policy. Precisely, we try to answer the following two questions: first from the social viewpoint, is the Cartelized RJV always better than the CL system? Second are firms more tempted to collude under the CL system than under the Cartelized RJV?

Cooperation in R&D is usually considered to be good for both producers and consumers, provided that the participating firms remain competitors in the product market (D'Aspremont and Jacquemin, 1988, 1990, Kamien et al, 1992). The R&D activity of a firm is affected by the importance of the technological spillovers it generates, i.e. the degree of appropriation of the benefits resulting from the firm's investment efforts by its competitors, which results in under-investment in R&D (Arrow, 1962). D'Aspremont and Jacquemin (1988, 1990), de Bondt et al. (1992), de Bondt (1997), Kamien et al. (1992), Motta (1992), Suzumura (1992), show how cooperative R&D agreements between otherwise competing firms may help firms internalize the spillovers, resulting in social welfare improvement. Such arguments provide a theoretical foundation for the support of cooperative R&D by antitrust authorities.

Another policy to support innovation is the patent system. By giving temporary exclusivity to the innovator, the patent secures the appropriation of technological knowledge thus increases the incentive to invest in R&D. Moreover the patent may be yielded through "licenses". Cross-licensing of patents which makes each firm both a potential transferor and recipient of a technology, exists in real life (for example Cross-Licensing between Summit and VISX or IBM and Intel): the R&D results are transferred ex-post, which may mitigate the effect of the exclusivity of the owner.

The objective of this paper is twofold. First, we introduce simply the Cross-Licensing model (CL) in which firms are assumed to trade non-cooperatively R&D cost-reducing innovation results and compete in the innovation and product market, the level of spillovers thus being determined endogenously. Second, this model is compared with the Cartelized RJV, the cooperative R&D organization mode recognized to be the best one[1].

We show that for high R&D costs, the CL system results in higher R&D efforts and higher social surplus than the Cartelized RJV, but results in lower firms' profits.

The conclusion is subtle in terms of antitrust policy. For firms the most favorable collusion mode thus the most relevant to consider is Joint Exploitation. On the one hand, either firms are under CL or under the Cartelized RJV, they are equally tempted by this type of collusion. On the other hand, the temptation to move to Monopoly is also the same under both modes except for a narrow range of R&D costs. More precisely, whether they are under the CL system or under the Cartelized RJV, they do not wish to cooperate fully for low R&D costs while they are tempted by this collusion for high R&D costs. For intermediate values of R&D costs, they are tempted to move to Monopoly when they under CL but not when they are under Cartelized RJV. But for those R&D costs, the CL system is socially better.

To these findings should be added the fact that it may be difficult to encourage cooperation in R&D and simultaneously prevent joint production or collusion, as cooperation in R&D may increase the likelihood of collusion in the product market (Martin, 1996, Cabral, 2000, Lambertini, et al., 2002); whereas the suggested CL system is in a completely non-cooperative framework.

This analysis proves that the preference for cooperative R&D by European and American antitrust authorities and their mistrust in Cross-Licensing are not always founded, neither in terms of social welfare nor in terms of the potential for collusion.

The related literature. An abundant literature deals with the issue of knowledge transfer between firms. In the literature on patents, licensing is unilateral between a patent holder and licensees. Much of this literature is reviewed in Kamien (1992) and further by Choi (2002), Arora and Fosfuri (2003), Li and Song (2008) or Stamapoulos and Tauman (2008). The paper of Fauli-Oller and Sandonis (2003) belongs to this strand of literature even if it deals with an issue close to ours comparing licensing contract and merger between a patent holder and another firm. The patent pool is another mode for knowledge transfer different from Cross-Licensing (Shapiro, 2001, Kato, 2004, Lerner and Tirole, 2004, Lerner et al., 2007 or Brenner, 2008). Indeed a patent pool is defined by Brenner (2008) as "a coalition of patent holders who entitle the administrator of the pool to market the respective intellectual property and to sell licenses as a package." Hence a patent pool corresponds to a cooperative behavior and knowledge transfer is unilateral between the coalition and the licensees.

Cross-Licensing of patents which makes each firm both a potential transferor and recipient of a technology, has not received much attention from economists except in few theoretical papers [2]. Fershtman and Kamien (1992) analyze a Cross-Licensing model with two complementary technologies needed by each firm to produce the good. Eswaran (1994) explains how Cross-Licensing of competing brands can facilitate implicit collusion in the product market, fueling the mistrust of anti-trust authorities in Cross-Licensing. However they consider imperfect substitute goods in a repeated

[1]Kamien et al. (1992), Amir et al. (2002) and Brod and Shivakumar (1997) prove that the Cartelized RJV is socially better than the other known forms of R&D cooperation: Cartelized R&D, RJV, Monopoly and Joint Exploitation.

[2]Empirical considerations are developed by Nagoaka and Kwuong (2006)

game framework. Moreover, both papers focus on product innovation, while we examine cost-reducing process innovation. Pastor and Sandonis (2002) compare a Research Joint Venture with a Cross-Licensing Agreement (CLA) but the definitions of these modes and the analysis framework are quite different from ours. Indeed research is carried out in laboratories with asymmetric information as the lab's effort is not observable. In the RJV, firms have a joint lab with which each firm contracts and for which it decides of the amount of knowledge to be disclosed. In the CLA, firms carry out research in separate labs but may exchange the obtained results.

