R&D Organization: Cooperation or Cross-Licensing?

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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?

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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. When the firm does not secure the results of its research, under-investment in R&D may result (Arrow, 1962). The knowledge transfer is thus at the heart of the question of the support of innovation and the resulting benefits for consumers. Two different solutions have been proposed by the existing literature to deal with this issue, in order to foster firms' innovation.

First, knowledge transfer may occur freely between possibly innovative firms generally in a cooperative context. In R&D cooperation, firms coordinate their R&D activity (often maximize joint profit) while exchanging freely their results. A strand of literature based on the seminal model of d'Aspremont-Jacquemin (1988) shows how cooperative R&D agreements between otherwise competitive firms (in the product market) may help firms internalize their technological spillovers. When spillovers are large enough, the effect of technological spillovers on joint profit overcomes the competitive effect of spillovers on rivals' costs, fostering firms' investments in R&D and resulting in social welfare improvement. This point has been widely examined by many authors [1] providing a theoretical foundation for the support of cooperative R&D by antitrust authorities.

A second approach of knowledge transfer supposes that R&D results may be protected and traded. In concrete terms, the knowledge embedded in a patent giving temporary exclusivity to the innovator, may be transferred through "licenses". Cross-Licensing is a bilateral licensor/licensee relationship where each firm is in the same time a potential transferor and recipient of technological transfer. Cross-Licensing of patents existing in real life (for example Cross-Licensing between Summit and VISX or IBM and Intel), may mitigate the effect of the exclusivity of the owner as the R&D results may be transferred ex-post.

The paper investigates theoretically whether the Cross-Licensing system may be socially better than R&D cooperation. The objective of this paper is twofold. First, we introduce simply a non-cooperative version of the Cross-Licensing system (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 and *non-cooperatively.* In other words, the Cross-Licensing scheme may be viewed as a way for firms to obtain a market-related value of their innovation, both by using it in their own production and by selling it to their competitors. Second, this model is compared with the Cartelized

1 See, among many others, d'Aspremont and Jacquemin (1988, 1990), Kamien et al. (1992), Motta (1992), Suzumura (1992), de Bondt et al. (1992), de Bondt (1997). Katsoulacos and Ulph (1998), Poyago-Theotoky (1999), Piga and Poyago-Theotoky (2005), Amir et al. (2003) and Tesoriere (2008) deal with endogenous spillovers.

RJV, the cooperative R&D organization mode recognized to be the best one [2].

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, even though it results in lower firms' profits. Hence the CL system may be socially better than the Cartelized RJV, while the Cartelized RJV is always better for firms, which explains why firms more frequently prefer and use it (Anand and Khanna, 2000).

In terms of antitrust policy, we compare firms' temptation to collude under the CL system and under the Cartelized RJV. For firms, Joint Exploitation is the most favorable collusion mode, thus the most relevant to consider. We prove that, whether firms are under CL or under the Cartelized RJV, they are equally tempted by this type of collusion. Under the CL system, the only specific "danger" is to move to the Cartelized RJV, the cooperation mode which is precisely trusted and encouraged by authorities!

Therefore the preference of authorities for the Cartelized RJV is founded only for low R&D costs. For high R&D costs, this preference being justified neither by the usual efficiency criterion, nor in terms of the potential for collusion, authorities should instead encourage Cross Licensing and prevent firms from moving to the Cartelized RJV as they would be tempted to! 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.

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. This literature has extensively explored the licensing mechanisms (fixed licensing fees or royalties). Based on the works of Kamien and Tauman (1986) and Katz and Shapiro (1986), 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

[2] 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.

defined by Kato (2004) as “a combination of patents made available to third parties, whereas cross-licensing is the exchange of patents between two parties”. Hence a patent pool corresponds to a cooperative behavior within the coalition where knowledge transfer is unilateral between the coalition and the licensees; whereas the Cross-Licensing system considered in this paper, is a non-cooperative trade between two firms that grants each the right to use the other’s patents.

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 [3]. 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 game framework and focus on product innovation, while we examine cost-reducing process innovation for a homogenous good in a static framework. Finally, in these papers, even though the effects on social welfare have been investigated, no attempt has been made to compare the different organizational forms of R&D. Pastor and Sandonis (2002) compare a Research Joint Venture with a Cross-Licensing Agreement (CLA). However, first, the definitions of these modes and the analysis framework are quite different from ours. Second, their objective is to study the optimal internal organization of cooperation when a double moral hazard problem appears in Cross-Licensing Agreement. Finally, while proposing a comparison between R&D cooperation and Cross-Licensing, they evaluate the impact of information asymmetries without going into their implications for social welfare or competition policy.

