

## FIRMS' LOCATION AND R&D COOPERATION IN AN OLIGOPOLY WITH SPILLOVERS

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### ABSTRACT:

This paper aims at explaining if firms's decision about location revises when firms cooperate or compete in R&D. For that purpose, it is proposed a three stage game amongst three firms where each firm decides about location, R&D and output. Firms' decision about location determines a R&D spillover, which is inversely related to the distance between firms. R&D output is assumed to be cost reducing and exhibit diminishing returns. Cooperation is only allowed in the R&D stage. Our results allow us to conclude that there is a positive relationship between R&D output equilibrium and the distance between firms when firms act independently. When firms cooperate in R&D, the R&D output for a cooperating firm increases with the degree of information sharing between them, as well as with a reduction of the distance between cooperating firms. Firms' decision about location is also affected by R&D activities: if R&D activities run independently, the clustering of firms only occurs for a convex spillover function; if R&D activities run cooperatively, clustering is always observed if there is an increased information sharing between firms.

**Keywords:** Location; R&D cooperation; R&D spillovers

JEL classification: R30, 031, L13

### RESUMO:

Neste artigo pretende-se avaliar se as decisões das empresas quanto à sua localização se alteram quando estas cooperam ou concorrem em Investigação & Desenvolvimento (I&D). Para tal, é desenvolvido um jogo com três estágios e três empresas em que cada uma decide sobre a localização, I&D e produção. A decisão sobre a localização determina o spillover de I&D, que está inversamente relacionado com a distância entre as empresas. Assume-se que o output de I&D apresenta rendimentos decrescentes e reduz o custo unitário de produção. Admite-se ainda que as empresas podem cooperar entre si, exclusivamente na decisão de I&D. Da resolução do modelo é possível concluir que existe uma relação positiva entre o output de I&D de equilíbrio e a distância entre as empresas quando estas concorrem em I&D. Quando as empresas cooperam em I&D, o output de I&D de equilíbrio aumenta com o grau de partilha de informação entre as empresas bem como com uma redução da distância entre elas. A decisão das empresas quanto à localização é também afectada pela forma como as actividades de I&D são desenvolvidas: se as empresas concorrem em I&D, então elas aglomeram-se se o spillover de I&D for convexo na distância; se as empresas cooperarem em I&D, então elas aglomeram-se desde que a partilha de informação entre as empresas aumente.

**Palavras-chave:** Localização; Cooperação em I&D; Spillovers de I&D



## 1. INTRODUCTIN

Ever since Marshall (1920 [1890]), it is widely accepted that firms gain from their joint location because they benefit from economies on the transport of goods, people and ideas. However, if firms are rivals in the product market, geographical proximity makes competition between them fiercer and this acts as a centrifugal force. Obviously, the outcome of both centripetal and centrifugal forces depends on their relative strengths. Additionally, even if being strong competitors in the product market, firms frequently adopt a cooperative behavior in what concerns, for instance, Research and Development (R&D) activities (e.g. d'Aspremont and Jacquemin (1988) and Kamien et al. (1992)). This is generally justified by the public good nature of R&D activities, as firms cannot fully appropriate the returns of their R&D investments, due to the existence of R&D spillovers<sup>(1)</sup>.

The purpose of this research is to evaluate whether firms' decision about location revises if firms cooperate or compete in R&D. For that end, we will develop a strategic interaction model that merges the topic of firms' location within a R&D cooperation/competition game.

Spatial competition models typically assume that firms interact strategically with respect to location, as they encompass oligopolistic rivalry (Fujita and Thisse (1996)). This approach finds its roots in the seminal work of Hotelling (1929), according to whom competition for market areas is a centripetal force that would lead firms to congregate, a result known in the literature as the *Principle of Minimum Differentiation*. In a subsequent paper, d'Aspremont

et al. (1979) demonstrated that the *Principle of Minimum Differentiation* was invalid, and since then, a considerable effort has been devoted to restoring the validity of that principle. For example, by introducing enough heterogeneity in both consumers and/or firms (e.g. Palma et al. (1985)), by considering explicitly price collusion (e.g. Friedman and Thisse (1993)) or by recurring to search models (e.g. Schultz and Stahl (1996)).

Recently, spatial competition models have been extended to capture the topic of firms' location under knowledge spillovers and market competition. In general, it is proposed a partial equilibrium model to explain the formation of regional clusters (e.g. Belleflamme et al. (2000) and Soubeiran and Weber (2002)) or the dynamic of a regional system (Soubeiran and Thisse (1999)), focusing on the explanation of the diversity of equilibrium spatial systems under technological externalities.

Nevertheless, few attempts were made to merge R&D cooperation into location models. Mai and Peng (1999) presented a very simple model of spatial competition à la Hotelling that introduces an element of tacit cooperation through information exchanges between firms that are distance sensitive. They have shown that equilibrium location can be achieved in a wide range from minimum to maximum differentiation depending upon the relative strength of the cooperation effect over competitive effect. Additionally, they concluded that the larger the externality between firms, the less will be the location differentiation between them. Long and Soubeiran (1998) conditioned R&D spillovers to firms' decision about location and investigated how firms' decision about location is affected by the shape

<sup>1</sup> R&D cooperation is usually justified by the need to internalize spillovers, to capture of economies of scale or complementarities in R&D, as well as potential beneficial effects coming from firms' coordination of research activities and the diffusion of know-how and R&D output among cooperating firms. Against these advantages is the fear that the participating firms may free-ride on other firms, as well as the possibility of reduction of competition in the product market, which would result in a welfare loss.

of the spillover function and by the decision of firms to cooperate or not in R&D. They concluded that the only Nash equilibrium for a duopoly with symmetric locations is the agglomeration one, while for an oligopoly with asymmetric locations, agglomeration is only guaranteed if the spillover effect is convex in distance. Baranes and Tropeano (2000) intended to explain why spatial proximity makes knowledge sharing between firms easier in the context of clusters of competing firms. They developed a model where firms must decide about location, researchers' wages, research's team formation and prices. Information asymmetry arises, as firms are unable to observe the researcher's effort or to verify the innovation size. Several equilibria emerge, depending upon both the transport costs and the research spillovers.

Research on R&D cooperation is typically apart from spatial competition models. Usually, cooperative R&D is identified with research collaboration and it is often investigated in the context of two stage oligopoly models in which firms make their R&D decisions in a first pre-competitive stage and their quantity/price setting in a second stage. The most influential article on R&D cooperation is due to d'Aspremont and Jacquemin (1988), who assumed that there are spillovers in R&D output and concluded that for a large spillover coefficient, the collusive level of R&D was higher than the non-cooperative one. Another prominent work is Kamien et al. (1992), which proposed spillovers in R&D expenditures and allowed for different R&D organization models that may involve R&D expenditures cartelization and/or full information sharing. They have shown that Research Joint Venture (RJV) competition was the least desirable model as it yields higher product prices, while RJV canalization was the most desirable, because it provides the highest consumer plus producer surplus<sup>(2)</sup>.