Katsoulacos and Ulph (1998), Poyago-Theotoky (1999) and Gersbach and Schumtzler (2003) also consider knowledge transfer between possibly innovating firms but not through the patent system. The two first papers suppose indeed that R&D results may be disclosed freely. The third one supposes that the knowledge transfer occurs through the moves of R&D employees and that if a firm succeeds in attracting an employee from its rival it benefits completely from the rival's cost reduction, the spillover taking by hypothesis extreme values and the firm not controlling knowledge transfer to its rival.

The remaining of the paper is organized as follows. Section 2 describes the Cross Licensing model (CL) and presents its predictions. Section 3 compares the CL model with the Cartelized RJV. Section 4 offers some concluding comments.

2 The Cross Licensing system

In this section, the CL system is presented detailing the hypotheses and the game structure. Then the outcome at the subgame perfect equilibrium is provided.

2.1 The model

Consider an industry composed of two firms $i = 1, 2$, each of which engages in upstream R&D and downstream production. Each firm produces a homogenous good. Let the inverse demand function be linear:

$$P = a - Q,$$

where Q is the total quantity available on the market, and a is some positive parameter which captures the size of the market.

Let q_i denote Firm i's output. Initially each firm produces with a linear cost function: cq_i. c is the initial marginal cost borne by firms if they do not invest in R&D. We suppose $c < a$.

Each firm has the possibility to lower its costs through innovation and/or through the purchase of all or part of the innovation of its competitor. Denote by x_i Firm i's innovation effort. The cost of R&D is assumed to be quadratic, implying the existence of diminishing returns to R&D efforts, namely: $\gamma x_i^2/2$. Parameter $\gamma > 0$ reflects the efficiency of R&D technology.

In most R&D cooperation models (including d'Aspremont and Jacquemin, 1988), R&D is characterized by imperfect appropriability of innovation: each firm cannot avoid that a part of its innovation benefit to its competitor. This literature has supposed that spillover levels are exogenous, that is, if one firm achieves some innovation, through uncontrolled technological transfers, other firms benefit at least partially from the innovation. In the Cross Licensing model introduced in this paper, firms are assumed to control this type of externality and are allowed to trade it.

More precisely β_i denotes the part of the innovation of Firm j bought by Firm i. The total amount of innovation bought by Firm i from Firm j is given by $\beta_i x_j$, with $\beta_i \in [0,1]$. $\beta_i = 0$ means that the firm buys no innovation from its competitor and $\beta_i = 1$ means that the firm buys all the innovation of its competitor. Indeed innovation may involve several components. For instance a new software may be composed of several functionalities thus may be sold only partly; a know-how in some field may be yielded only partially through a less or more intensive training; a chemical process may imply several applications, etc. The resulting marginal cost equals:

$$c_i = c - x_i - \beta_i x_j.$$

Hence, we assume that the cost reductions are complementary, namely that a firm's own cost reduction does not duplicate the cost reduction of the rival in any way[3].

Denote by $A = a - c > 0$. We suppose[4] $\gamma > \frac{4}{9}(a/c)$ (thus $\gamma > \frac{4}{9}$) and $\frac{12A}{9\gamma - 4} < c$.

The Cross Licensing system is modeled through a four stage game.

1. In the first stage, firms choose simultaneously their innovation efforts x_i.
2. Firms fix simultaneously the unit sale prices of their innovation p_i.
3. Firms choose the amounts of innovation to be bought from one another β_i.
4. Finally, firms choose the quantities of the product to be sold q_i.

All stages are non-cooperative. At each stage firms know the choices made at the preceding stages (if any).

For $i = 1, 2$, the profit function under the Cross-Licensing system is:

$$\pi_i = p_i \beta_j x_i - p_j \beta_i x_j + (a - q_i - q_j - c_i) q_i - \gamma \frac{x_i^2}{2}.$$

In case there is indifference in terms of profit between $\beta_i = 0$ and a positive β_i, we adopt the convention that the positive β_i is selected. This optimistic convention means that in case of indifference between no transfer and a positive transfer, the latter is chosen. It will be referred to later as $\mathcal{SC}$.

It is worth noting that the relevant comparison in terms of R&D efforts has to be made in terms of the effective cost reduction of each firm, which is the sum of its own R&D effort and a fraction of the other firm's effort:

$$X_i = x_i + \beta_i x_j.$$

[3]This point has been discussed in detail by Amir (2000).

[4]This is to secure that the profit functions are concave and to have no corner solutions in terms of innovation efforts.

We will see that in the Cross-Licensing, the Cartelized RJV and Joint Exploitation, firms end up sharing completely their R&D results (by hypothesis in the Cartelized RJV and Joint Exploitation and endogenously in CL). In the symmetric outcome, the effective R&D effort can then be written $X = 2x$, where x is the effort of each firm. However, in the monopoly situation, the effective cost reduction X^M corresponds to joint R&D effort x^M because both firms have the same R&D structure (joint lab) thus there is no spillover effect.

