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Duarte Leite [1 2]
Pedro Campos [1 2]
Isabel Mota [1 3]

[1] Faculdade de Economia, Universidade do Porto,
[2] LIAAD – INESC, LA
[3] CEF.UP

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Computational Results on Membership in R&D Cooperation Networks: To Be or Not To Be in a Research Joint Venture[1]

Duarte Leite[1,2], Pedro Campos[1,2] and Isabel Mota[1,3]

[1]FEP (1Faculdade de Economia, Universidade do Porto)

[2]LIAAD – INESC, LA (Laboratory of Artificial Intelligence and Decision Support)

[3]CEF.UP (Center for Economics and Finance at UP)

Abstract. In this study, we analyze firms' membership in R&D (Research and Development) cooperation networks. Our main research hypothesis is that the membership in cooperation networks is related to the degree of the knowledge spillover. The approach focus on both cost symmetry and cost asymmetry. For that purpose, our work is developed in two tasks: we first develop an analytical model with three stages: in the first, firms decide whether to participate in a cooperative research network; in the second they simultaneously choose the level of R&D output, and finally firms choose the level of output through Cournot competition under both cost symmetry and cost asymmetry. Then we proceed with computational simulations in order to verify our hypothesis. From our results, we were able to conclude that cooperation leads to an improvement on RJV firms' position in the market as it allows them to produce more than others with the same production conditions. Additionally, cooperating firms have to spend fewer resources on research, which turns the network a tremendous success on the productive efficiency level.

Keywords: R&D; networks; spillover; simulation; RJV

JEL codes: D85; L24; C63

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1. Introduction

In recent years, cooperation networks is one of the most appealing topics to study, gathering researchers from different scientific fields, such as economy, management, computer science, as well as politicians and entrepreneurs.

It is generally recognized that R&D (Research and Development) activities have some public good features, as firms cannot fully appropriate the returns of their R&D investments, due to the existence of R&D spillovers.[2] As a result, R&D expenditures are usually less than socially optimal. For this reason, R&D cooperation frequently emerges, so as to internalize spillovers.

Cooperation in R&D is usually 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. 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.

Since these starting articles, a lot of scientific models emerged around the topic of R&D cooperation, providing numerous extensions to those original models. Particularly interesting are the extensions to an oligopolistic scenario with industry-wide agreements (Suzumura, 1992) or partial industry agreements (Poyago-Theotoky, 1995). Other authors considered diverse degrees of spillover between cooperating firms (Vonortas, 1994), both inter and intra-industry R&D spillovers (Steurs, 1995) or one-way spillovers from the firm with higher R&D activity to its rival (Amir and Wooders, 2000). Other approaches introduce the concept of absorptive capacity, which means that each firm needs to conduct its own R&D in order to realize spillovers from other firms' R&D activity (Cohen and Levinthal, 1989; Kamien and Zang, 2000). Alternatively, some papers involve dynamic models, as it was the case of Petit and Tolwinski (1999), who extended the existing literature on cooperative/competitive R&D into a context of a dynamic model. Also, other more recent research studies have been interested on the same dynamical process of innovation using spillovers and trying to analyze

[2] According to Scitovsky (1954), spillovers (or technological externalities) deal with the effects of non-market interactions, being realized through processes that affect the production (or profit) function of a firm. Spillovers may respect to the diffusion of learning across firms, which can take place through interfirm mobility of employees or cooperation.

the impact on welfare, studying the private and social incentives of R&D cooperation (Cellini and Lambertini, 2009).

Many also used the differentiation through asymmetry, namely in costs and spillovers to observe the behaviour of firms when facing these kinds of constraints. In Atallah (2005) or Atallah (2007) we observe asymmetry in spillovers (and not cost asymmetry, as in this work).

Most of the research on R&D cooperation is theoretical, but empiric analysis is also possible and desirable. If intuitively and theoretically we can predict benefits from cooperation, only from empirics we can assure that these benefits are real. Some interesting studies try to depict the results of R&D cooperation, which is the case of Aschhoff and Schmidt (2008), where they observe the effects of R&D cooperation on future innovation and firms' efficiency improvement that lead to better economic performances.