Since these starting articles, a lot of scientific models emerged around the topic of R&D cooperation, providing numerous extensions to those pioneering articles. Particularly relevant for our research are the extensions to a oligopolistic scenario with industry wide agreements (Suzumura (1992)) or with cooperation among a subset of firms (Poyago-Theotoky (1995)). Additionally, we found quite interesting some papers that conditioned the R&D spillovers to a strategic decision made by firms (Katsoulacos and Ulph (1998), Poyago-Theotoky (1999) and Amir et al. (2003)), besides other articles that introduce the concept of firms' absorptive capacity (Kamien and Zang (2000)), that consider both inter and intra industry spillovers (Steurs (1995)) or one-way spillovers (Amir and Wooders (2000)) and other asymmetries in R&D spillovers (Vonortas (1994)).

The purpose of this research is to explain if firms' decision about location revises whether firms cooperate or compete in R&D, in the context of competing firms and knowledge spillovers. For that purpose, we developed a three stage game amongst three firms where firms decide about location and R&D expenditures and after that engage in Cournot competition. Firms' decision about location determines a R&D spillover, which is inversely related to the physical distance between firms. R&D output is assumed to be cost reducing and exhibit diminishing returns. Cooperation is allowed in the R&D stage through R&D cartelization and an increase of the information sharing between cooperating firms .

The model we developed is related to Long and Soubeyran (1998), but we extended it by introducing an intermediate stage where firms decide about R&D output. This allows us to evaluate the sensitivity of R&D output to the distance between firms, as well as to consider the strategic R&D decision either

<sup>2</sup> Amir (2000) presented an analytical comparison of both models.

if firms run R&D independently or in cooperation. Additionally, Long and Soubeyran evaluated how firms' decisions about location were affected by their decisions on R&D cooperation but assuming that firms cooperate in their location decisions if they collusively decide about R&D expenditures. Unlikely, we study the problem of an entrant firm choosing its location among two incumbent firms in a scenario of independent or R&D cooperation, whilst cooperation is only allowed in the R&D game.

The remainder of the paper is organized as follows. We start with a description of the model. Next we develop it under two scenarios-R&D competition and R&D cooperation-and investigate how firms' decision about location and R&D cooperation were related. The final section concludes the paper.

## 2. THE MODEL

There are  $N$  identical firms that produce a homogeneous output, whose inverse demand function is given by:

$$P = a - bQ$$

Where  $Q$  is total output

$$(Q = \sum_{t=1}^N q_t) \quad (a, b > 0 \text{ e } Q \leq a/b).$$

Each firm chooses its location in an open convex space  $M$ . As a result of location decisions, firms will benefit from a R&D spillover,  $\beta(d_{rs})$ , which is inversely related with  $d_{rs}$  where  $d_{rs} = d(r,s)$  is a measure of the physical distance between firms  $r$  and  $s$  ( $r \neq s$ ).

The spillover function is such that

$0 \leq \beta(d_{rs}) \leq 1$  e  $\beta'(d_{rs}) < 0$  that is,  $\beta(d_{rs})$  is a positive and decreasing function of the distance  $d_{rs}$  between firms. For convenience, we will simply denote it

$$\beta_{rs} = \beta(d_{rs}).$$

As it is typical in R&D cooperation models (e.g. d' Aspremont and Jacquemin (1988)), we will assume that R&D output is cost reducing through an additive formulation, that is:

$$c_r = c - x_r - \sum_{t \neq r}^N \beta(d_{rt}) x_t$$

where  $c$  accounts for stand alone marginal costs (identical to all firms) ( $0 < c < a$ ) and  $x_r$ , measures firm  $r$ 's R&D output. Additionally, it will be assumed that there are diminishing returns to R&D expenditures, that is,  $C'(x_r) > 0$  e  $C''(x_r) > 0$ . In order to ensure positive quantities, we will impose

$$x_r + \sum_{t \neq r}^N \beta(d_{rt}) x_t \leq c.$$

The profit of firm  $r$  is then given by:

$$\pi_r = (P - c_r) q_r - C(x_r)$$

As we focus on the physical distance between firms and its impact on R&D activities through a spillover function, we will neglect transport costs to the product market.

It is proposed a three stage game, where firms decide about location, R&D and production. The timing is the following:

1<sup>st</sup>) Firms choose its location in space  $M$ , from which results  $d_{rt} \in \mathbb{R}^+$  e  $\beta_{rt} \in [0, 1]$ ;

2<sup>nd</sup>) Firms simultaneously choose the level of R&D output,  $x_r \in \mathbb{R}^+$ , independently or under cooperation;

3<sup>rd</sup>) Firms simultaneously choose the level of output,  $q_r \in \mathbb{R}^+$  through Cournot competition.

For our purposes, we will assume  $N=3$  ( $r = i, j, k$ ), whilst our results remain valid for a larger number of firms. Additionally, and as in d' Aspremont and Jacquemin (1988), we will consider a specific functional form for the R&D cost function,  $C(x_r) = 0.5\gamma x_r^2$ .

The game will be solved by backward induction to ensure subgame perfectness and we will consider two alternative scenarios: *Independent R&D*, where firms choose its R&D output independently, and *R&D Cooperation*, where a subset of firms cooperate and coordinate R&D output in order to maximize joint profits.

## 2.1 INDEPENDENT R&D

Firm  $i$ 's profit function is given by:

$$\pi_i(q, x, d) = (a - bQ - c_i) q_i - 0.5\gamma x_i^2$$

where  $q = (q_i, q_j, q_k)$ ,  $x = (x_i, x_j, x_k)$ ,

$d = (d_{ij}, d_{ik}, d_{jk})$  e  $c_i = c - x_i - \beta_{ij}x_j - \beta_{ik}x_k$ .

From the Cournot game it is straightforward to determine output equilibrium (see the equation 1) and second-stage profit function (see the equation 2).

After taking first-order condition and assuming that firms make a symmetric choice (that is,  $x_i = x_j = x_k = x$ ), we may determine R&D output equilibrium <sup>(4)(5)</sup> (see the equation 3) where  $8b\gamma - (3 - \beta_{ij} - \beta_{ik})(2\beta_{ij} + 2\beta_{ik} - 2\beta_{jk} + 1) > 0$

in order to ensure an interior and positive solution for R&D output and quantities <sup>(6)</sup>.

**Proposition 1** When firms run R&D independently, there is a positive relationship between R&D output equilibrium and the physical distance between firms.