Finally, Gersbach and Schumtzler (2003) consider differently knowledge transfer between possibly innovating firms. They suppose that 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 provides the outcome at equilibrium. Section 3 compares the CL model with the Cartelized RJV. Section 4 offers some concluding comments. Proofs and technical results are provided in Appendix.

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

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 capturing 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: $\gamma x_i^2/2$. The cost 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: a 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 more or less 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 [4].

Denote by $A = a - c > 0$. We suppose [5] $\gamma > \frac{4}{9}(a/c)$ (thus $\gamma > \frac{4}{9}$), $\frac{12A}{9\gamma - 4} < c$ and [6] $c < \frac{2}{5}a$.

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

1. First, 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 ones (if any).

Several authors (for instance Pastor and Sandonis, 2002) have adopted a cooperative approach to account for Cross-Licensing, modeling it as a contract between firms for technological transfers. There is no reason *a priori* to adopt rather the cooperative approach. The non-cooperative one seems a relevant alternative to consider the possibility for each firm to acquire the competitor's innovation. Thus Cross-Licensing is considered in our paper in terms of possibility of transferring technology and not in terms of obligation for both to do so (through a contract), each firm remaining free to do it or not.

We suppose that technology transactions involve only a fixed fee depending linearly on the amount of R&D purchased, and not on the quantity produced as it is the case with running royalties. Indeed, according to the empirical study of Rostoker (1984), several methods of license compensation are used in real life: down payment with running royalties, straight royalties and paid-up licenses. The latter compensation method corresponds to our model which is thus supported by some evidence. Software licences and employees' training are indeed often yielded through paid-up licences not depending on quantities.

With these hypotheses, the profit function of Firm i ($i = 1, 2$), 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

4 This point has been discussed in detail by Amir (2000).

5 This is to secure that the profit functions are concave and to avoid corner solutions in terms of innovation efforts.

6 This is to secure the existence of equilibrium at the step of choice of innovation prices (see the proof of Lemma 2 in Appendix).

optimistic convention means that in case of indifference between no transfer and a positive transfer, the latter is chosen [7]. It will be referred to later as 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:

$$X_i = x_i + \beta_i x_j$$

We will see that in the Cross-Licensing system, 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.

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 SC, firms exchange totally the results of their innovation efforts ($\beta_i = \beta_j = 1$), the unit price of innovation, the effective R&D effort, total quantity, the market price, industry equilibrium profit and social welfare, are respectively given below.*

$$p_i^* = \frac{4A(9\gamma + 2)}{9(9\gamma - 4)}, \quad \forall i = 1, 2;$$

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

[7] With the pessimistic convention, there may be a problem of existence of equilibrium at the step of choice of innovation prices.

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

$$P^* = \frac{a(9\gamma - 28) + 2c(9\gamma + 8)}{3(9\gamma - 4)};$$

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

and

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

As we see in Proposition 1, there is a complete transfer of innovation between competitors ($\beta_1 = \beta_2 = 1$). This result is not so obvious, as the unit innovation price is fixed by the competitor. A firm may *a priori* have interest to discourage the purchase of its own innovation by the competitor by setting a high price. Indeed when a firm sells a part of its innovation, it earns some profit but hurts its own profitability by lowering its competitor's cost. Such tradeoff is clear in the proofs of Lemmas 1 and 2.

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 then shows that when firms cooperate in the R&D stage, they choose to disclose fully private knowledge and hence to operate under maximal spillovers, leading to the same outcome as the Cartelized Research Joint Venture with maximal exogenous spillovers [8].

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. This is so 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

8 Tesoriere (2008) also provides a simple sufficient condition for optimal spillovers between cooperating firms to involve maximal spillovers (i.e. complete sharing of information) when firms do not have symmetric R&D profiles.

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, we need to deal with 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 two following R&D organization modes:

(i) Cartelized Research Joint Venture (referred to in the results 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 [9]).

(ii) 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 [10] (d'Aspremont and Jacquemin, 1988, Brod and Shivakumar, 1997).

Table 1 synthesizes the characteristics of the two modes of interest, together with those of the CL system suggested in this paper.

Table 1. *The R&D cooperative modes together with the CL system*

	C: Cartelized RJV	**J: Joint Exploitation**	**CL system**
R&D results	Free exchange	Free exchange	Non-cooperative trade
R&D efforts	Cooperate in separate labs	Cooperate in separate labs	Compete
Output	Compete	Cooperate	Compete

9 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.