We may also refer that there are few empirical studies that aim at studying the effects of production conditions and spillover degrees over cooperation among firms. One of the most relevant studies is the one developed by Cassiman and Veugelers (2002) that show the effects of incoming spillovers and appropriability on having cooperation. Using data from Belgium they found that incoming spillovers have a positive and significant effect on the probability of cooperating firms. They also found that the higher appropriability, the higher the probability of network cooperation. However, they showed that it may depend on the kind of partners that firms deal with in the market. In addition, some non-spillover determinants of cooperation are also examined, and they found that larger firms are more likely to cooperate.

Starting from the literature on R&D cooperation, in our study we intend to analyze the membership and profitability of cooperation networks. Our main research hypothesis is that membership in cooperation network is associated with the degree of spillover. Therefore, this approach tries to offer a (less typical) extension to the analysis of R&D cooperation for more than 2 asymmetric costs firms. So, its main value are the extension of the number of companies that exist in the market, the consideration of asymmetric marginal costs of productions, as well as the computational simulation of the interactions, and the results that emerge from it.

Our work is, then, developed in two parts, each of them divided in two steps. In the first part, we assumed that firms are symmetric in what respects the marginal cost of production, R&D costs and the spillover outside the network. In the second part, we considered that firms may have different marginal costs of production. As for the steps of each part, we propose developing (i) an analytical model, followed by (ii) a computational approach that finds a numerical solution to verify our hypothesis.

2. Part I – R&D Cooperation Networks under symmetric marginal costs

In the first level, we made an analytical solution for the problem of R&D cooperation by extending the model of d'Aspremont and Jacquemin (1988) to an oligopolistic scenario with partial-industry agreements between symmetric firms. We then developed a three-stage game where firms decide about entering in the R&D cooperation network, then about its R&D expenditures and afterwards they compete in the output market.

After developing the model, and due to the complexity of the solution for the equilibrium R&D output, we decided to use numerical simulations. Therefore we consider both a repetition of the game by introducing a numerical solution through an Agent-Based Simulation. The firms are represented by heterogeneous agents that possess distinct profit levels and whose decisions are based on individual preferences. We measure the profits of the firms in two different periods of time and conclude that there is an association between the participation in cooperation networks and the corresponding profitability in the long run.

2.1. The Model

There are *n* firms that produce a homogeneous output, whose inverse demand function is given by

$$P = a - bQ \qquad \textbf{(1)}$$

where the parameter *a* captures the dimension of the market and *b* is a constant. *Q* is the total output given by the expression:

$$\left(Q = \sum_{i=1}^{n} q_i \right) \; (a,\ b>0 \text{ and } Q \leq a/b). \qquad \textbf{(2)}$$

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:

$$c_i = \overline{\alpha_i} - x_i - \beta \sum_{j \neq i}^{n} x_j \quad \textbf{(3)}$$

where $\overline{\alpha_i}$ accounts for stand-alone marginal costs ($0 < \overline{\alpha_i} < a$) and x_i measures firm *i*'s R&D output. Each firm also benefits from the R&D developed by other firms through a spillover, $\beta \in [0, 1]$. Additionally, it will be assumed that there are diminishing returns to R&D expenditures, that is, $C'(x_i) > 0$ and $C''(x_i) > 0$. In order to ensure positive quantities, we will impose that:

$$x_i + \beta \sum_{j \neq i}^{n} x_j \leq c \quad \textbf{(4)}$$

Additionally, and as in d'Aspremont and Jacquemin (1988), we will consider a specific functional form for the R&D cost function:

$$C(x_i) = 0{,}5\gamma x_i^2 \quad \textbf{(5)}$$

The profit of firm *i* is then given by:

$$\pi_i = (P - c_i)q_i - C(x_i) = \quad \textbf{(6)}$$

$$= (a - b\sum_{j=1}^{n} q_j - \overline{\alpha_i} + x_i + \beta \sum_{j \neq i}^{n} x_j)q_i - 0{,}5\gamma(x_i)^2$$

It is proposed a three-stage game, where firms decide about cooperation, R&D output level and afterwards select the level of output non-cooperatively. The timing is the following:

In the first stage (*membership stage*), firms decide whether to participate in a cooperative research network. For simplicity, we will assume that within the cooperative network, the degree of information sharing is set at its maximum level ($\beta=1$), a structure known in the literature as *Research Joint Venture* (RJV) (Kamien *et al*,, 1992). Additionally, we will consider that insiders can obstruct the entry of an additional firm if it reduces their profits, while an outside firm will join the RJV only if it increases its profits. Therefore, the following conditions[3] ensure the stability of a RJV of size *m*:

[3] The stability conditions here used are similar to those usually adopted in the literature (e.g. Poyago-Theotoky, 1995; Atallah, 2003).

$$\text{(i) } \pi_i^m(m) \geq \pi_i^m(m-1) \tag{7}$$

$$\text{(ii) } \pi_i^m(m) \geq \pi_i^{n-m}(m-1) \tag{8}$$

$$\text{(iii) } \pi_i^m(m) \geq \pi_i^m(m+1) \text{ or } \pi_i^{n-m}(m) \geq \pi_i^m(m+1) \text{ or both.} \tag{9}$$

where $\pi_i^m(t)$ represents the profit of an insider and $\pi_i^{n-m}(t)$ the profit of an outsider when the RJV is of size *t*. π_i^m (m) represents the average profit of firms in a network of size m and π_i^m (m-1) represents the average profit of firms in a network of size m, not taking into account one specific firm.

In the second stage (*development stage*), firms simultaneously choose the level of R&D output, independently or under cooperation. If firms cooperate, then they will coordinate R&D output in order to maximize joint profits.

At last, in the *production stage*, firms simultaneously choose the level of output through Cournot competition.

2.2. Analytical Solution

We will assume that *m* firms join the Research Joint Venture (RJV) and maximize joint profits. As mentioned before, there is full information sharing between the RJV participants (β = 1), while for the remaining (*n-m*) firms, $\beta \in$ (0, 1). Additionally, we will assume that firms are symmetric, that is, $\overline{\alpha_i} = c, \ \forall i.$

Second-stage Cournot profits for an RJV – firm come:

$$\pi_i^C = \left(\frac{a-c-(n-m)(x_i^N + \beta(n-m-1)x_i^N + \beta m x_i^C) - (m-n-1)(m x_i^C + (n-m)x_i^N)}{b(n+1)} \right)^2 \tag{10}$$

where *C* stands for cooperating and *N* for non-cooperating firms.

Additionally, a non-RJV-firm will have Cournot profits equal to:

$$\pi_i^N = \left(\frac{a-c-(n-m-1)(x_i^N + \beta(n-m-1)x_i^N + \beta m x_i^C) - m(m x_i^C + \beta(n-m-2)x_i^N) - n(x_i^N + \beta(n-m-2)x_i^N)}{b(n+1)} \right)^2 \tag{11}$$

In the R&D stage, firms must decide about its R&D output under cooperation or competition. From Cournot profits maximization and by imposing symmetry, the R&D output equilibrium for both cooperating (x^C) and non-cooperating (x^N) firms then comes:

$$x^C = \frac{(a-c)}{b}\left[\frac{\gamma(n+1)^2 - 2[n(1-\beta)+\beta][\beta(n-m)+(1+m)(1-\beta)]}{2[n(1-\beta)+\beta]} + (n-m)(2\beta-1)\right] \qquad \textbf{(12)}$$

$$x^N = \frac{(a-c)}{b}\left[\frac{\gamma(n+1)^2 - 2m^2[(n-m)(1-\beta)+1]^2}{2m[(n-m)(1-\beta)+1]} + m[\beta(m+1)-m]\right] \qquad \textbf{(13)}$$

Due to the complexity of the solution for the equilibrium R&D output, we decide to use numerical simulations that we explore in the following section.

2.3. Numerical Results

In order to obtain numerical results to test our hypothesis, an algorithm has been implemented using R language (R Development Core Team, 2005). The outline of the algorithm is presented in the appendix 1. First, we start with the initialization of the main parameters of the model. There are many parameters to initialize in the simulation and it would be fastidious to describe all the set up choices. Focusing on the main parameters that have been initialized: *a*=80; *C*=50; γ = (8*(n+1)^2)/27+10 (according to Poyago-Theotoky, 1995); *n* = 5 (number of firms in the market) and *m* = 2 (number of firms in the network).