2.2 The outcome at equilibrium

The game is solved by backward induction. First quantities q_i are calculated for given x_i, p_i and β_i. Second, the exchanged amounts of innovation β_i are calculated for given x_i and p_i. Third the innovation prices p_i are calculated for given x_i. Finally the innovation efforts x_i are calculated at the subgame perfect equilibrium.

Calculations of the quantities sold by firms for given x_i, β_i and p_i amount to solve a competition à la Cournot, yielding

$$q_i = \frac{a - 2c_i + c_j}{3}.$$

The result for the amounts of innovation exchanged (β_i) is provided in Lemma 1. Lemma 2 provides the innovation prices. Proposition 1 provides the main result of the section: the outcome at the subgame perfect equilibrium. Lemmas 1, 2 and all proofs are given in Appendix.

Proposition 1 *At the subgame perfect equilibrium, under $\mathcal{SC}$, firms exchange totally the results of their innovation efforts ($\beta_i = \beta_j = 1$), the effective R&D effort, total quantity, industry equilibrium profit and social welfare, are given below.*

$$X^* = 2x^* = \frac{12A}{9\gamma - 4},$$

$$Q^* = 2q^* = \frac{2A(9\gamma + 8)}{3(9\gamma - 4)},$$

$$\Pi^* = 2\pi_i^* = \frac{2A^2}{(9\gamma - 4)^2}(9\gamma^2 - 2\gamma + (64/9)),$$

and

$$W^* = \frac{4A^2}{9(9\gamma - 4)^2}(81\gamma^2 + 63\gamma + 64).$$

In the recent literature dealing with endogenous spillovers, Poyago-Theotoky (1999) is the closest to our approach. She supposes in a model à la d'Aspremont and Jacquemin that a firm may disclose freely a part of its R&D results. When firms decide non-cooperatively of the amount of knowledge to disclose, no disclosure of information occurs. This is a natural result as "by disclosing a positive amount of R&D knowledge a firm is, in a sense, lowering its rival's unit cost and increasing the rival's market share.

Hence it is hurting its own profitability" (Poyago-Theotoky, 1999). The author has concluded that no information disclosure should be possible in a competitive setting. She suggests a cooperative setting where firms choose jointly the spillover level and the R&D efforts while competing at the production stage, leading to the same outcome as the Cartelized Research Joint Venture.

However our paper proves on the one hand that when firms are allowed to trade their results, an incentive is created to disclose information in a competitive setting so that firms end up sharing completely their innovation results, while no net profit is made by firms from this trade at equilibrium as the revenue from the sale of the firm's R&D results equals exactly the expenditure stemming from the purchase of the rival's R&D results. On the other hand, as will be proved, the obtained outcome may be socially better than the Cartelized RJV's one thus better than the outcome of the cooperative setting suggested by Poyago-Theotoky.

3 Comparative results

The main comparison is made between the CL system and the Cartelized RJV. But to do so, other comparisons are required with Monopoly and Joint Exploitation. To make a clear presentation, we suggest to provide first synthetically the characteristics and the results of each mode of interest.

3.1 The outcomes with the R&D cooperative modes

We are interested in the three following R&D organization modes.

(i) The Cartelized Research Joint Venture (referred to by C) in which firms compete at the production level but choose cooperatively their R&D efforts while sharing their R&D results. Following Kamien et al. (1992), the Cartelized Research Joint Venture is superior to all other organization modes of R&D cooperation (as competitive Research Joint venture or R&D Cartel[5]).

(ii) Full cooperation or Monopoly (M), in which firms choose R&D efforts cooperatively and collude in the production market. In this scenario, firms undertake R&D in a joint lab with equal R&D cost-sharing. Then, this scenario is equivalent to Monopoly with a unique lab (Amir et al., 2002).

(iii) Joint Exploitation (J), in which firms coordinate their R&D efforts while sharing their results and collude at the production stage. Differently from the full cooperation case, firms undertake research in separate labs[6] (d'Aspremont and Jacquemin, 1988, Brod and Shivakumar, 1997).

[5]In the competitive RJV, firms just share their R&D results while competing in the R&D and production stages. In R&D cartel, firms coordinate their R&D activities so as to maximize the sum of overall profits without sharing the R&D results. These two modes have in common with the Cartelized RJV the assumptions that each firm develops its part of R&D activity in its own lab and firms compete at the production stage.

[6]This case is similar to the case of monopoly with two labs but we will avoid this expression to avoid confusion with the full cooperation case.

Table 1 synthesizes the characteristics of the three modes of interest.

	C: Cartelized RJV	**M:** Monopoly	**J:** Joint Exploitation
R&D results	exchange	same lab	exchange
R&D efforts	Cooperate in separate labs	Cooperate in a joint lab	Cooperate in separate labs
Output	Compete	Cooperate	Cooperate

Table 1: The three R&D cooperative modes.

In the three scenarii, firms engage in a two stage game where they choose R&D efforts in the first stage and output in the second one. The demand, the cost structure and the effect of R&D on costs are the same as in d'Aspremont and Jacquemin (1988) and the CL model.

