Cooperative R&D with endogenous technology differentiation*

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Abstract

The choice of a particular technology when there is a set of them available to firms has not appeared in the R&D literature yet. We show some examples and present a model in which firms choose their technologies from a continuum of available profiles and the resulting

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spillovers depend on the compatibility among firms' R&D technologies. Our results indicate that non-cooperating firms are interested in using the same or very similar technologies. Therefore firms seek to establish coordination mechanisms such as patent pools or Research Joint Ventures. A RJV leads to higher levels of social welfare than patent pools or the non-cooperative case.

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1 Introduction

There is vast literature dealing with the phenomenon of Research Joint Ventures (RJVs) from several points of view. One of these approaches is aimed at explaining the emergence of RJVs as a way of internalizing spillovers[1], which can allow firms to free-ride their rivals' R&D results. Since the seminal paper by d'Aspremont and Jacquemin (1988, 1990), several contributions have extended their model in different ways[2]. Building on the work

[1]Other approaches have studied the problematic of the intangible assets and incomplete contracts (see for instance Sandonis and Perez Castillo (1996)) or the international joint ventures as transmissors of know-how (see Nakamura and Xie (1998), Maniagurria and Singh (1997) or Nakamura et al. (1996)).

[2]For instance, Suzumura (1991) extends their model to n-firms, Kamien and Zang (1993) evaluate the social desiderability of a single RJV as a form of industry coordination, Poyago-Theotoky (1995) studies the endogenous number of participants in the RJV

of D'Aspremont and Jacquemin, Kamien el al. (1990) define and compare two different types of RJVs, cartelised and competing RJVs. In both cases, the degree of spillovers is perfect, laying the difference between them in the setting of the R&D investments (non-cooperative in the first case and co-operative in the second). Nevertheless, the degree of spillovers remains exogenous[3]. An especially interesting research line has aimed at introducing endogenous spillovers, therefore permitting firms to decide on the amount of knowledge that flows from one firm to another. Particularly, in Poyago-Theotoky (1999), firms decide on the degree of information about their R&D results to share, while in Kamien and Zang (2000) firms choose the specificity of their R&D[4]. In both cases, it is shown that firms are interested in minimizing the spillovers which they produce when competing on R&D, while they aim at maximizing them when they cooperate on R&D. Nonetheless, in these works each firm can reduce the flow of spillovers its own R&D originates in a completely autonomous way by reducing to zero its share of information or by choosing a totally firm-specific approach. However, when the design

and Petit and Tolwinski (1999) transform the original model to introduce dynamics and asymmetries.

[3]The authors contemplate only perfect spillovers in the case of RJVs, without allowing firms to decide about the degree of them.

[4]Another attempt to study endogeneous spillovers but in a different framework can be found Katsoulacos and Ulph (1998).

of the R&D process requires the choice of a particular technology (for example, choosing between a biotechnology or a more traditional technology) spillovers can not be completely controlled by firms. Therefore, the existing models fail to explain accurately firms' behavior in situations in which they have to choose their R&D technologies from a set of available technologies as well as the arising of certain types of cooperative agreements such as patent pools.

In our paper, we introduce an alternative way of modeling spillovers, focusing on the design of the R&D process. Our idea is the following: Each firm can choose a type of technology among a continuum of technologies in order to undertake its R&D process. The more compatible (the closer) the chosen technologies are, the higher the spillovers. All available technologies are ex-ante equally efficient[5]. Therefore, differently to the existing literature, in our model the spillovers depend on the compatibility between firms' technologies.

Our main conclusions are the following: Firms are interested in using very similar or identical R&D technologies in all the cases. Then, in order to achieve this goal, some mean of coordination is needed, like the formation of

[5]This assumption is made in order to focus on the strategic effect of the R&D (spillovers), letting the efficiency effect aside.

a RJV or the establishment of patent pools. As a general rule, RJVs choose identical technologies for partners. Moreover, from the social point of view, a RJV implies higher levels of social welfare, contrary to other mechanisms of coordination.

This paper is structured as follows: In section 2 we describe some empirical observations not fully explained by current models. In section 3 we describe our model. In section 4 we solve the non-cooperative case and in section 5 and 6 the cases of patent pools and the RJVs respectively. In section 7 we study the socially optimal choice of technologies and compare social in the cooperative and in the non-cooperative cases. We briefly summarize the main conclusions in section 8.