To make the algorithm work it is necessary to establish initial values for the number of repetitions of the cycle. We set up Generations = 20.

In Table 1 some results of the simulation for different values of *n* (number of firms in the market) are presented.

N=5						
Marginal cost=50						
Beta (β)	-	0.2	0.4	0.6	0.81	0.9
RJV Profits	46,72	48,73	50,25	51,25	51,73	51,76
Non-RJV profits	24,28	24,76	25,17	25,50	25,75	25,83
RJV Profits for (n-1) RJV firms	74,07	76,06	77,56	78,57	79,07	79,10
RJV R&D output	0,16	0,16	0,16	0,16	0,16	0,16
Non-RJV R&D output	0,41	0,35	0,28	0,21	0,15	0,12
RJV Profits for (n+1) RJV firms	24,50	25,08	25,48	25,71	25,75	25,71
N=20						
Marginal cost=50						
Beta (β)	-	0.2	0.4	0.6	0.81	0.91
RJV Profits	3,99	4,04	4,07	4,09	4,10	4,09
Non-RJV profits	2,02	2,04	2,04	2,05	2,05	2,05
RJV Profits for (n-1) RJV firms	5,99	6,06	6,11	6,14	6,14	6,14
RJV R&D output	0,02	0,02	0,02	0,02	0,02	0,02
Non-RJV R&D output	0,02	0,01	0,01	0,01	0,00	0,00
RJV Profits for (n+1) RJV firms	2,02	2,03	2,05	2,05	2,05	2,05
N=5						
Marginal cost=50 and R&D cost (γ)=50						
Beta (β)	-	0.2	0.4	0.6	0.81	0.91
RJV Profits	48,90	49,58	50,09	50,42	50,58	50,59
Non-RJV profits	24,75	24,92	25,06	25,17	25,25	25,28
RJV R&D output	0,05	0,11	0,11	0,11	0,11	0,11
Non-RJV R&D output	0,14	0,11	0,09	0,07	0,05	0,04
Marginal cost=50 and R&D cost (γ)=90						
Beta (β)	-	0.2	0.4	0.6	0.81	0.91
RJV Profits	49,34	49,75	50,05	50,25	50,35	50,35
Non-RJV profits	24,85	24,95	25,03	25,10	25,15	25,17
RJV R&D output	0,03	0,07	0,07	0,07	0,07	0,07
Non-RJV R&D output	0,08	0,07	0,06	0,04	0,03	0,02

Table 1: Results of the simulation for different values of *n* (number of firms in the market)

Firstly, we can see that all firms outside the RJV want to enter the network and firms inside the RJV let them enter. The network then is formed by all firms in the market. There is stability when all firms are inside the network and therefore there is no entrance or exit of firms to and from the RJV. Whatever is the number of companies in the market and for every spillover levels, companies will sooner or later enter in the RJV and there will be a huge cooperation network between all companies in the market, after interaction starts.

From our computational exercise, we first observe that there is a direct relationship between the R&D spillover that exists outside the network (β) and firms' profit (Figure 1). In fact, we may conclude that an increase of the R&D spillover outside the RJV will make firms to benefit from other firms' knowledge, and, therefore, to increase its profits. And this is true for both RJV and non-RJV firms, while in the first case, profits are higher due to a maximum spillover among cooperating firms. Also, a correlation coefficient of 0,997 between spillover and firms' profit was found to be statistically significant at 0.05 level of significance.