In the Cartelized RJV and Joint Exploitation, the spillover parameter β is common to both firms and exogenously set $\beta = 1$. In the Monopoly case, firms undertake R&D in a common unit or in a joint lab. By definition, this form of cooperation is independent of spillover effects (Amir et al., 2002, Amir, 2000).

Note that for different reasons, as in the CL system, in each one of the other examined modes of R&D organization, each firm benefits from the same amount of R&D results. In the case of Cartelized RJV and Joint Exploitation, firms benefit from the total R&D effort; and in the case of monopoly they undertake R&D in the same lab thus have the same reduction of costs.

Proposition 2 *Suppose $\gamma > \frac{a}{c}$. The outcomes obtained in each cooperative mode of interest are provided in Table 2 below.*

Outcomes:	**C**	**M**	**J**
R&D effort:	$X^C = \frac{8A}{9\gamma-8}$	$X^M = \frac{A}{2\gamma-1}$	$X^J = \frac{A}{\gamma-1}$
Total Quantity:	$Q^C = \frac{6A\gamma}{9\gamma-8}$	$Q^M = \frac{A\gamma}{2\gamma-1}$	$Q^J = \frac{A\gamma}{2(\gamma-1)}$
Total profit:	$\Pi^C = \frac{A^2\gamma}{4.5\gamma-4}$	$\Pi^M = \frac{A^2\gamma}{4\gamma-2}$	$\Pi^J = \frac{A^2\gamma}{4(\gamma-1)}$
Total surplus:	$W^C = \frac{A^2\gamma(9\gamma-4)}{(4.5\gamma-4)^2}$	$W^M = \frac{A^2(3\gamma^2-\gamma)}{2(2\gamma-1)^2}$	$W^J = \frac{A^2\gamma(3\gamma-2)}{8(\gamma-1)^2}$

Table 2: Outcomes with the R&D cooperative modes.

Although calculations have been made by preceding authors (Amir et al., 2002, d'Aspremont et Jacquemin, 1988, Brod and Shivakumar, 1997, Kamien et al., 1992), the proof is given in Appendix for completeness.

3.2 The comparison

We restrict the comparison to the CL system with the Cartelized RJV. Indeed it has been proved that the Cartelized RJV is always socially better than Monopoly (Amir et al., 2002) on the one hand and Joint Exploitation (Brod and Shivakumar, 1997) on the other hand. Thus the choice remains for authorities between CL and the Cartelized RJV.

The performance comparison between the CL system and the Cartelized RJV mode regarding the usual efficiency criteria is given in Proposition 3. Its proof is given in Appendix.

Proposition 3 (Efficiency) *Assume $\gamma > \frac{8}{9}(a/c)$. Comparing the CL model with the Cartelized RJV model yields:*

(a) $X^* > X^C$ *if* $\gamma > \frac{16}{9}$;

(b) $Q^* > Q^C$ *if* $\gamma > \frac{16}{9}$;

(c) $\Pi^* \leq \Pi^C$ *for all values of* γ;

(d) $W^* > W^C$ *if* $\gamma > \frac{16}{9}$.

Proposition 3 shows that for sufficiently high R&D costs ($\gamma > \frac{16}{9} \simeq 1.77$) the CL system yields a better performance compared to the Cartelized RJV in three criteria of interest: R&D investments, consumers' surplus and social welfare. When R&D is costly, the incentive in terms of R&D and the exchange of innovation allowed by the CL system, results in higher consumer surplus and higher social surplus. This means that society wins in making the innovation tradable non-cooperatively, relative to the situation where firms coordinate their R&D efforts and exchange freely their innovation in the Cartelized RJV. The possibility to sell R&D results urges firms to increase their innovation efforts relative to the situation where this exchange is free, which lowers production costs and increases quantities. The CL system is favorable to consumers, boosting innovation except when R&D is not very costly ($\gamma < \frac{16}{9} \simeq 1.77$).

These results can be intuitively explained in terms of the "free-riding" effect. Indeed in the Cartelized RJV, when deciding its R&D efforts, each firm takes into account the fact that it benefits from its rival's innovation and therefore free-rides on the other firm's R&D efforts. In the CL system, each firm controls completely its spillover and has moreover the possibility of selling a part of its innovation, which eliminates the free-riding effect and leads to more R&D efforts. But more innovation is also favorable to consumers since production costs are lower at the product market stage. When the cost of R&D is relatively low, the coordination of R&D activities permitted by the Cartelized RJV leads to better R&D efforts than the CL system as the incentive for free-riding is stronger the more firms can save in terms of R&D costs.