**Proof.** Taking partial differentiation of R&D output to the physical distance between firms we get:

$$\frac{\partial x^*}{\partial \beta_{ij}} \frac{\partial \beta_{ij}}{\partial d_{ij}} = \frac{-(a-c)(8b\gamma - 2(3 - \beta_{ij} - \beta_{ik}))^2}{(8b\gamma - (3 - \beta_{ij} - \beta_{ik})(1 + 2\beta_{ij} + 2\beta_{ik} - 2\beta_{jk}))^2} \beta'_{ij}$$

$$\frac{\partial x^*}{\partial \beta_{ik}} \frac{\partial \beta_{ik}}{\partial d_{ik}} = \frac{-(a-c)(8b\gamma - 2(3 - \beta_{ij} - \beta_{ik}))^2}{(8b\gamma - (3 - \beta_{ij} - \beta_{ik})(1 + 2\beta_{ij} + 2\beta_{ik} - 2\beta_{jk}))^2} \beta'_{ik}$$

Given our assumptions, we have

$$\beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1] \text{ and } \beta'_{ij} < 0, \beta'_{ik} < 0.$$

If we assume  $8b\gamma - 2(3 - \beta_{ij} - \beta_{ik})^2 > 0$  <sup>(7)</sup>, then we will have  $\partial x^*/\partial \beta_{ij} < 0$  e  $\partial x^*/\partial \beta_{ik} < 0$ . As a result,  $(\partial x^*/\partial \beta_{ij}) \beta'_{ij} > 0$  e  $(\partial x^*/\partial \beta_{ik}) \beta'_{ik} > 0$ .

### EQUATION 1

$$q^* = \frac{a - c + (3 - \beta_{ij} - \beta_{ik}) x_i + (3\beta_{ij} - \beta_{jk} - 1) x_j + (3\beta_{ik} - \beta_{jk} - 1) x_k}{4b}$$

### EQUATION 2

$$\pi_i(q^*, x, d) = \frac{(a - c + (3 - \beta_{ij} - \beta_{ik}) x_i + (3\beta_{ij} - \beta_{jk} - 1) x_j + (3\beta_{ik} - \beta_{jk} - 1) x_k)^2}{16b} - 0.5\gamma x_i^2$$

### EQUATION 3

$$x^* = \frac{(3 - \beta_{ij} - \beta_{ik})(a - c)}{8b\gamma - (3 - \beta_{ij} - \beta_{ik})(2\beta_{ij} + 2\beta_{ik} - 2\beta_{jk} + 1)}$$

<sup>4</sup> Second order condition implies  $b\gamma > 9/8$ ,  $\forall \beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1]$ .

<sup>5</sup> According to Henriques (1990), it is necessary to set proper parameter restrictions for the existence and stability of equilibrium:  $b\gamma > 15/8$ ,  $\forall \beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1]$ .

<sup>6</sup> An interior solution is guaranteed for by  $b\gamma > 5/8$ ,  $\forall \beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1]$ .

<sup>7</sup> This assumption only requires that  $b\gamma > 2.25$ ,  $\forall \beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1]$ .

This result accords with intuition: as the distance between firms increases, firms will perform a higher R&D output because a lower proportion of its R&D results will flow over the other firms. Two effects give reason to this result. On one side, the inverse relationship between firms' distance and R&D spillovers,  $\partial\beta/\partial d < 0$ , which derives from our assumptions and can be ascertained for instance, in Mai and Peng (1999) and Long and Soubeyran (1998). On the other side, the well documented negative effect between R&D spillovers and R&D output,  $\partial x/\partial\beta < 0$ . In fact, several authors concluded that when firms run R&D independently, its R&D output (or expenditure) is higher for a lower R&D spillover. d' Aspremont and Jacquemin (1988) concluded that, for the non-cooperative solution, R&D output decreases with R&D spillover. In an extensive survey on the topic of spillovers and R&D cooperation, Bondt (1997) concluded that with low spillovers, Nash rivals are supposed to invest more in R&D than with high spillovers. Also, he concluded that positive and symmetric intra-industry spillovers tend to reduce the incentive for non-cooperative investments in R&D. Poyago Theotoky (1995) demonstrated that, if firms run R&D independently, the incentive to carry out R&D is greatly reduced in the presence of high R&D spillovers because the benefits of R&D are common to all firms.

First-stage profit function is defined in equation 4).

In the location game, we will focus on firms' best location choice for different R&D *spillover* shapes, whilst spatial competition is leaved apart. For that purpose, we will consider the problem of a single firm  $i$ , choosing its location in a convex space where firms  $j$  and  $k$  were located. So, firm  $i$  must choose  $d_{ij}$  and  $d_{ik}$ , given  $d_{jk}$ .

Formally, given other firms' location, firm  $i$  must choose its location subject to the following triangle inequality:

$$d_{ij} + d_{ik} \geq d_{jk}$$

Additionally, and as  $d_{jk} \geq 0$ , we must have:

$$d_{ik} \geq 0$$

$$d_{ij} \geq 0$$

Without loss of generality, we will impose:

$$d_{ik} - d_{ij} \geq 0$$

If we assume  $d_{ik} - d_{ij} \geq 0$  and  $d_{ij} \geq 0$ , then  $d_{ik} \geq 0$  is always true, and so, this constraint may be avoided.

#### EQUATION 4

$$\pi_i(q^*, x^*, d) = \frac{0.5\gamma(a - c)^2 \left(8b\gamma - (3 - \beta_{ij} - \beta_{ik})^2\right)}{(8b\gamma - (3 - \beta_{ij} - \beta_{ik}) (1 + 2\beta_{ij} + 2\beta_{ik} - 2\beta_{jk}))^2}$$

Firm  $i$  will then solve the following problem:

$$\max_{d_{ij}, d_{ik} \in M} \pi_i(q^*, x^*, d)$$

$$s.t. \quad g^1(d) = d_{ij} + d_{ik} - d_{jk} \geq 0$$

$$g^2(d) = d_{ik} - d_{ij} \geq 0$$

$$g^3(d) = d_{ij} \geq 0$$

The Lagrangean function corresponding to the maximization problem is then defined by:

$$L(d, \lambda) = \pi_i(q^*, x^*, d) + \\ + \lambda_1(d_{ij} + d_{ik} - d_{jk}) + \lambda_2(d_{ik} - d_{ij}) + \lambda_3(d_{ij})$$

where  $\lambda = (\lambda_1, \lambda_2, \lambda_3)$  e  $d = (d_{ij}, d_{ik}, d_{jk})$ .