2 Empirical observations

A good example to motivate our point is the use of biotechnology as an alternative to traditional technologies. Biotechnology has a number of applications in many different industries, like chemistry, plastics, paper, textiles, food or agriculture (Biotechnology Industry Organization (2003)). It is used not only to produce new commodities, but also to improve the efficiency of manufacturing processes, due to the use of less energy and less inputs[6]. All in all, a firm can decide to employ its R&D in order to prepare its systems to use biotechnology or to improve some steps of its traditional manufacturing process. As a consequence, spillovers appear only if firms' R&D profiles are similar. Moreover, even among firm using biotechnology, the degree of spillovers will depend on the similarity between the chosen technologies used[7].

Another interesting issue is the arising of patent pools. Firms involved in such agreements license among them or to third parties complementary knowledge that is substantial to a particular technology, facilitating this way further research[8]. These type of cooperation has been followed carefully by antitrust authorities (see for instance U.S. Department of Justice and Federal Trade Commission (1995)). Moreover, there is an evidently increasing interest in understanding and assessing the effect of these agreements in biotechnology-related industries (see Clark et al. (2001) or OECD (2002)).

[6]For instance, while reactions using biological molecules require conditions compatible with life, therefore needing less energy than chemical reactions. Other benefits of biotechnologies are the generation less waste and byproducts.

[7]For instance, with respect to cell culture, three types of technologies are available in order to produce therapeutic proteins: plant cell culture, insect cell culture and mammalian cell culture. Another example appears in drug development, food processing or industrial manufacturing, where recombinant DNA technology can be used in conjunction with either molecular cloning or protein engineering.

[8]The first examples of this collaborations can be found in the 20s in the industries of sewing machines aircraft and radio manufacturing. More recently, in the late 90s, patent pools have been created around the DVD and MPEG2 technologies.

Patent pools seem to be a way of spreading basic R&D findings and enhance new research aimed at developing commercial applications. Therefore, these agreements allow firms to develop complementary R&D processes without investing in a cooperative way (i.e. setting projects together)[9]. However this possibility should be ruled out by firms according to the existing theories, which predict the minimization of spillovers when firms are not investing cooperatively.

3 The model

We consider an industry with two firms facing a linear inverse demand function:

$$P = a - Q \tag{1}$$

where $Q = q_1 + q_2$ is the total quantity produced and $a > Q \geq 0$.

The total costs of production of each firm depend on their initial marginal costs, A, and the effective level of R&D, X_i. Consequently, each firm's total

[9]This is similar to the RJV competition case in Kamien et al. (1993), although in their case the degree of spillovers is exogenous. We consider that in a patent pool firms can endogenously determine their degree.

costs of production are given by:

$$C_i(q_i, X_i) = [A - X_i]q_i \quad i \in \{1, 2\} \tag{2}$$

where X_i depends not only on the own investment, x_i, but also on the other firm's investment, x_j, via spillovers:

$$X_i = x_i - \beta x_j \quad \{i, j\} \in \{1, 2\} \tag{3}$$

β, the degree of spillovers is a function of the distance between the two firms' R&D technologies (L_i, L_j) rather than a firm-specific parameter. Then, β can be written as follows:

$$\beta(d) = (1 - d)S \tag{4}$$

where d is the "distance" between the two technologies, $d = |L_i - L_j|$. L_i, L_j can be chosen from a continuum of technologies ranging from 0 to 1, that is $L_i, L_j \in [0...1]$. On the other hand, S is the parameter that measures the spillover potential, which depends on exogenous aspects and ranges between

0 and 1[10]. Therefore, the closer firms' R&D technologies are (the smaller d is), the more firms can benefit from the spillovers. Hence, $\beta(d)$ ranges from 0 (when firms use the technologies which are as different as possible from each other) and S (when both firms use the same technology).

In order to ensure that marginal costs are positive, we must assume that $A > x_i + \beta x_j$. Besides, each firm's R&D costs are assumed to be quadratic, as described in (5). γ determines the profitability of the R&D (the higher γ is, the lower the profitability of the R&D):

$$CR\&D_i = \frac{1}{2}\gamma x_i^2 \quad i = \{1, 2\} \quad \gamma > 0 \tag{5}$$

All in all, i's profit function is:

$$\pi_i = [a - Q]q_i - [A - X_i]q_i - \frac{1}{2}\gamma x_i^2 \qquad \{i, j\} \in \{1, 2\} \tag{6}$$

Firms choose in the first stage the R&D technologies (L_i, L_j). In the second stage they decide on R&D investment (x_i, x_j). Finally, in the third stage, they decide on quantities (q_i, q_j). As usual, we solve this game by backward induction.