Considering firms, the additional R&D effort with the CL system relative to the Cartelized RJV involves too high costs of R&D, which has a negative impact on profits, resulting in profits lower under the CL system than under the Cartelized RJV. This finding allows to understand why firms are not numerous to adopt the CL system and why cooperation agreements in R&D are more commonly observed (Anand and Khanna, 2000). The adoption of the CL system by firms instead of the Cartelized RJV would stem from other considerations. For instance if firms cannot secure the agreement reinforcement, they may fear the free riding problem with the Cartelized RJV while they do not at all have to worry about the issue with the CL system (Atallah, 2006; Cabon-Dhersin and Ramani, 2003; Kesteloot and Veugelers, 1995; Kogut, 1989). Furthermore, the CL system may provide procompetitive benefits by integrating complementarity technologies, reducing transaction costs, clearing blocking positions and avoiding costly infringement litigation (Shapiro, 2001).

We now compare both modes in terms of antitrust policy to know whether there are any theoretical foundation to mistrust the CL system more than the Cartelized RJV in terms of potential for collusion. This question requires the comparison between the profits under the CL system and under Joint Exploitation and Monopoly on the one hand and between the profits under the Cartelized RJV and under the two other modes on the other hand.

Proposition 4 (Antitrust policy) *Comparing the total profit obtained under the CL system,*

- *with Joint Exploitation: for all values of* γ, $\Pi^* < \Pi^J$.
- *with Monopoly:* $\Pi^* > \Pi^M$ *if and only if* $\gamma < 3.51$.

Comparing the total profit obtained under the Cartelized RJV mode,

- *with Joint Exploitation, for all values of* γ, $\Pi^C < \Pi^J$.
- *with Monopoly,* $\Pi^C > \Pi^M$ *if and only if* $\gamma < 4$.

The profit comparison between the CL system or the Cartelized RJV and monopoly follows non-standard lines. Under CL and Cartelized RJV, the effect of more important R&D cost-reduction is sufficient to over-turn the loss of profit inherent to competition when the R&D cost parameter (γ) is relatively low ($\gamma < 3.51$ respectively $\gamma < 4$). For low R&D costs, production cost replication and competition effects are completely outweighed by higher R&D efforts stemming from a higher incentive to innovate. Moreover, it seems that the CL system somehow allows firms to "subsidize" each other non-cooperatively, as it would have been more costly to reach the same cost reduction by investing more in R&D efforts because of diminishing returns in R&D. For sufficiently high values of γ ($\gamma > 3.51$ respectively $\gamma > 4$), producers make higher profits when they collude relative to the CL system or Cartelized RJV as the reduction in production costs implied by higher R&D effort, is not enough to compensate the required R&D costs and the competitive effect relative to the monopoly case.

The results concerning the comparison with Joint exploitation are more easy to explain. In the three scenarii considered (Joint Exploitation, CL or Cartelized RJV), firms undertake research in separate labs and do face decreasing returns in the R&D process. Consequently, whatever the scenario in the first stage, the marginal profitability of R&D is greater when firms collude downstream, and Joint exploitation in which firms collude at the production stage generates less output and more profit than Cartelized RJV or CL.

In terms of potential for collusion, Proposition 4 proves that the temptation for firms to move to Joint Exploitation always exists whether they are under the CL system or under the Cartelized RJV, as in each case, they improve their profits whatever the level of R&D costs. Concerning the temptation to collude totally, i.e. to form a monopoly with a unique lab, whether firms are under CL or Cartelized RJV, when R&D costs are low ($\gamma < 3.51$), they do not wish to collude totally. They may be tempted to do so when R&D costs are high enough ($\gamma > 4$). There is only a limited segment of R&D costs ($\gamma \in [3.51; 4]$) where firms may wish to move to Monopoly when they are under CL but never wish to do so under Cartelized RJV.

Taking into account Propositions 3 and 4, authorities may have a very good reason to prefer the Cartelized RJV when $\gamma < 16/9$ as it is socially better than CL and is equivalent to CL in terms of antitrust policy. For all the other values of γ the CL system is socially better. The unique reason to prefer the Cartelized RJV would be then in terms of antitrust policy. It is only for $\gamma \in [3.51; 4]$ that the Cartelized RJV is less tempting for firms than CL as they are tempted to move to Monopoly under CL while they are not under Cartelized RJV.

However Monopoly is not the relevant collusion mode to be considered. Indeed a simple calculation proves that the firms' profits are always higher under Joint Exploitation than under Monopoly[7]. Whenever firms are tempted by collusion, they would be tempted by the best form of collusion in terms of profits thus by Joint Exploitation, and by the latter mode they are equally tempted whether they are under CL or under Cartelized RJV.

4 Conclusion

This paper contributes to an abundant literature on the incentives to innovate. It proposes a framework to evaluate the efficiency of an R&D organization mode, namely Cross-Licensing which has not received much attention from economists and compares it with the Cartelized RJV, the best R&D cooperative mode. The comparison is made in terms of efficiency and antitrust policy.

The results obtained are sensitive to the parameter of the R&D cost function. First we prove that R&D efforts and consumers' surplus are higher under CL relative to the Cartelized RJV for sufficiently high R&D costs. In terms of antitrust policy, considering Joint Exploitation, the most favorable collusion mode for firms, whether firms are under CL or Cartelized RJV, they are always tempted by this collusion mode.

[7]This stems from the fact that the returns in R&D are assumed to be decreasing. Consequently, it is more efficient to use two separate labs (Joint exploitation) instead of a joint one (Monopoly).