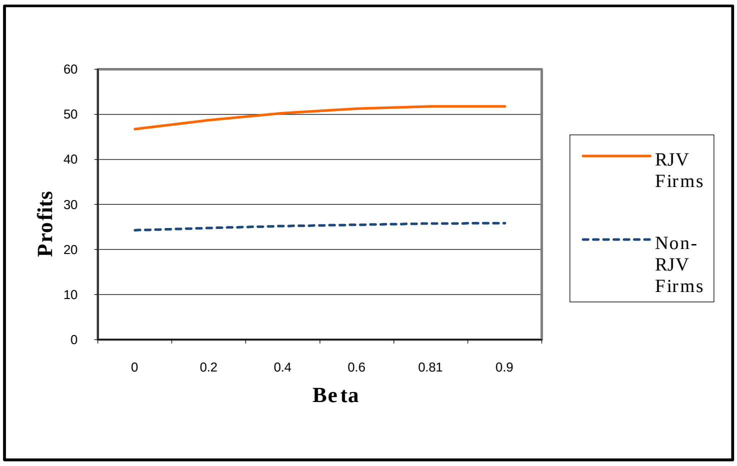

Figure 1: Profits evolution with the spillover between non-cooperating firms (beta)

Additionally, when we focus on the R&D investment, we observe that it is higher for non-cooperating firms when compared with cooperating firms, except for a high degree of information sharing among non-cooperating firms (Figure 2). At the same time, we observe that for non cooperating firms, there is an inverse relationship between the level of knowledge spillover and the investment in R&D. This result is rather intuitive: higher degrees of information sharing means lower appropriateness of R&D efforts and, therefore, lower R&D investments:

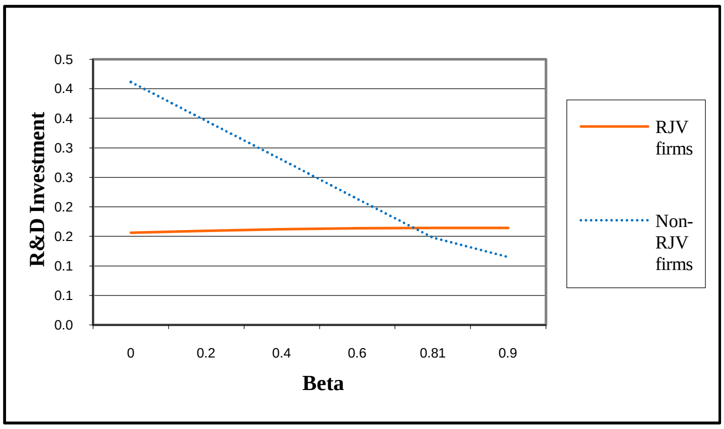

Figure 2: R&D output evolution with the spillover between non-cooperating firms

We also observe that as the R&D cost (γ) increases, each firm's profit also increases, but with a higher effect on the RJV firms than for the case of no cooperation (Figure 3). This might be explained by the increasing need to share know-how when it is more expensive to do research.

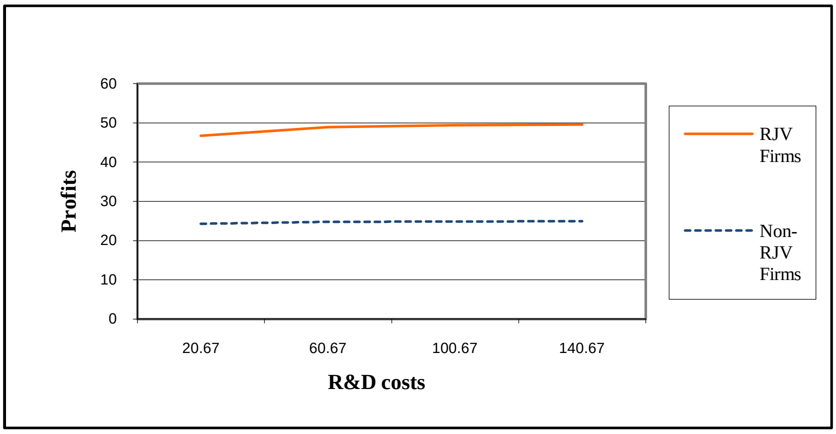

Figure 3: Profits evolution under R&D costs increasing

In what concerns the investment in R&D, it appears to decrease abruptly with small R&D cost values but then it has smaller reductions for greater values of R&D cost (Figure 4). This phenomenon may explain the evolution of the profits since the evolution of the investment compensates the increase of its cost.