Through Kuhn-Tucker conditions, we have:

$$\frac{\partial L(d, \lambda)}{\partial d_{ij}} = \frac{\partial \pi_i^*}{\partial \beta_{ij}} \frac{\partial \beta_{ij}}{\partial d_{ij}} + \lambda_1 - \lambda_2 + \lambda_3 = 0 \quad (5)$$

$$\frac{\partial L(d, \lambda)}{\partial d_{ik}} = \frac{\partial \pi_i^*}{\partial \beta_{ik}} \frac{\partial \beta_{ik}}{\partial d_{ik}} + \lambda_1 + \lambda_2 = 0 \quad (6)$$

with  $\lambda_1 \geq 0, \lambda_2 \geq 0, \lambda_3 \geq 0, g^1(d) \geq 0, g^2(d) \geq 0, g^3(d) \geq 0$  e  $\lambda_1(d_{ij} + d_{ik} - d_{jk}) = 0, \lambda_2(d_{ik} - d_{ij}) = 0, \lambda_3(d_{ij}) = 0$ .

From equation (4) we obtain equation (7) and (8).

Given our assumptions, we have

$$\beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1] \text{ and } \beta'_{ij} < 0, \beta'_{ik} < 0.$$

Additionally, if we assume

$$8b\gamma(4 - 2.5\beta_{ij} - 2.5\beta_{ik} + \beta_{jk}) - \\ - (3 - \beta_{ij} - \beta_{ik})^3 > 0 \quad (8), \text{ then } (\partial \pi_i^* / \partial \beta_{ij}) \beta'_{ij} < 0 \\ \text{and } (\partial \pi_i^* / \partial \beta_{ik}) \beta'_{ik} < 0 \quad (9).$$

Allowing for different location choices, we will evaluate the best location choice for the entrant firm, assuming first, that the incumbent firms were agglomerated and second, that the incumbent firms were dispersed. We may then formulate the following propositions:

**Proposition 2** If two firms were close located and no cooperation is allowed, then the best location choice for an entrant firm is agglomeration.

**Proof.** Assume  $d_{jk} = 0$ , that is, firms  $j$  and  $k$  are close located in space  $M$ . Under this scenario, we may have agglomeration ( $d_{ij} = d_{ik} = 0$ ) or dispersion ( $d_{ij} = d_{ik} > 0$ ). For  $d_{ij} = d_{ik}$ , then  $(\partial \pi_i^* / \partial \beta_{ij}) \beta'_{ij} = (\partial \pi_i^* / \partial \beta_{ik}) \beta'_{ik} < 0$  and so, firm  $i$  will choose to be as close as possible to incumbent firms.

Note that, as  $d_{jk} = 0$  e  $\beta'_{ij} = \beta'_{ik} < 0$ , the entrant firm will always prefer to reduce its distance to both firms in order to benefit from maximal spillovers. But what will happen if the incumbent firms were dispersed?

**Proposition 3** If two firms were dispersed in a convex space  $M$  and no cooperation is allowed, then the best location choice for an entrant firm is in the straight line between incumbent firms that is:

$$d_{ij} + d_{ik} = d_{jk}.$$

**Proof.** Assume false, that is, suppose that firm  $i$  chooses to locate in the vertices of a triangle. In this case,  $g^1(d)$  is non-binding and  $\lambda_1 = 0$ . Then, we may have one of the following situations: either (a)  $d_{ik} = d_{ij}$  or (b)  $d_{ik} > d_{ij}$ .

<sup>8</sup> We have  $8b\gamma(4 - 2.5\beta_{ij} - 2.5\beta_{ik} + \beta_{jk}) - (3 - \beta_{ij} - \beta_{ik})^3 > 0$  for  $\beta_{ij} + \beta_{ik} < 1.570$ , which accords with Amir (2000), which imposed that for the consistency of the additive nature of the spillover process, we must have  $\beta < \beta^{\max} = (\sqrt{n+1})^{-1}$ .

<sup>9</sup> Previous research on this topic confirms these results (e.g. Long and Soubeyran (1998) established that  $\partial \pi_i / \partial \beta_{ij} >$  and  $\partial \pi_i / \partial \beta_{ik} > 0$ ).

EQUATION 7

$$\frac{\partial \pi_i^*}{\partial \beta_{ij}} \frac{\partial \beta_{ij}}{\partial d_{ij}} = \frac{2\gamma(a-c)^2 \left(8b\gamma(4 - 2.5\beta_{ij} - 2.5\beta_{ik} + \beta_{jk}) - (3 - \beta_{ij} - \beta_{ik})^3\right)}{(8b\gamma - (3 - \beta_{ij} - \beta_{ik})(1 + 2\beta_{ij} + 2\beta_{ik} - 2\beta_{jk}))^3} \beta'_{ij}$$

EQUATION 8

$$\frac{\partial \pi_i^*}{\partial \beta_{ik}} \frac{\partial \beta_{ik}}{\partial d_{ik}} = \frac{2\gamma(a-c)^2 \left(8b\gamma(4 - 2.5\beta_{ij} - 2.5\beta_{ik} + \beta_{jk}) - (3 - \beta_{ij} - \beta_{ik})^3\right)}{(8b\gamma - (3 - \beta_{ij} - \beta_{ik})(1 + 2\beta_{ij} + 2\beta_{ik} - 2\beta_{jk}))^3} \beta'_{ik}$$

(a) If  $d_{ik} = d_{ij}$ , then  $g^2(d)$  is binding and the remaining restrictions are non-binding. Then, Kuhn-Tucker conditions may be resumed to:

$$(5) (\partial \pi_i^* / \partial \beta_{ij}) \beta'_{ij} = \lambda_2 \geq 0$$

$$(6) (\partial \pi_i^* / \partial \beta_{ik}) \beta'_{ik} = -\lambda_2 \leq 0$$

which are incompatible with (7) and (8).

(b) If  $d_{ik} > d_{ij}$ , all restrictions are non-binding and Kuhn-Tucker conditions became:

$$(5) (\partial \pi_i^* / \partial \beta_{ij}) \beta'_{ij} = 0$$

$$(6) (\partial \pi_i^* / \partial \beta_{ik}) \beta'_{ik} = 0$$

which are incompatible with (7) and (8).

This proposition is quite intuitive: as the spillover is a decreasing function of the physical distance between firms, firm  $i$  will proceed to be as close as possible to both firms, and so, she will be located in the straight-line between them. The exact location will be sketched in the following proposition:

**Proposition 4** *If two firms were dispersed in a convex space  $M$  and no cooperation is allowed, then the best location choice for an entrant firm depends on the shape of the spillover function:*

(i) *If  $\beta$  is a strictly concave function of the distance between firms, then the entrant firm will be located exactly in between incumbent firms;*

(ii) *If  $\beta$  is a linear function of the distance between firms, then any location along the straight line is possible;*

(iii) *If  $\beta$  is a strictly convex function of the distance between firms, then the entrant firm will choose to cluster with one of the firms.*

**Proof.** From previous proposition, we have that  $d_{ij} + d_{ik} = d_{jk}$ . Then, we may have one of the following mutually exclusive locations:

(a) Firm  $i$  locates at the same local of firm  $j$  and away from firm  $k$

In this case,  $d_{ij} = 0$ , and so,  $g^1(d)$  and  $g^3(d)$  are binding.