[10]In the following discussion we ommit the extreme case of $S = 0$, since it is trivial.

Since there is no collusion in any of the contemplated cases, the solution to the output stage is the same for all of them and is given by[11]:

$$q_i^* = \frac{(a-A) + (2-\beta)x_i + (2\beta - 1)x_j}{3}, \ \{i,j\} \in \{1,2\} \tag{7}$$

The reader should keep in mind that here β is a function, not a parameter. Hereinafter we use the subindexes n, pp and rjv for the fully non-cooperative case, the patent pool and the RJV respectively.

4 Competition in all stages

Inserting (7) in the profit function, first order conditions (hereinafter FOC)[12] yield:

$$x_{n,i}^* = \frac{2(a-A)(2-\beta)}{9\gamma - 2(2-\beta)(\beta+1)} \quad i \in \{1,2\} \tag{8}$$

Using $x_{n,i}^*$ as a solution to the second stage, the individual profit function can be written as follows:

$$\pi_n = \pi_{n,i} = \frac{\gamma(a-A)^2(9b\gamma - 2(2-\beta)^2)}{(9\gamma - 2(2-\beta)(\beta+1))^2} \quad i \in \{1,2\} \tag{9}$$

[11]It is easy to verify that the SOC is fulfilled.

[12]Second order conditions (SOC hereinafter) are fulfilled for any value of β if $\gamma > 8/9$.

The study of $\frac{\partial \pi_{n,i}}{\partial d}$ is sufficient for characterizing the different equilibria in the technology choice stage. In fact, firms choose L_i, L_j aiming at achieving their optimal d. This derivative is given by:

$$\frac{\partial \pi_{n,i}}{\partial d} = \frac{\partial \pi_{n,i}}{\partial \beta} \frac{\partial \beta}{\partial d} \quad i \in \{1, 2\} \tag{10}$$

where:

$$\begin{aligned} \frac{\partial \pi_{n,i}}{\partial \beta} &= \frac{4\gamma(a-A)^2[27\gamma(1-\beta) - 2(2-\beta)^3]}{(9\gamma - 2(2-\beta))(\beta+1))^3} \\ \frac{\partial \beta}{\partial d} &= -S \end{aligned}$$

Since $\frac{\partial \beta}{\partial d}$ is a constant, $\frac{\partial \pi_{n,i}}{\partial \beta}$ is enough to determine the sign of $\frac{\partial \pi_{n,i}}{\partial d}$. Thus, we implicitly find the optimal degree of spillovers, δ_n. Moreover, since the denominator in $\frac{\partial \pi_{n,i}}{\partial \beta}$ is positive (to have positive outputs) and $-4\gamma(a-A)^2$ is a constant, we can state that $\frac{\partial \pi_{n,i}}{\partial \beta} = 0$ when $[27\gamma(1-\beta) - 2(2-\beta)^3] = 0$. δ_n is obtained by solving this equation and is plotted in figure 1[13].

[Insert figure 1 near here]

[13]SOC are fulfilled.

It is interesting to note that the optimal degree of spillovers ranges from 0.9 to 1 and is increasing in γ. Firms choose their technologies in order to obtain a degree of spillovers which is as close as possible to the optimal one. Nevertheless, firms face the constraint of the potential spillovers, S. This implies that provided that the spillover potential is greater than the optimal one, firms are interested in keeping a distance between their technologies that reduces the degree of spillovers to the optimal one. On the contrary, if the spillover potential is below the optimal level, they rather choose the same technology to have a degree of spillovers that is as close as possible to the optimal one. This constitutes our first proposition:

Proposition 1 *In the non-cooperative case, firms choose L_i, L_j so that d_n is:*

i) $0, \forall\ S \leq \delta_n$

ii) $\frac{S-\delta_n}{S}, \forall S > \delta_n$

The achievement of the goals remarked in proposition 1 bears an obvious difficulty for non-cooperating firms, given the available set of technologies and the simultaneity of choices. As a consequence, firms are interested in seeking a way of coordinating their choices in order to obtain higher profits. One of such mechanisms is the formation of patent pools, allowing firms to conduct parallel complementary research afterwards. This would mean coordination in the first stage (R&D technology) but not in the second (R&D level of investment) Another mechanism of coordination is the formation of RJVs, which implies coordination in the first and in the second stage. In the following sections we analyze these two mechanisms of coordination. Moreover, in section 7 we give some insights into the welfare implications of patent pools.