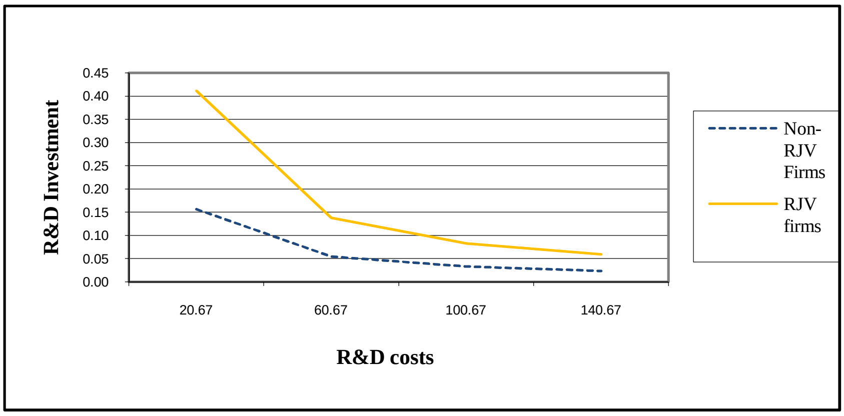

Figure 4: Evolution of R&D output with R&D costs (γ)

Now, if we change the parameter *a* (related with demand size) we observe a positive change of the profits (Figure 5). This change was indeed expected, as when the dimension of the market increases, the profit increases as well. The investment in R&D also increases in both groups (RJV and non-RJV), and we observe that firms outside the network (non-RJV) invest more than firms inside the RJV.

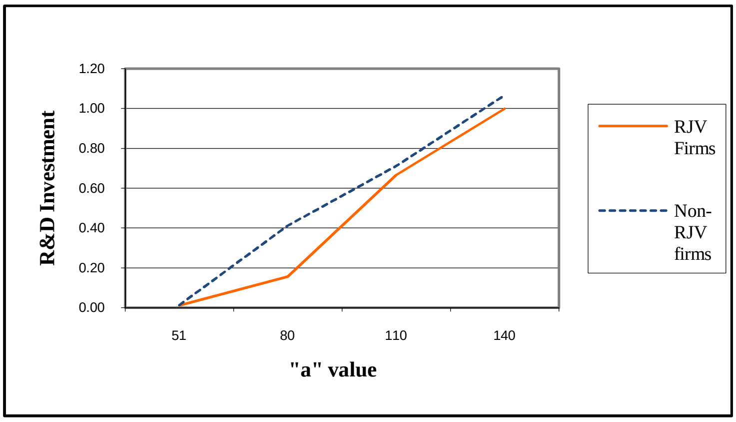

Figure 5: Evolution of R&D output when the market size increases (a)

Finally, we repeat the simulation for different number of firms in the market (*n*) and observe that when *n* increases, the R&D output decreases (Figure 6). This fact can be explained by the inverse relationship between the R&D output and the spillover. Therefore, as the number of firms in the market increases the R&D output decreases due to the fact that the spillover is greater for larger number of firms in the market and the need for R&D output is lower.

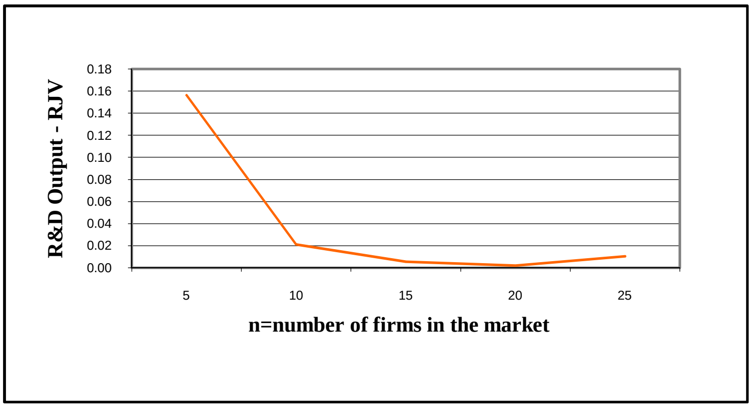

Figure 6: Evolution of R&D output when the number of firms in the market increase

3. Part II – R&D Cooperation Networks under asymmetric marginal costs

In this second section we develop an analytical solution for the problem of R&D cooperation, maintaining the key assumptions of the model of d'Aspremont and Jacquemin (1988) and extend it to an oligopolistic scenario with partial-industry agreements between asymmetric-costs firms. We assume that these companies have asymmetric marginal costs of production, although the spillover and the R&D cost are identical for every firm. As in the former part, we developed a three-stage game where firms decide about entering in the R&D cooperation, then about its R&D expenditures and finally they compete in the output market.