Kuhn-Tucker conditions then come:

$$(5) (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} = -\lambda_1 - \lambda_3 \leq 0$$

$$(6) (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} = -\lambda_1 \leq 0$$

which accord (7) and (8). Additionally, through simple arithmetic manipulation, we have:

$$[(5)-(6)] (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} - (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} = -\lambda_3 \leq 0$$

$$[(7)-(8)] (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} - (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} =$$

$$= \frac{2\gamma(a-c)^2(8b\gamma(4-2.5\beta_{ij}-1.5\beta)-(3-\beta_{ij}-\beta)^3)}{(8b\gamma-(3-\beta_{ij}-\beta_{ik})(1+2\beta_{ij}+2\beta_{ik}-2\beta_{jk}))^3} (\beta'_{ij} - \beta'_{ik})$$

which are only compatible for a convex or linear spillover function.

(b) Firm  $i$  locate along the straight line joining  $j$  and  $k$  but nearer to firm  $j$

In this case,  $0 < d_{ij} < d_{ik}$ , and so,  $g^1(d)$  is binding.

Kuhn-Tucker conditions then come:

$$(5) (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} = -\lambda_1 \leq 0$$

$$(6) (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} = -\lambda_1 \leq 0$$

which accord (7) and (8). Additionally,

$$[(5)-(6)] (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} - (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} = 0$$

$$[(7)-(8)] (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} - (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} =$$

$$= \frac{2\gamma(a-c)^2(8b\gamma(4-2.5\beta_{ij}-2.5\beta_{ik}+\beta_{jk})-(3-\beta_{ij}-\beta_{ik})^3)}{(8b\gamma-(3-\beta_{ij}-\beta_{ik})(1+2\beta_{ij}+2\beta_{ik}-2\beta_{jk}))^3} (\beta'_{ij} - \beta'_{ik})$$

which are only compatible for a linear spillover function.

c) Firm  $i$  locates exactly at the middle point of the straight line joining  $j$  and  $k$

In this case,  $d_{ij} = d_{ik} > 0$  and so,  $g^1(d)$  and  $g^2(d)$  are binding. Kuhn-Tucker conditions then come:

$$(5) (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} = -\lambda_1 + \lambda_2$$

$$(6) (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} = -\lambda_1 - \lambda_2 \leq 0$$

which accord with (7) and (8). Additionally,

$$[(5)-(6)] (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} - (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} = 0$$

$$[(7)-(8)] (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} - (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} =$$

$$= \frac{2\gamma(a-c)^2(8b\gamma(4-5\beta+\beta_{jk})-(3-2\beta)^3)}{(8b\gamma-(3-2\beta)(1+4\beta-2\beta_{jk}))^3} (\beta'_{ij} - \beta'_{ik})$$

which are compatible for any shape of the spillover function.

Our results allow us to conclude that the entrant firm will always cluster with one of the firms if the R&D spillover is linear or convex in firms' physical distance, while for the case of a strictly concave spillover function, no clustering is observed, as the entrant firm chooses to stay in between the two incumbent firms. This conclusion is simply justified by the shape of the spillover function:

(i) If the spillover function is linear in distance, then it is indifferent for firm  $i$  to cluster or not with an incumbent firm, as any location yields the same total spillover effect (see figure 1).

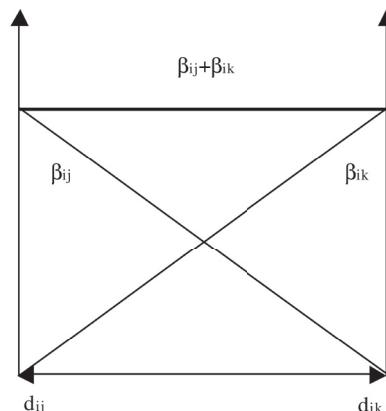
(ii) If the spillover function is concave, then locating at the middle point between the incumbent firms is the best choice as it yields the maximum total spillover for firm  $i$  (see figure 2).

- (iii) Finally, if the spillover function is convex, then clustering with one of the incumbent firms is the best choice, as it yields the maximum total spillover for firm  $i$  (see figure 3).

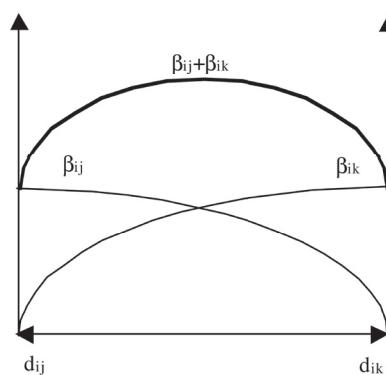
So, from our results we may conclude that the best location's strategy for an entrant firm, given other firms' location, depends on the shape of the spillover function. However, if we consider that all firms choose their locations sequentially, then the result will be an agglomeration equilibrium, whilst it would be gathered faster if the R&D spillover is convex in distance. If fact, if the spillover function is convex, then a sequential game implies that the first firm chooses its location,

and after that all firms, sequentially, cluster with her. If the spillover function is concave, the entrant firm locates in between other two firms, but sequentially, each other firm will locate in between the other firms. At the end, all firms will be agglomerated in a single point, whilst the agglomeration process would be slower if the R&D spillover is concave in distance. Alternatively, if we consider that all firms choose their locations simultaneously, then all of them anticipate that each other's best response either is in the middle point location if the R&D spillover is concave, or to cluster if the R&D spillover is convex. In any case, but faster if the last case, the result will be an agglomeration equilibrium.

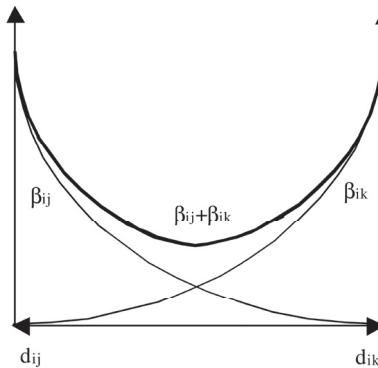
**FIGURE 1**  
**Firm  $i$ 's total spillover with a linear spillover function**



**FIGURE 2**  
**Firm  $i$ 's total spillover with a concave spillover function**



**FIGURE 3**  
Firm  $i'$ 's total spillover with a convex spillover function



**Proposition 5** In a non-cooperative game with R&D spillovers that are distance sensitive, if all firms choose their locations simultaneously or sequentially, then the subgame perfect Nash equilibrium is agglomeration.