Remark: *Patent pools and RJVs constitute mechanisms of coordination for firms' R&D technology decisions.*

5 The Patent Pool

In the case of patent pools, firms choose cooperatively their R&D technologies (cooperation in the first stage) but non-cooperatively their level of investments (competition in the second stage). This means that the solution to the second stage is given by (7) and thus, cooperative profits in the first stage can be written as follows:

$$\pi_{pp} = \sum_{i=1}^{2} \pi_{n,i} = 2\pi_n \tag{11}$$

It is straightforward to see that the solution to the first stage in the case of a patent pool is the same that in the non-cooperative case (i.e. the distance between technologies that allow firms to achieve a degree of spillovers as close as possible to the optimal ones, δ_n). In this case, as pointed out before, the solution to the first stage is immediately reached by firms as opposed to the non-cooperative case, in which firms face a coordination problem in the technology choice subgame.

6 The Research Joint Venture

A RJV decides cooperatively on R&D technology and on R&D investment (cooperation in the first and second stages). Cooperative profits can be written as $\pi_{rjv} = \pi_1 + \pi_2$. After inserting (7) in π_{rjv}, we have:

$$\pi_{rjv} = \frac{1}{9b} \sum_{i=1}^{2} \left\{ [(a - A) + (2 - \beta)x_i + (2\beta - 1)x_j]^2 - \frac{1}{2}\gamma x_i^2 \right\} \quad \{i, j\} \in \{1, 2\} \tag{12}$$

which is maximized at the following individual level of investment[14]:

$$x^*_{rjv,i} = \frac{2(a - A)(\beta + 1)}{9\gamma - 2(\beta + 1)^2} \quad i \in \{1, 2\} \tag{13}$$

[14]SOC holds for any value of β when $\gamma > \frac{10}{9}$.

Inserting $x^*_{rjv,i}$ in π_{rjv} and deriving with respect to d, we have:

$$\frac{\partial \pi_{rjv}}{\partial d} = \frac{\partial \pi_{rjv}}{\partial \beta}\frac{\partial \beta}{\partial d} \tag{14}$$

where:

$$\begin{aligned} \frac{\partial \pi_{rjv}}{\partial \beta} &= \frac{8\gamma(a-A)^2(\beta+1)}{(9b\gamma-2(\beta+1)^2)^2} \\ \frac{\partial \beta}{\partial d} &= -S \end{aligned}$$

It is obvious that $\frac{\partial \pi_{rjv}}{\partial d}$ is always negative. As a consequence, the solution to this stage implies that $d = |L_i - L_j| = 0$. The following proposition summarizes our main findings in these sections:

Proposition 2 *The RJV chooses identical technologies for the two firms while a patent pool firms choose L_i, L_j so that d is:*

i) $0, \forall\ S \leq \delta_n$

ii) $\frac{S-\delta_n}{S}, \forall S > \delta_n$

7 Social Welfare

In this section we analyze social welfare. Social welfare (SW), that is the sum of consumer surplus (CS) and producer surplus (PS), is calculated by introducing the solutions to the output and R&D investments stages in equilibrium as functions of the distance between technologies. In table 1, the reader can find the values of CS, PS and SW for both the case with cooperative investment (RJVs) and non-cooperative investment (competition in all the stages and patent pools)[15]. We use the subindex nci to refer to the regimes with non-cooperative investments.