To develop the analytical model, due to its complexity as the solution was exceedingly complex and extremely difficult to solve without technological help, we use numerical simulations to find the solution for the equilibrium R&D output. Therefore we consider both a repetition of the game by introducing a numerical solution through an Agent-Based Simulation similar to the previous process in part I. The firms are represented by heterogeneous agents that possess distinct marginal costs of production and whose decisions are based on individual preferences. We measure the profits of the firms in two different periods of time and analyze if there is an association between the membership in cooperating networks and the corresponding profitability in the long run.

We consider nine firms, because the electronic resources only had capacity to derivate the model equations with less than ten companies. Each firm have a different marginal cost of production $\propto_i$, for $i = 1, \ldots, 9$ and equal R&D costs. The spillover is also equal for every firm outside the network although its value was not fixed. Inside the network the spillover was set equal to one, just like in the first part.

With these new hypotheses we determine the new company cost function, which is almost similar to the previous one but with asymmetric marginal costs. After that we determine all the new equilibrium equations necessary to calculate the R&D output and the output of each firm.

3.1. The Model

In this second model we consider both equations 1 and 2, showed and explained in part I's model. Equation 3 change according to the hypothesis considered above, which means that it now measures the impact of the existence of diverse marginal costs of production between firms. In this case, there will not be a constant α_i on the equation (3'):

$$c_i = \alpha_i - x_i - \beta \sum_{j \neq i}^{n} x_j \qquad \textbf{3')}$$

α_i, as in part I, accounts for stand-alone marginal costs ($0 < \alpha_i < a$) and x_i measures firm *i*'s R&D output. The R&D spillover keeps the same properties, $\beta \in [0, 1]$, and as written before, it will be assumed that there are diminishing returns to R&D expenditures, that is, $C'(x_i) > 0$ and $C''(x_i) > 0$.

The subsequent equations 4 and 5 did not change too. Equation 6 changes because of the adjustment of the third equation. So, the profit function has change so that it reflects the differences on marginal costs of production between firms:

$$\pi_i = (P - c_i)q_i - C(x_i) =$$

$$= (a - b\sum_{j=1}^{n} q_j - \alpha_i + x_i + \beta \sum_{j \neq i}^{n} x_j)q_i - 0{,}5\gamma(x_i)^2 \qquad \textbf{(6')}$$

It is proposed the same three-stage game used in Part I, where firms decide about cooperation, R&D output level and then select the level of output non-cooperatively. We use the same assumptions of Part I on the membership issue: non-members only want to enter the network if their profit increases with their entrance, while members want to leave the network if their profit increases by being out the network. However, in this Part we assume three different decision criteria on the members' decision of letting non-members enter or not the network. Each one of these three options is used to find out how network formation can present different features by changing this condition. The three possibilities were:

(1) The average profit inside the network must increase with the entrance of a non-member firm;

(2) The profit of the firm that will enter must be superior to the network average profit;

(3) The profit of the firm with highest income (a kind of "leader" firm) must keep the same or increase with the entrance of a new member.

3.2. Analytical Solution

As before, we perform the analytical solution by considering only nine firms because of the difficult on calculation. These firms may join the Research Joint Venture (RJV) and maximize joint profits. There is full information sharing between the RJV participants ($\beta = 1$), while for the remaining (*n*-*m*) firms, $\beta \in (0, 1)$.