## 2.2 COOPERATION IN R&D

Cooperation in R&D may involve different dimensions and run through different design models. Typically, cooperation involves R&D cartelization, that is, the coordination of R&D expenditures in order to maximize joint profits. Most of the literature usually assumes industry-wide agreements (e.g., d'Aspremont and Jacquemin (1988), Kamien et al. (1992) and Suzumura (1992), Vonortas (1994)), while others analyze cooperation within a subset of firms of a given industry (e.g., Poyago-Theotoky (1995)). Recently, the size of the R&D cartel is exogenous, whilst few papers aim at endogenize it (e.g., Katz (1986) and Atallah (2001)). Besides R&D cartelization, cooperating firms may jointly agree to internally raise the spillover parameter. In the limit, the sharing of R&D results could be set to its maximal value, a scenario described by Kamien et al. (1992) as cartelized RJV. Typically, the degree of information sharing between cooperating firms is assumed to be exogenous, while some articles aim at endogenize it (e.g., Katsoulacos

and Ulph (1998), Poyago-Theotoky (1999), Piga and Poyago-Theotoky (2001) and Amir et al. (2003)).

In this research, we will assume that a subset of firms cooperate and form a R&D cartel, whilst cooperation in the location decision or the production stage is never allowed. In our approach, R&D cooperation involves both R&D cartelization and increasing the information sharing between cooperating firms. Formally, this may be modelled through an increase of the spillover through a coefficient  $\delta \geq 1$ , where  $\delta \beta \leq 1$ . Throughout this approach, we intend to separate the effect of the location's decision ( $\beta$ ) from the effect of the cooperation decision ( $\delta$ ) on total spillover,  $\delta\beta$ . Having in mind Kamien et al. (1992)'s typology, we will have, for the case of RJV cartelization,  $\delta \beta = 1$ , while for the R&D cartelization case, we will have  $\delta = 1$  and  $\delta \beta = \beta$ .

Assume firms  $i$  and  $j$  decide to cooperate in R&D. Unit production costs then become:

$$c_i = c - x_i - \delta\beta_{ij}x_j - \beta_{ik}x_k$$

$$c_j = c - x_j - \delta\beta_{ij}x_i - \beta_{jk}x_k$$

$$c_k = c - x_k - \beta_{ik}x_i - \beta_{jk}x_j$$

where  $\delta\beta_{ij} \leq 1$

Firms' second stage profit function is defined the equation 9, where  $d = (d_{ij}, d_{ik}, d_{jk})$  and  $x = (x_i, x_j, x_k)$ .

In the R&D stage, cooperation implies that each firm within the R&D cartel will choose its R&D output in order to maximize joint profits, while non-cooperating firms will maximize individual profit:

$$\frac{\partial}{\partial x_i} [\pi_i(q^*, x, d) + \pi_j(q^*, x, d)] = 0$$

$$\frac{\partial}{\partial x_k} [\pi_k(q^*, x, d)] = 0$$

Imposing symmetry between cooperating firms

( $x_i = x_j = x$  = R&D output for a cooperating firm) and non-cooperating firms ( $x_k = y$  = R&D output for a non-cooperating firm) and solving for  $x$  and  $y$  gives us R&D output equilibrium (10) (see the equation 10).

Literature usually refers that R&D output equilibrium for cooperating firms is higher than R&D output equilibrium for non-cooperating firms when R&D spillovers are high because in this case, it can avoid resources duplication (see, at this purpose, Katsoulacos and Ulph (1998), Bondt and Henriques (1995), Steurs (1995) and Bondt (1997)).

Simple simulations on R&D output equilibrium for cooperating and non-cooperating firms also confirms this conclusion (see figures 4, 5 and 6):

So, we have that for the RJV cartelization case ( $\delta \beta_{ij} = 1$ ), R&D output for cooperating firms is always higher than R&D output for non-cooperating firms. However, if there is no increasing of information sharing between cooperating firms ( $\delta = 1$ ) and focusing on the clustering location ( $\beta_{ik} = \beta_{jk}$ ) and on the dispersion location ( $\beta_{ij} = \beta_{ik}$ ), then R&D output equilibrium for cooperating firms is higher than R&D output equilibrium for non-cooperating firms only for high spillovers between cooperating firms.

Let's now evaluate how R&D output changes with the distance between firms.

**Proposition 6** When a subset of firms cooperate in R&D, its R&D output equilibrium will be higher for a higher degree of information sharing and for a lower physical distance between them.

**Proof.** Given our assumptions, we have

$\beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1]$ ,  $\beta'_{ij} < 0$ ,  
 $\beta'_{ik} < 0$  e  $\delta \beta_{ij} \leq 1$ . Then, for  $b\gamma > 2.5328$ ,  
we have  $\partial x / \partial \delta = \partial x / \partial \beta_{ij} > 0$  and then  
 $(\partial x / \partial \beta_{ij}) \beta'_{ij} < 0$ .

#### EQUATION 9

$$\pi_i(q^*, x, d) = \frac{(a - c + (3 - \delta \beta_{ij} - \beta_{ik})x_i + (3\delta \beta_{ij} - \beta_{jk} - 1)x_j + (3\beta_{ik} - \beta_{jk} - 1)x_k)^2}{16b} - 0.5\gamma x_i^2$$

<sup>10</sup> Second order condition requires  $b\gamma > 5/4, \forall \beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1]$  e  $\delta \beta_{ij} \leq 1$ . Sufficient condition for the stability of equilibrium requires  $b\gamma > 5/2, \forall \beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1]$  and  $\delta \beta_{ij} \leq 1$  (Henriques (1990)).

## EQUATION 10

$$x^* = [(a - c) (4b\gamma (1 - \beta_{ik} + \delta\beta_{ij}) - (3 - \beta_{ik} - \beta_{jk}) (\beta_{ik}^2 - 5\beta_{ik} + \delta\beta_{ij}\beta_{ik} + \beta_{ik}\beta_{jk} + \beta_{jk} + 2\delta\beta_{ij} - 3\delta\beta_{ij}\beta_{jk} + 2))]/[2b\gamma(8b\gamma - 13 + 12\beta_{ik} + 8\beta_{jk} - 8\delta\beta_{ij} - 4\beta_{ik}\beta_{jk} + 6\delta\beta_{ij}\beta_{ik} + 2\delta\beta_{ij}\beta_{jk} - 3\beta_{ik}^2 - \beta_{jk}^2 - 4\delta^2\beta_{ij}^2) + (-3 + \beta_{ik} + \beta_{jk})(-\beta_{ik}^3 - 5\delta\beta_{ij}\beta_{ik}^2 - 2\beta_{ik}^2\beta_{jk} + 7\beta_{ik}^2 + 2\beta_{ik}\beta_{jk} + 4\delta^2\beta_{ij}^2\beta_{ik} + 2\delta\beta_{ij}\beta_{ik} - 4\delta^2\beta_{ij}^2\beta_{jk} + 2\delta\beta_{ij}\beta_{ik}\beta_{jk} - \beta_{ik}\beta_{jk}^2 + 7\delta\beta_{ij}\beta_{jk}^2 - 2\delta^2\beta_{ij}^2 - 2 + 4\beta_{jk} - 4\delta\beta_{ij} - 5\beta_{jk}^2 - 2\beta_{ik})]$$