	Non-Cooperative Investment	Research Joint Venture
CS	$\frac{18\gamma^2(a-A)^2}{(9\gamma-2(2-\beta)(\beta+1))^2}$	$\frac{18\gamma^2(a-A)^2}{(9\gamma-2(\beta+1)^2)^2}$
PS	$\frac{2\gamma(a-A)^2(9b\gamma-2(2-\beta)^2)}{(9\gamma-2(2-\beta)(\beta+1))^2}$	$\frac{2\gamma(a-A)^2}{9\gamma-2(\beta+1)^2}$
SW	$\frac{4\gamma(a-A)^2(9b\gamma-(2-\beta)^2)}{(9\gamma-2(2-\beta)(\beta+1))^2}$	$\frac{4\gamma(a-A)^2(9\gamma-(\beta+1)^2)}{(9\gamma-2(\beta+1)^2)^2}$

Table 1: Values for CS, PS and SW.

[15]Given that we are interested in deriving the socially optimal distance between technologies, we need to express SW as a function of d. It is obvious that this expression is the same in the fully non-cooperative case than in the patent pool case (since the two regimes provide the same level of investment). Therefore we represent both regimes under the same label ("non-cooperative investment").

The socially optimal distance between firms' technologies (d^o) is the distance that maximizes social welfare. In the case of non-cooperative investment (competition in all the stages and patent pools), the derivative of the social welfare (SW_{nci}) with respect to d is the following:

$$\frac{\partial SW_{nci}}{\partial d} = \frac{\partial SW_{nci}}{\partial \beta}\frac{\partial \beta}{\partial d} \tag{15}$$

where:

$$\begin{aligned} \frac{\partial SW_{nci}}{\partial \beta} &= \frac{8(a-c)^2\gamma[9\gamma(4+5\beta)-2(2-\beta)^3]}{((9\gamma-2(2-\beta)(\beta+1))^3} \\ \frac{\partial \beta}{\partial d} &= -S \end{aligned}$$

As before, the study of $\frac{\partial SW_{nci}}{\partial \beta}$ is enough to characterize d^o_{nci}. This distance will be the one that facilitates the degree of spillovers which is the closest to the socially optimal ones, δ^o_{nci}. It is easy to see that $\frac{\partial SW_{nci}}{\partial \beta} = 0$ if $[9\gamma(4+5\beta)-2(2-\beta)^3] = 0$. δ^o_{nci} is determined by solving this equation[16] and plotted in figure 2[17].

[Insert figure 2 near here]

[16] Whenever $x^*_{nci,i}$ is positive, the denominator in $\frac{\partial SW_{nci}}{\partial \beta}$ is positive too.
[17] SOC are fulfilled.

Therefore, there is an interior solution for d^o_{nci} for each of the combinations of γ and S: If $S > \delta^o_{nci}$, d^o_{nci} is a value such that $\beta = \delta^o_{nci}$, that is $d^o_{nci} = \frac{S - \delta^o_{nci}}{S}$. On the other hand, if $S \leq \delta^o_{nci}$, then $d^o_{nci} = 0$.

For the case of a RJV, we have:

$$\frac{\partial SW_{rjv}}{\partial d} = \frac{\partial SW_{rjv}}{\partial \beta} \cdot \frac{\partial \beta}{\partial d} \tag{16}$$

where

$$\frac{\partial SW_{rjv}}{\partial \beta} = \frac{4(a-A)^2\gamma(\beta+1)[27b\gamma - 2(\beta+1)^2]}{(9b\gamma - 2(\beta+1)^2)^3}$$
$$\frac{\partial \beta}{\partial d} = -S$$

Given that the denominator and the numerator in $\frac{\partial SW_{rjv}}{\partial \beta}$ are positive[18], the socially optimal degree of spillovers, δ^o_{rjv}, is equal to 1. As a consequence, $d^o_{rjv} = 0$.

Furthermore, it is interesting to study which of the cases (non-cooperative or cooperative) is superior from the social welfare point of view. We find that a RJV leads to higher social welfare levels than the case of non-cooperative

[18] The denominator is positive provided that $x^*_{rjv,i}$ is positive.

investments. That is, for each γ, SW_{rjv} is always higher than SW_{nci}. The proof follows: The maximum value of SW_{nci} is achieved with $\beta = \delta^o_{nci}$, which implies values for S between δ^o_{nci} and 1. On the other hand, within this range of S ($S \in [\delta^o_{nci}, 1]$), the minimum value of SW_{rjv} will be achieved with $S = \delta^o_{rjv}$, since in equilibrium in the cooperative case $d = 0$ and SW_{rjv} is increasing across the spillovers. It can be seen from table 2[19] that the maximum value of SW_{nci} is always below the minimum of SW_{rjv} for any value of γ, although the difference between the two decreases in γ.