10 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.

In both cooperative scenarii (Cartelized RJV and Joint Exploitation), 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 equal to $\beta = 1$. Hence for different reasons, as in the CL system, in each one of the two other examined modes of R&D organization, each firm benefits from the same amount of R&D results. Result 1 recalls the results already obtained in the existing literature about both the Cartelized RJV (C) and Joint Exploitation (J).

Result 1. *Suppose* $\gamma > \frac{a}{c}$. *The outcomes obtained in each cooperative mode of interest are provided in Table 2 below.*

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.

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

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

3.2 The comparison

We restrict the comparison to the CL system with the Cartelized RJV, as it has been proved that the Cartelized RJV is always socially better than all the other R&D cooperative modes known (Amir et al., 2002; Brod and Shivakumar, 1997). Thus, the choice remains 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 2.

Proposition 2 (Efficiency) *Assume* $\gamma > \frac{8}{9}(a/c)$. *Comparing the CL model with the Cartelized RJV model yields:*

(a) R&D efforts: $X^* > X^C$ *if* $\gamma > \frac{16}{9}$

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

(c) Total profit: $\Pi^* \leq \Pi^C$ for all values of γ.

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

Proposition 2 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 innovation and has moreover the possibility of selling it partly, 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 under the CL system lower 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 spontaneous adoption of the CL system by firms instead of the Cartelized RJV would stem from other considerations. For instance, a firm may not be able to secure the agreement reinforcement with the Cartelized

RJV, thus may not be sure to benefit effectively from the whole transfer of the competitor's knowledge; while it does 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 is any theoretical foundation to mistrust the CL system more than the Cartelized RJV in terms of the potential for collusion. This amounts to know whether firms improve their profits when they move to Joint Exploitation either from CL or from the Cartelized RJV.

Proposition 3 (Antitrust policy) *Comparing the total profit obtained under Joint Exploitation*

- with the total profit obtained under CL, for all values of γ, $\Pi^* < \Pi^J$.
- with the total profit obtained under the Cartelized RJV mode, for all values of γ, $\Pi^C < \Pi^J$.

The results concerning the comparison with Joint exploitation are 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 3 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.

Taking into account Propositions 2 and 3, 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. In this case, they have nothing to do as firms will spontaneously choose the Cartelized RJV. For $\gamma > 16/9$, the CL system is socially better and is equivalent to the Cartelized RJV in terms of anti-trust policy. Authorities should then encourage Cross Licensing and prevent all the other forms of cooperation including the Cartelized RJV. In this case, they have to do something, because if firms are given the choice, they would prefer the Cartelized RJV giving them better profits but leading to inferior social welfare.

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 under Cartelized RJV, they are always tempted by this collusion mode.

This finding questions the statements of the European and American authorities against CL (the "regulation 240-96" of the European Commission, 1996, 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), as the Cartelized RJV is not always better than CL, neither in terms of efficiency nor in terms of antitrust policy.

There are several possibilities to continue this research. In this paper, we suppose that firms control completely spillovers. In real life, there is always a fraction of knowledge transfer which may not be controlled by firms (for instance, through employees' movement). A simple way to deal with the issue is to suppose (as in Katsoulakos and Ulph, 1998) that the spillover to be purchased is exogenously and positively lower-bounded.

The pricing scheme of knowledge transfer may be explored further. In this paper, we postulate a constant price per unit cost reduction. This pricing scheme called by Rostoker paid-up licenses, corresponds to only 13 % of the observed data. Hence the other forms of compensation methods deserve to be explored. The possible superiority of Cross-Licensing relative to Cartelized RJV has been proved only in the framework of a particular innovation pricing scheme. It may not hold for the other pricing schemes more widely used in real life. First, decreasing returns imply that later units of innovation are more costly. Hence it would be natural to deal with non-linear pricing schemes. The simplest one is a two-part tariff where the buyer pays a fixed amount to have the right to purchase innovation at a constant unit price. A priori our results cannot generalize in an obvious way to the two-part tariff scheme. Second, the running royalties scheme is more widely used in real life. Therefore, another way to continue this work is to suppose that the payment depends also on the produced quantities. The fact that the two other compensation methods are more used does not at all mean that they are "better", the individual interest not necessarily converging to the collective one. The comparison between the three compensation methods at the resulting equilibrium for a given R&D organization mode, would be helpful to identify the best one regarding the incentive for innovation and more generally the usual efficiency criteria.