$$y^* = [2(a - c)(3 - \beta_{ik} - \beta_{jk})(b\gamma - (1 - \beta_{ik} + \delta\beta_{ij})(\delta\beta_{ij} - \beta_{jk} + 1 - \beta_{ik}))]/[2b\gamma(8b\gamma - 13 + 12\beta_{ik} + 8\beta_{jk} - 8\delta\beta_{ij} - 4\beta_{ik}\beta_{jk} + 6\delta\beta_{ij}\beta_{ik} + 2\delta\beta_{ij}\beta_{jk} - 3\beta_{ik}^2 - \beta_{jk}^2 - 4\delta^2\beta_{ij}^2) + (-3 + \beta_{ik} + \beta_{jk})(-\beta_{ik}^3 - 5\delta\beta_{ij}\beta_{ik}^2 - 2\beta_{ik}^2\beta_{jk} + 7\beta_{ik}^2 + 2\beta_{ik}\beta_{jk} + 4\delta^2\beta_{ij}^2\beta_{ik} + 2\delta\beta_{ij}\beta_{ik} - 4\delta^2\beta_{ij}^2\beta_{jk} + 2\delta\beta_{ij}\beta_{ik}\beta_{jk} - \beta_{ik}\beta_{jk}^2 + 7\delta\beta_{ij}\beta_{jk}^2 - 2\delta^2\beta_{ij}^2 - 2 + 4\beta_{jk} - 4\delta\beta_{ij} - 5\beta_{jk}^2 - 2\beta_{ik})]$$

FIGURE 4

R&D output equilibrium for cooperating (x) and non-cooperating (y) firms when  $\delta\beta=1$  ( $b=1, \gamma=5$ ).

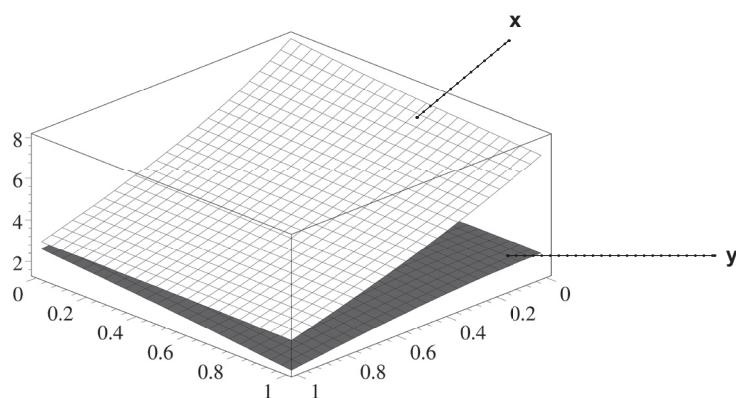


FIGURE 5

R&D output equilibrium for cooperating (x) and non-cooperating (y) firms when  $\delta=1$  e  $\beta_{ik} = \beta_{jk}$  ( $b=1, \gamma=5$ ).

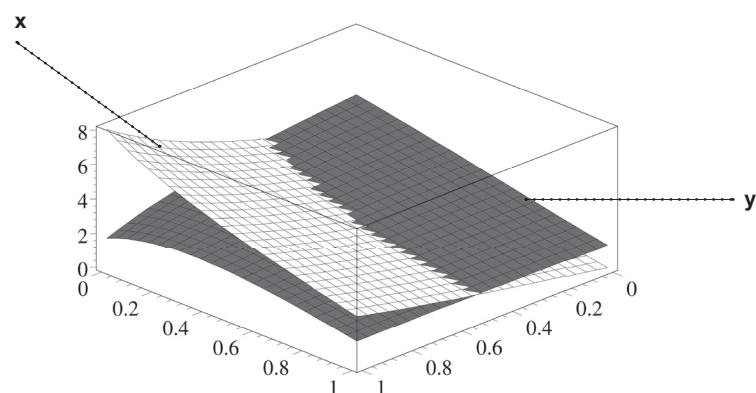
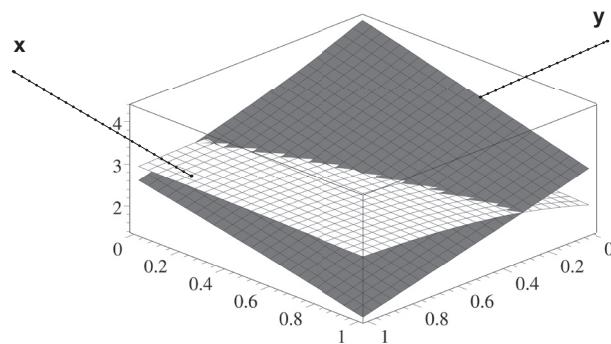


FIGURA 6

R&D output equilibrium for cooperating (x) and non-cooperating (y) firms when  $\delta=1$  e  $\beta_{ij} = \beta_{ik}$  ( $b=1, \gamma=5$ ).



These results are quite intuitive and find confirmation in related literature. In fact, and leaving apart the inverse relationship between firms' distance and R&D spillovers, the positive relationship between R&D output equilibrium and the spillover between cooperating firms is well documented in R&D texts. After evaluating different R&D design models, Kamien et al. (1992) found that R&D effective output is higher in the RJV, cartelization case, where  $\delta \beta = 1$ . When comparing with simple R&D cartelization, where  $\delta \beta = \beta$ . Comparing a secretariat RJV ( $\delta \beta = \beta$ ) with a operating RJV ( $\delta \beta = 1$ ), Vonortas (1994) concluded that the operating entity is more effective than the secretariat in improving firm's performance over the non-cooperative industry. Particularly, he observed that the operating entity members always invest more in R&D than the members of a secretariat, even when they both spend less than the non-cooperative case. Bondt (1997) reached that cooperative R&D investments are typically stimulated by larger spillovers.

The following corollary completes previous proposition:

**Corollary 1** *R&D output equilibrium for cooperating firms increases with the distance to non-cooperating firms.*

**Proof.** Given our assumptions, we have

$\beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1], \beta'_{ij} < 0, \beta'_{ik} < 0$  e  $\delta \beta_{ij} \leq 1$ . Then for  $b\gamma > 2.6768$ , we have  $\partial x / \partial \delta = \partial x / \partial \beta_{ij} > 0$ . Similarly, for  $b\gamma > 2.5328$ , we have  $(\partial x / \partial \beta_{ij}) \beta'_{ij} < 0$ .