γ	$\frac{SW_{nci}}{4(a-A)^2\gamma}$	$\frac{SW_{rjv}}{4(a-A)^2\gamma}$
1.25	0.205038	0.295726
2	0.0885465	0.10667
5	0.0263233	0.02801
10	0.0120637	0.0124249
15	0.00782093	0.0079355
100	0.00112006	0.001123222

Table 2: Minimum SW_{rjv} and maximum SW_{nci}.

[19]Note that SW is the product of the values in the table times $4(a - A)^2\gamma$.

Finally, it is interesting to remark that patent pools can damage social welfare when the spillover potential, S, is very high. For instance, when $\gamma_i = 1.25$, if $S = 1$, d^o_{nci} is 0.273420, although firms in a patent pool would choose $d = 0.0732642$. Then if firms coordinate their choices of technologies but not their level of investment, as in the case of patent pools, the result might be socially worse than in the uncoordinated case. Thus, policy-makers must consider this potential damage when they analyze cooperative R&D.

Remark: *When there is high potential spillover potential, coordination between firms in the choice of technologies can reduce social welfare if it is not accompanied by coordination in investment levels.*

Finally, the results of this section are reported in the following proposition:

Proposition 3 *The socially optimal distance between technologies is:*

For the case of non-cooperative investments (competition in all the stages and patent pools): $d^o_n =$

i) $0, \forall\ S \leq \delta^o_{nci}$

ii) $\frac{S-\delta^o_{nci}}{S}, \forall S > \delta^o_{nci}$

For the case of the RJV : $d^o_{rjv} = 0$.

For all the values of γ, social welfare is always with RJVs than in the case of non-cooperative investments.

8 Conclusions

In this paper we have introduced a novel way of modeling R&D spillovers, the emissions of which depend on the choices on R&D technologies made by all firms in the market. The more similar the technologies are, the higher the degree of spillovers. This situation takes place when a firm can choose between different alternatives (for instance, choosing between traditional technologies or new technologies). We find that even in the fully non-cooperative case firms are interested in using very similar R&D technologies in order to obtain a very high degree of spillovers. Considering the evident difficulty in achieving these goals, several mechanisms of coordination can arise, like the formation of patent pools or RJVs. Furthermore, a RJV uses the same technology in both firms.

With reference to social welfare, the socially optimal distance between technologies is generally zero. Exceptions to this rule appear when firms are not cooperating on investments and spillover potential is very high. In those cases, it is socially better that firms use very similar technologies rather than identical ones. Moreover, social welfare is higher in the case of a RJV than in the cases of non-cooperative investments.

All these facts illustrate an alternative motivation for the formation of patent pools and RJVs, as a way of coordinating the decisions of firms concerning their R&D profiles. Furthermore, the RJV implements the solutions that provide the highest levels of social welfare. Alternative ways of coordination, such as patent pools, which do not imply coordination in the levels of investment might damage social welfare when the spillover potential is very high.

References

[1] d´Aspremont, C. and A. Jacquemin, 1988, Cooperative and Noncooperative R&D in Duopoly with Spillovers, *American Economic Review*, 16, pp.1133-1137.

[2] d´Aspremont, C. and A. Jacquemin, 1990, Cooperative and Noncooperative R&D in Duopoly With Spillovers: Erratum, *American Economic Review*, 80, pp.641-642.

[3] Biotechnology Industry Organisation, 2003, *Editors' and Readers' Guide to Biotechnology 2003-2004*, Biotechnology Industry Organisation, Washington, US. Available at: www.bio.org

[4] Clark, J., J. Piccolo, B. Stanton, 2001, Patent Pools: A Solution to the Problem of Access in Biotechnology Patents?, Unpublished USTPO paper.

[5] Kamien, M.I. E. Muller and I. Zang, 1992, Research Joint Ventures and R&D Cartels, *American Economic Review*, 82, pp.1293-1306.

[6] Kamien, M.I.and I. Zang, 1993, Competing Research Joint Ventures, *Journal of Economics and Management Strategy*, 2, pp. 23-40.

[7] Kamien, M.I.and I. Zang, 2000, Meet Me Halfway: RJV and Absorptive Capacity, *International Journal of Industrial Organization*, 18, pp.995-1012.