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Appendix

Lemma 1. *Under SC, at the subgame perfect equilibrium the amounts of innovation exchanged are given in the following table:*

$p_2 \backslash p_1$	$0 \leq p_1 \leq \lambda_2$	$\lambda_2 < p_1 \leq \mu_2$	$\mu_2 < p_1$
$0 \leq p_2 \leq \lambda_1$	$(1,1)$	$(1,0)$	$(1,0)$
$\lambda_1 < p_2 \leq \mu_1$	$(0,1)$	$(1,0)$ *and* $(0,1)$	$(1,0)$
$\mu_1 < p_2$	$(0,1)$	$(0,1)$	$(0,0)$

with $\lambda_i = (4/9)(A + x_i)$; $\mu_i = (4/9)(A + 2x_i)$.

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 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,

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

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 SC and $c < \frac{2}{5}a$, 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, $\beta_i = 1$. Two cases emerge.

- When $p_i > \frac{4}{9}(A + x_j)$, $\beta_j = 0$. 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. The discontinuity of the profit stems from the discontinuity of the earnings from the innovation sale and from the discontinuity of the produced quantity depending on β_i and on β_j through the resulting marginal costs.

Recall that $q_i = \dfrac{a - 2c_i + c_j}{3}$

When $p_i = \frac{4}{9}(A + x_j)$, the produced quantity q_i^- is given by:

$$q_i^- = \frac{A + x_i + x_j}{3},$$

and the profit is given by:

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

Now as p_i tends to $[\frac{4}{9}(A + x_j)]^+$, the produced quantity converges to

$$q_i^+ = \frac{A + 2x_i + x_j}{3},$$

and the profit converges to

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

For a best response to exist, it is necessary and sufficient to have:

$$\pi_i^+ \leq \pi_i^-,$$

equivalent to

$$3x_i < 2A + 2x_j,$$

which is true by hypothesis $c < \frac{2}{5}a$ (implying $3c < 2A$) and $x_i < c$.

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

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

The same reasoning leads to the following result. For all $p_j > \frac{4}{9}(A + 2x_i)$, a best response to such a price exists if and only if

$$3x_i < 2A + 10x_j,$$

ensured by hypothesis $c < \frac{2}{5}a$, and is given by:

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

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 in the zone $\frac{4}{9}(A + x_j) < p_i \leq \frac{4}{9}(A + 2x_j)$, there is a discontinuity of the profit on the left of the price $p_i = \frac{4}{9}(A + x_j)$.

The best response exists if and only if $\pi_i^+ < \pi_i^-$, which is equivalent to $3x_i < 2A$ and is ensured by hypothesis $c < \frac{2}{5}a$. It is given by:

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

2. If $(\beta_i=0, \beta_j=1)$ is selected in the zone $\frac{4}{9}(A+x_j) < p_i \leq \frac{4}{9}(A+2x_j)$, there is a discontinuity of the profit on the left of the price $p_i = \frac{4}{9}(A+2x_j)$. The best response exists if and only if

$$x_i(2A - 3x_i) > x_j(4A - 9p_j - 2x_i).$$

But we are in the case $p_j > \frac{4}{9}(A+x_i)$, which implies $4A - 9p_j - 2x_i < -6x_i < 0$. Hence if $3x_i < 2A$ then the best response exists and is given by

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

Considering 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 when $\gamma > 2/9$ which is implied by hypothesis $\gamma > \frac{4}{9}$.

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

(i) *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 $\gamma > 8/9$, which is implied by $\gamma > \frac{a}{c} (> \frac{8}{9}\frac{a}{c})$ and $a > c$.

After calculation, firms make the same effort $x^c = \frac{4A}{9\gamma - 8}$. The total effort is given by $X^c = 2x^c$. Inequality $X^c < c$ requires $\gamma > \frac{8}{9}\frac{a}{c}$, which is also implied by $\gamma > \frac{a}{c}$ and $a > c$. 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) *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: $\gamma > 1$, implied by $\gamma > \frac{a}{c}$ and $a > c$. First order conditions yield:

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

Inequality $X^J = x^i + x^j < c$ is ensured by $\gamma > \frac{a}{c}$.

Proof of Proposition 2.

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,

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

which has the same sign as $243\gamma^3 - 288\gamma^2 - 512\gamma + (64/3)^2$ which is negative if and only if $\gamma \in \left(\frac{8}{9}, \frac{16}{9}\right)$ 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 3.

1) Consider first the CL system.

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.

2) The results concerning the cartelized RJV are proved in Brod and Shivakumar (1997).