The temptation to move to Monopoly is also the same under both modes except for a narrow range of R&D costs but for which CL is socially better that the Cartelized RJV.

This finding questions the statements of the European and American authorities against CL (the "regulation 240-96" of the European Commission, 2001, and the "Antitrust guidelines for licensing of intellectual property" of the U.S. Department of Justice and Federal Trade Commission, 1995) and favorable to cooperative R&D (Articles 85 and 86 of the Treaty of Rome and the National Cooperative Research Act). The Cartelized RJV is not always better than CL neither in terms of efficiency nor in terms of antitrust policy.

Appendix

Lemma 1 *Under $\mathcal{SC}$, at the subgame pefect equilibrium the amounts of innovation exchanged are given in the following table:*

$p_2 \backslash p_1$	$0 \leq p_1 \leq \alpha$	$\alpha < p_1 \leq \beta$	$\beta < p_1$
$0 \leq p_2 \leq \omega$	$(1,1)$	$(1,0)$	$(1,0)$
$\omega < p_2 \leq \phi$	$(0,1)$	$(1,0)$ *and* $(0,1)$	$(1,0)$
$\omega < p_2$	$(0,1)$	$(0,1)$	$(0,0)$

with $\alpha = (4/9)(A + x_2)$*;* $\beta = (4/9)(A + 2x_2)$*;* $\omega = (4/9)(A + x_1)$*;* $\phi = (4/9)(A + 2x_1)$

Lemma 1 provides the equilibrium in terms of the amounts of innovation exchanged, for given R&D efforts and R&D unit prices. Lemma 1 shows that the exchange of innovation in this setting is total or null.

Proof. We have:

$$\frac{\partial \pi_i}{\partial \beta_i} = -p_j x_j + 2q_i \frac{\partial q_i}{\partial \beta_i}$$

The second derivative of the profit w.r.t. β_i is given by:

$$\frac{\partial^2 \pi_i}{\partial \beta_i^2} = \frac{8x_j^2}{9} > 0$$

Therefore the function to be maximized at this step is a convex function w.r.t. β_i. It reaches its maximum at $\beta_i = 0$ or $\beta_i = 1$. It is thus sufficient to solve the game considering that the strategy space is reduced to the pair $\{0, 1\}$.

We calculate the best response of firm i, φ_i, for each of its competitor's relevant strategies $\beta_j = 0, 1$. Denote by $\pi_i(\beta_i, \beta_j)$ the profit of Firm i when its strategy is β_i and its competitor's strategy is β_j.

We have:

$$\pi_i(1, 0) - \pi_i(0, 0) = x_j(\frac{4}{9}(A + 2x_i) - p_j).$$

Thus, with the adopted convention $\mathcal{SC}$,

$$\varphi_i(\beta_j = 0) = \begin{cases} 1 & \text{if} \quad p_j \leq \frac{4}{9}(A + 2x_i) \\ 0 & \text{if} \quad p_j > \frac{4}{9}(A + 2x_i) \end{cases}$$

Similarly,

$$\pi_i(1,1) - \pi_i(0,1) = x_2(\frac{4}{9}(A + x_i) - p_j).$$

Thus,

$$\varphi_i(\beta_j = 1) = \begin{cases} 1 & \text{if} \quad p_j \leq \frac{4}{9}(A + x_i) \\ 0 & \text{if} \quad p_j > \frac{4}{9}(A + x_i) \end{cases}$$

To summarize, depending on the competitor's innovation price, three cases have to be distinguished.

- When $p_j \leq \frac{4}{9}(A + x_i)$, the best response of Firm i is given by:

$$\begin{cases} \varphi_i(\beta_j = 1) = 1 \\ \varphi_i(\beta_j = 0) = 1 \end{cases}$$

- When $\frac{4}{9}(A + x_i) < p_j \leq \frac{4}{9}(A + 2x_i)$,

$$\begin{cases} \varphi_i(\beta_j = 1) = 0 \\ \varphi_i(\beta_j = 0) = 1 \end{cases}$$

- When $\frac{4}{9}(A + 2x_i) < p_j$,

$$\begin{cases} \varphi_i(\beta_j = 1) = 0 \\ \varphi_i(\beta_j = 0) = 0 \end{cases}$$

■

Lemma 2 *Under $\mathcal{SC}$, at the subgame perfect equilibrium, the unit prices of innovation are given by:*

$$p_i = \frac{4}{9}(A + x_j),$$

for $i, j = 1, 2$ and $i \neq j$.

Proof. We calculate the best response of Firm i, φ_i^p to each price p_j of its competitor.

Suppose first that $p_j \leq \frac{4}{9}(A + x_i)$. According to the table providing the equilibrium in β_i, for all possible value of p_i, at equilibrium, $\beta_i = 1$. The marginal cost of Firm i resulting from its own innovation efforts and the part of innovation bought from its competitor, and thus the cost of information and its quantity at equilibrium do not vary with p_i. In the expression of profit, only the part of profit stemming from the sale of innovation depends on p_i as the choice of the competitor in terms of innovation purchase depends on it. Two cases emerge.