[8] Katsoulacos, Y. and D. Ulph, 1998, Endogenous Spillovers and the Performance of RJV, *Journal of Industrial Economics*, 46, pp.333-357.

[9] Maniagurria, M.and N. Singh, 1997, Foreign Technology, Spillovers and R&D Policies, *International Economic Review*, 38, pp.405-430.

[10] Nakamura, M., J. Myles Shaver and B. Yeung, 1996, An Empirical Investigation of JV Dynamics: Evidence From US-Japan JV, *International Journal of Industrial Organization*, pp.521-541.

[11] Nakamura, M.and J. Xie, 1998, Non-Verifiability, Noncontractibility and Ownership Determination Models in FDI, with an Application to Foreign Operations in Japan, *International Journal of Industrial Organization*, 16, pp.571-599.

[12] OECD, 2002, *Genetic Inventions, Intellectual Property Rights and Licensing Practices. Evidence and Policies*, OECD Publications, Paris, France.

[13] Perez-Castillo, J.D. and J. Sandonis, 1996, Disclosure of Know-How in RJV, *International Journal of Industrial Organization*; 15, pp.51-75.

[14] Petit, M^{a}L. and B. Tolwinski, 1999, R&D Cooperation or Competition, *European Economic Review*, 43, 2, pp.185-208.

[15] Poyago-Theotoky, J., 1995, Equilibrium and Optimal Size of a RJV in an Oligopoly With Spillovers, *Journal of Industrial Economics*; 43, pp.209-226.

[16] Poyago-Theotoky, J., 1999, A Note on Endogenous Spillovers in a Non-Tournament R&D Duopoly, *Review of Industrial Organization*, 15, pp.253-262.

[17] Suzumura K., 1992, Cooperative and Noncooperative R&D in an Oligopoly with Spillovers, *American Economic Review*, 82, pp.1307-1320.

[18] U.S. Department of Justice and Federal Trade Commission, 1995, Antitrust Guidelines for Licensing of Intellectual Property, reprinted at http://www.usdoj.gov/atr/public/guidelines/ipguide.htm