When taking under consideration the distance between cooperating and non-cooperating firms, proposition 1 remains valid. Aditinally, we expect that R&D output equilibrium for non-cooperating firms increases with the distance from non-cooperating to cooperating firms. This behavior is justified by the need to avoid that R&D output spillovers to competing firms.

First-stage profit function is defined in equation 11).

In the location decision game, we will consider again the problem of a single firm  $i$  choosing its location in a delimited space where firms  $j$  and  $k$  were located.

Note that cooperation is not allowed in the location stage, and so, the formulation of the problem is very similar to the independent case:

$$\max_{d_{ij}, d_{ik} \in M} \pi_i(q^*, x^*, y^*, d)$$

$$\text{s.t. } g^1(d) = d_{ij} + d_{ik} - d_{jk} \geq 0$$

$$g^2(d) = d_{ik} - d_{ij} \geq 0$$

$$g^3(d) = d_{ij} \geq 0$$

Applying Kuhn-Tucker conditions to the Lagrangean function gives us similar expression to (5) and (6). Through tedious calculations we have, for  $\beta'_{ij} < 0, \beta'_{ik} < 0, \beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1], \delta \geq 1, \delta\beta_{ij} \leq 1$  and assuming  $b\gamma > 2.5328$ :

$$\frac{\partial \pi^*}{\partial \beta_{ij}} \frac{\partial \beta_{ij}}{\partial d_{ij}} < 0 \quad (12)$$

$$\frac{\partial \pi^*}{\partial \beta_{ik}} \frac{\partial \beta_{ik}}{\partial d_{ik}} \geq 0 \quad (13)$$

After evaluating different scenarios for location, we concluded that propositions 2 and 3 remain valid for the cooperation case, and so, we will omit its proofs:

**Proposition 7** If two firms were close located and cooperation in the R&D stage is allowed, the best location choice for an entrant firm is agglomeration.

**Proposition 8** If two firms were dispersed in a convex space  $M$  and cooperation is allowed in the R&D stage, then the entrant firm will locate in the straight-line between incumbent firms, that is,

$$d_{ij} + d_{ik} = d_{jk}$$

The exact location of the entrant-cooperating firm will be sketch in the following proposition:

**Proposition 9** If two firms intend to cooperate in R&D through joint profit maximization and increased information sharing, then clustering is always observed.

**Proof.** Assume false, that is, assume firm  $i$  chooses to locate exactly in between  $j$  and  $k$ , so that  $d_{ij} = d_{ik}$ , whilst  $d_{ij} + d_{ik} = d_{jk} > 0$ . Kuhn-Tucker conditions are resumed to:

$$(5) \quad (\partial \pi_i^* / \partial \beta_{ij}) \beta'_{ij} = -\lambda_1 + \lambda_2$$

$$(6) \quad (\partial \pi_i^* / \partial \beta_{ik}) \beta'_{ik} = -\lambda_1 - \lambda_2 \leq 0$$

which accord with (12) and (13). However, through simple calculations, we have:

#### EQUATION 11

$$\pi_i(q^*, x^*, y^*, d) = \frac{(a - c + (2 + 2\delta\beta_{ij} - \beta_{ik} - \beta_{jk})x^* + (3\beta_{ik} - \beta_{jk} - 1)y^*)^2}{16b} - 0.5\gamma(x^*)^2$$

$$[(5)-(6)] (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} - (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} = 2\lambda_2 \geq 0$$

Having in mind that  $\beta_{ij}, \beta_{ik}, \beta_{jk} \in [0, 1]$  and assuming  $b\gamma > 2.5328$ , we have, for  $\delta > 1$ ,  $\delta\beta_{ij} \leq 1$  and so:

$$[(12)-(13)] (\partial\pi_i^*/\partial\beta_{ij})\beta'_{ij} - (\partial\pi_i^*/\partial\beta_{ik})\beta'_{ik} < 0$$

which contradicts Kuhn-Tucker conditions.

As we expected, R&D cooperation affects firms' decision about location: if there is an increasing information sharing between firms and joint profit maximization, then the entrant-cooperating firm always prefer to locate near the incumbent-cooperating firm for every shape of the spillover function, and so, clustering is a immediate result from cooperation. However, to achieve this result it is required an increasing information sharing between firms. In fact, if we assume  $\delta = 1$ , then  $(\partial\pi_i^*/\partial\beta_{ij}) - (\partial\pi_i^*/\partial\beta_{ik}) \geq 0$ , and so, we can not eliminate the middle point location.

### CONCLUDING REMARKS

Empirical research usually confirms the strong propensity for the clustering of innovative related activities, which is commonly justified by the existence of knowledge spillovers (Jaffe et al. (1993), Audretsch and Feldman (1996), among others). Additionally, proximity is frequently cited as an explanation for the emergence of cooperative behaviors among firms or between universities and firms (e.g., Varga (2000), Arundel and Geuna (2001) and Carrincazeaux et al. (2001)).

Inspired in several empirical results, we intended to evaluate if firms' decision about location revises wether firms cooperate or compete in R&D. Through a game between three firms, from which two of them intend to cooperate in R&D, it was possible to conclude that the clustering of firms is always true if

firms run R&D cooperatively. In fact, we demonstrated that if R&D runs independently, the entrant firm will cluster if the R&D spillover function is convex in the physical distance between firms. On the other hand, if R&D runs cooperatively between the entrant and an incumbent firm, then the entrant firm will always prefer to stay close to the cooperating-incumbent firm if there is an increasing information sharing among them. In any case, if the two incumbent firms were close located, agglomeration is always observed.

Our results also concern about R&D output equilibrium. We proved that if R&D runs independently, then R&D output equilibrium is larger as the distance between firms increases. The intuition is simple: as the distance between firms increases, firms will perform an higher R&D output because a lower proportion of its results will flow over the other firms. However, if R&D runs cooperatively, then R&D output equilibrium for cooperating firms increases with the degree of information sharing between them, as well as with a reduction of the distance between cooperative firms. On the other hand, it reduces when the distance from cooperative firms to non-cooperative firms is shorter. With respect to R&D output equilibrium for non-cooperating firms, results were similar to the independent case.

Research on the topic of location and R&D cooperation may proceed in several directions. One possible line of research is to introduce uncertainty with respect to R&D spillovers and evaluate its impact on firms' decision about R&D and location. Another possible research topic is to merge R&D cooperation models with spatial competition and focus on the determination of spatial equilibria under R&D spillovers and transportation costs. Finally, this research could proceed with the evaluation of the impact of firms' proximity into the degree of information sharing when firms cooperate in R&D activities.

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