- When $p_i > \frac{4}{9}(A+2x_j)$, $\beta_j = 0$. The profit of Firm i is thus given by:

$$\pi_i = -p_j x_j + q_i^2 - \gamma x_i^2/2$$

- When $p_i \leq \frac{4}{9}(A+x_j)$, $\beta_j = 1$. The profit of Firm i is thus given by:

$$\pi_i = p_i x_i - p_j x_j + q_i^2 - \gamma x_i^2/2$$

The profit of Firm i, is thus linear increasing in p_i up to $p_i = \frac{4}{9}(A+x_j)$, where it has a discontinuity, then becomes constant.

Therefore, for all $p_i \leq \frac{4}{9}(A+x_i)$,

$$\varphi_i^p(p_j) = \frac{4}{9}(A+x_j).$$

The same reasoning leads to the following result. For all $p_j > \frac{4}{9}(A+2x_i)$,

$$\varphi_i^p(p_j) = \frac{4}{9}(A+2x_j).$$

Now the case $\frac{4}{9}(A+x_i) < p_j \leq \frac{4}{9}(A+2x_i)$ is a special one as two equilibria in terms of β_i co-exist.

1. If $(\beta_i = 1, \beta_j = 0)$ is selected, the best response of Firm i is given by:

$$\varphi_i^p(p_j) = \frac{4}{9}(A+x_j).$$

2. If $(\beta_i = 0, \beta_j = 1)$ is selected, the best response of Firm i is given by:

$$\varphi_i^p(p_j) = \frac{4}{9}(A+2x_j).$$

Intersecting the two best responses leads, whatever the selected equilibrium in terms of β_i to $p_i = \frac{4}{9}(A+x_j)$. ■

Proof of Proposition 1. Integrating the preceding results, at equilibrium, for $i,j = 1,2$ and $i \neq j$,

$$p_i = \frac{4}{9}(A+x_j),$$
$$\beta_i = 1$$

and

$$q_i = \frac{A+x_i+x_j}{3}.$$

The profit is thus given by:

$$\pi_i = \frac{4}{9}A(x_i - x_j) + (\frac{A+x_i+x_j}{3})^2 - \gamma x_i^2/2.$$

The derivative of π_i w.r.t. x_i yields:

$$\frac{\partial \pi_i}{\partial x_i} = \frac{6}{9}A + x_i(\frac{2}{9} - \gamma) + \frac{2}{9}x_j.$$

The profit is concave w.r.t. x_i as $\gamma > \frac{4}{9}$.

The equilibrium is symmetric and given by:

$$x_i^* = x^* = \frac{6A}{9\gamma - 4}.$$

Thus at equilibrium, the marginal costs after innovation are

$$c_i^* = c - \frac{12A}{9\gamma - 4},$$

which are positive by hypothesis. Quantities are given by:

$$q_i = q^* = \frac{A(9\gamma + 8)}{3(9\gamma - 4)}.$$

■

Proof of Proposition 2. Note usefully that $\frac{a}{c} = \max(\frac{8}{9}\frac{a}{c}, \frac{1}{2}\frac{a}{c}, \frac{a}{c})$.

(i) *the Cartelized RJV.* We solve the game by backward induction, calculating the quantities chosen at Cournot-Nash equilibrium, given the R&D efforts.

They are given by:

$$q_i = q_j = \frac{A + x_i + x_j}{3}.$$

To calculate the R&D efforts chosen in the first stage, firms maximize jointly the sum of the profits of both firms $\{\pi_i + \pi_j\}$ with the obtained quantities:

$$\max_{x_i, x_j} \left\{ \left(\frac{A + x_i + x_j}{3} \right)^2 - \frac{1}{2}\gamma x_i^2 + \left(\frac{A + x_j + x_i}{3} \right)^2 - \frac{1}{2}\gamma x_j^2. \right\}$$

For the last function to be concave w.r.t. (x_i, x_j) we must have $\gamma > 8/9$.

After calculation, firms make the same effort $x^c = \frac{4A}{9\gamma - 8}$. The total effort is given by $X^c = 2x^c$. X^c requires $\gamma > \frac{8}{9}\frac{a}{c}$. But as we have $a > c$, $\gamma > \frac{8}{9}\frac{a}{c}$ implies $\gamma > 8/9$. Firms also produce the same quantity $q^c = \frac{3A\gamma}{9\gamma - 8}$, which yields the total quantity $Q^c = 2q^c$, thus the profit and the total surplus.

(ii) *Monopoly.* Full cooperation is equivalent to a single R&D performing firm (as in Amir et al., 2002). Firms undertake R&D in the same lab thus choose a common R&D effort (sharing the resulting costs) and choose cooperatively their output levels. Colluding in the second stage, they choose their outputs to maximize joint profits, $\pi_i + \pi_j$, with $\pi_i = (a - q_i - q_j)q_i - (c - x)q_i - \frac{1}{4}\gamma x^2$, which yields:

$$q_i + q_j = \frac{A + x}{2}.$$

Integrating the obtained quantities into the total profit, firms choose the R&D effort x so as to maximize:

$$\Pi = \frac{(A+x)^2}{4} - \frac{\gamma}{2}x^2.$$

The concavity of the last function requires $\gamma > 1/2$. The first order condition yields $X^M = x^M = \frac{A}{2\gamma-1}$. To have $x^M < c$, we must have $\gamma > \frac{1}{2}\frac{a}{c}$ which is sufficient to have $\gamma > 1/2$.