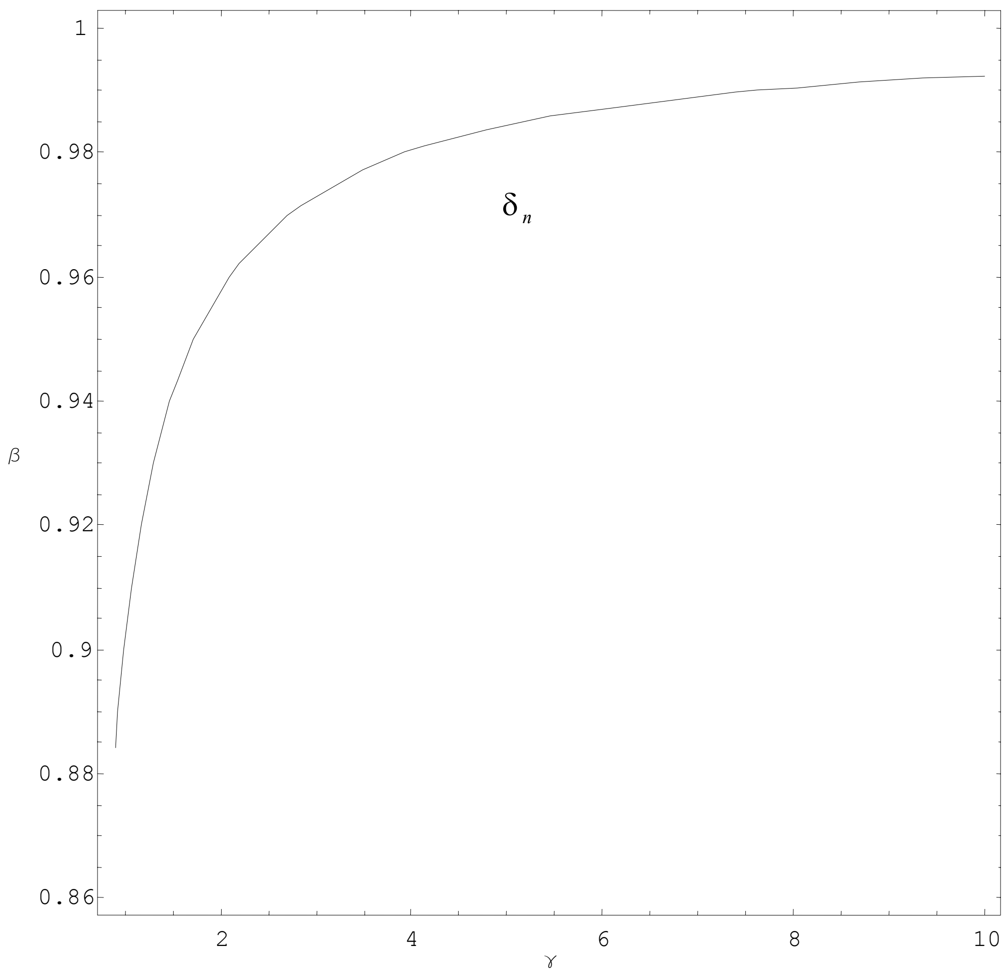

Figure 1: Optimal degree of spillovers. Competition in all the stages.

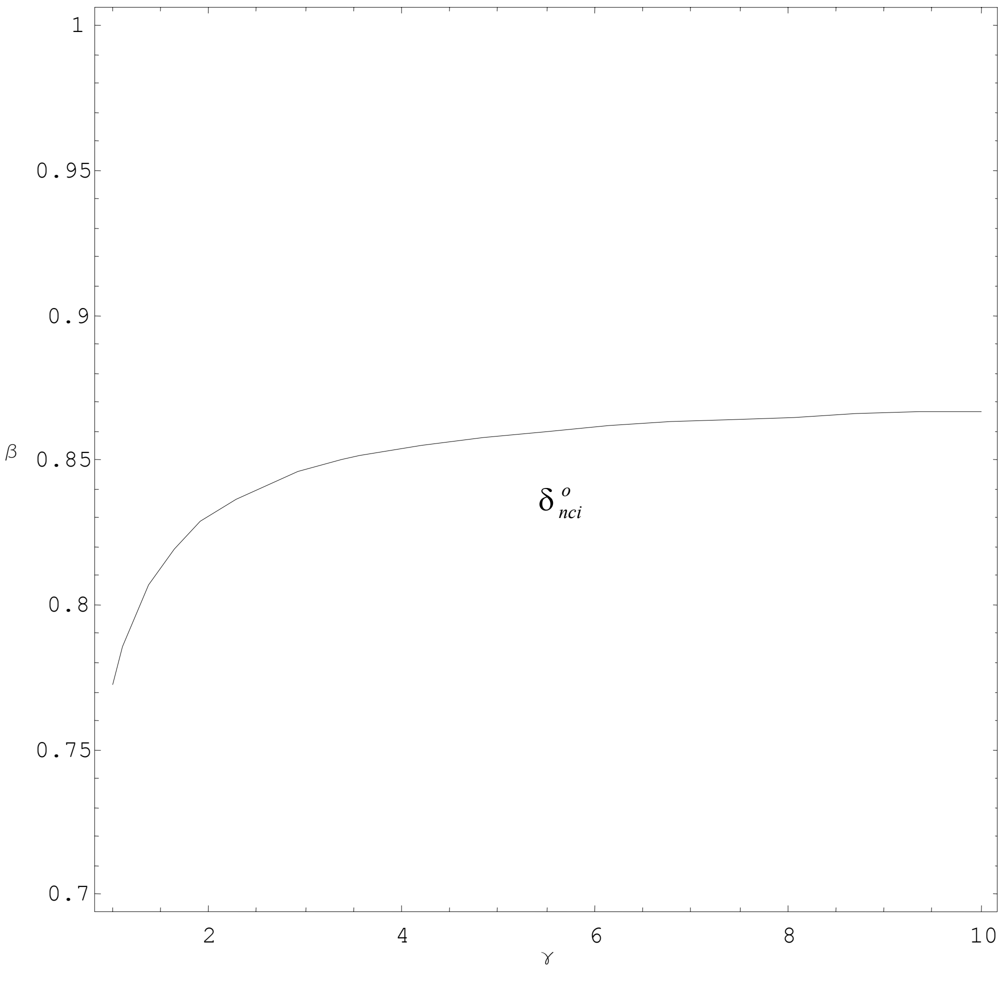

Figure 2: Socially optimal degree of spillovers. Non-cooperative investments.