(iii) *Joint Exploitation.* In the production stage, firms choose q_i and q_j jointly so as to maximise the total profit:

$$\Pi = (a - q_i - q_j)(q_i + q_j) - (c - x_i - x_j)(q_i + q_j) - \gamma\frac{x_i^2}{2} - \gamma\frac{x_j^2}{2},$$

which yields the optimal total quantity:

$$q_i + q_j = \frac{A + x_i + x_j}{2}.$$

Firms choose x_i and x_j so as to maximise the profit:

$$\Pi = \frac{(A + x_i + x_j)^2}{4} - \frac{\gamma}{2}x_i^2 - \frac{\gamma}{2}x_j^2.$$

For the last function to be concave w.r.t. (x_i, x_j), γ must satisfy: $\gamma > 1$. First order conditions yield:

$$x_i = x_j = \frac{A}{2(\gamma-1)}.$$

For $X^J = x^i + x^j < c$, we must have $\gamma > \frac{a}{c}$, which is sufficient to have $\gamma > 1$.

■

Proof of Proposition 3.

The s.o.c. for interior equilibria in both settings require $\gamma > \frac{8}{9}(a/c) > \frac{4}{9}(a/c)$.

(a) For R&D efforts,

$$X^* - X^C = \frac{12A}{9\gamma-4} - \frac{4A}{4.5\gamma-4} = \frac{4A(9\gamma-16)}{(9\gamma-4)(9\gamma-8)}.$$

For all $a > c$ and $\gamma > \frac{8}{9}(a/c)$, $X^* - X^{CJ}$ has the same sign as $4.5\gamma - 8$.

(b) For quantities,

$$Q^* - Q^C = \frac{2A(9\gamma+8)}{3(9\gamma-4)} - \frac{3A\gamma}{4.5\gamma-4} = \frac{2A(9\gamma-16)}{3(9\gamma-4)(9\gamma-8)},$$

which has the same sign $9\gamma - 16$.

(c) For profits,

$$\Pi^* - \Pi^C = \frac{2A^2(9\gamma^2 - 2\gamma + (64/9))}{(9\gamma-4)^2} - \frac{A^2\gamma}{(4.5\gamma-4)} = \frac{-4A^2(3\gamma-(16/3))^2}{(9\gamma-4)^2(9\gamma-8)} \leq 0.$$

(d) For total surplus,

$$W^* - W^C = \frac{4A^2(81\gamma^2 + 63\gamma + 64)}{9(9\gamma - 4)^2} - \frac{A^2\gamma(9\gamma - 4)}{(4.5\gamma - 4)^2}$$
$$= \frac{4A^2(243\gamma^3 - 288\gamma^2 - 512\gamma + (64/3)^2)}{9(9\gamma - 4)^2(9\gamma - 8)^2},$$

which has the same sign as $243\gamma^3 - 288\gamma^2 - 512\gamma + (64/3)^2$ which is negative if and only if $\gamma \in (\frac{8}{9}, \frac{16}{9})$ and becomes positive for all values of $\gamma > \frac{16}{9} = 1.777$. Taking into account that $\gamma > \frac{8}{9}(a/c)$, the conclusion follows. ∎

Proof of Proposition 4.

1) Consider first the CL system.

As for the comparison with Joint Exploitation, let $f(\gamma) = \pi^* - \pi^J = -9\gamma^3 - 16\gamma^2 + (512/9)\gamma - (512/9)$.

$f'(\gamma) = -27\gamma^2 - 32\gamma + (512/9)$. After calculations, $f'(\gamma) > 0$ for $\gamma < 0.97$ and negative for $\gamma > 0.97$. Thus f is increasing for $\gamma \in [0, 0.97]$ and decreasing for $\gamma > 0.97$ thus reaches its maximal value at $\gamma = 0.97$. This maximal value is negative. Hence f is negative everywhere.

As for the comparison with Monopoly,

$$\Pi^* - \Pi^M = \frac{2A^2(9\gamma^2 - 2\gamma + (64/9))}{(9\gamma - 4)^2} - \frac{A^2\gamma}{(4\gamma - 2)}$$
$$= \frac{A^2(-9\gamma^3 + 20\gamma^2 + (440/9)\gamma - (256/9))}{(9\gamma - 4)^2(4\gamma - 2)}.$$

The sign of the difference is the same as the term $-9\gamma^3 + 20\gamma^2 + (440/9)\gamma - (256/9)$ which is positive if and only if $\gamma \in (0.50, 3.51)$. Taking into account that $\gamma > \frac{1}{2}(a/c)$, the conclusion follows.

2) Considering the Cartelized RJV, the results are proved in Brod and Shivakumar (1997) for the comparison with Joint Exploitation and in Amir et al. (2002) for the comparison with Monopoly.

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