The R&D output that results from the solution on a second-stage Cournot for cooperating firms is defined by:

$$x_i^c = f\left(a, \beta, \gamma, \alpha_j^N, \alpha_i^c\right) \quad \textbf{(14)}$$

with x_i^c meaning the R&D output of a firm in the network. As for α_j^N, this parameter recalls the marginal cost of an outside firm, while α_i^c, is the one for RJV firms. And the same applies to the non-cooperating firms:

$$x_j^N = f\left(a, \beta, \gamma, \alpha_j^N, \alpha_i^c\right) \quad \textbf{(15)}$$

where x_j^N is the R&D output of a non-member. The other variables have the same meaning as the ones referred above. For calculating the output of each firm we have also to compute the equations for each case, as the number of firms in the network changes. For instance, when we have 2 companies in the network and the others outside it, the equations for firm one (cooperating) and three (non-cooperating) are:

$$q_i^c = f(a, \beta, x_i^c, x_j^N, \alpha_i^c, \alpha_j^N) \quad \textbf{(16)}$$

with q_i^c equal to the output produced by a company belonging to the R&D network, and

$$q_j^N = f(a, \beta, x_i^c, x_j^N, \alpha_i^c, \alpha_j^N) \quad \textbf{(17)}$$

where q_j^N represents the output produced by a non-member of the network.

Due to the complexity of the solution for the equilibrium R&D output, and as we did in the previous part, we decide to use numerical simulations. We explore them in the next section.

3.3. Numerical Results

We use the same structure of the first algorithm, and again it was implemented using R language (R Development Core Team, 2005). The outline of the algorithm is presented in the appendix 2. First, we started with the initialization of the main parameters of the model, the values *a*, *b* of equation (1), the spillover (β) of the firms outside the network, and all the other relevant values to set up the simulation..The main parameters have been initialized in the following manner: *a*=80, γ=100, *n*=9 (number of firms in the market), *m*=2 (number of firms in the network).

As said previously, to make the algorithm work it is necessary to establish some initial values for the number of repetitions of the cycle, and we set Generations = 20.From the simulations made we obtain very interesting results on the behaviour of firms and also we get a significant amount of data that was very useful to understand the gains and the differences between cooperating and non-cooperating firms. Regarding firms' asymmetry, it is possible to say that, in general, firms with low marginal production costs have higher profits, produce more output and are those who do more research, which means that they have higher R&D output. The R&D output values tend to grow when the spillover decreases, which means an increasing necessity of research because the less the spillover the less know-how spreading between firms, so they have to produce more R&D output in order to reduce production costs.

We then test some combinations of firms, with different marginal costs of production, in order to evaluate if there are some changes in the firms within the network. Not in all combinations but in most of them, network stability occurred for low levels of spillover. This means that when the spillover reaches a lower level, firms prefer to join the R&D network in order to benefit from a total share of research output and then have less production costs and so higher profits, contrasting with same background firms. The network advantages make possible firms with the same marginal costs of production have different profits, as the ones inside the RJV reduce more their production costs due to R&D output spread between them.

A relevant fact is that some networks are formed by a mix of firms with better and worse production skills. Therefore, with some exceptions, cooperation takes place not only between firms with high or low efficiency, but they are formed by middle marginal cost companies or joint "extreme marginal cost" firms where the ones with the lowest production efficiency are the most benefited by cost reduction.

On the profits issue, we can state that they tend to diminish with the fall of the spillover since the marginal production costs are not so reduced by efficiency achievements. Only if the firm belongs to the RJV then its profit increases in the first moment when the company joins the network.

3.3.1. Experiment Results

From all the data we select just an example to help us to show the conclusions reached on the R&D cooperation. In the following tables we sum up the results of one of the experiments where it is considered the first RJV joining criterion and where it is possible to confirm all the conclusions made. It was taken a group of companies that have different marginal costs of 10, 20 and 5. We verify that there is network formation for levels of spillover below 0.29, while for higher values it is profitable for companies not to cooperate. When 0.29 is reached, two of the more efficient firms (7^{th}, 8^{th}) join a network with a less efficient firm - the 4^{th}.

	Firms								
Spillovers	1^{st}	2^{nd}	3^{rd}	4^{th}	5^{th}	6^{th}	7^{th}	8^{th}	9^{th}
0,75	419,84	421,04	419,84	110,29	110,29	110,29	649,43	649,43	649,43
0,5	417,71	419,61	417,71	109,21	109,21	109,21	646,77	646,77	646,77
0,3	416,28	416,28	416,28	109,73	108,40	108,40	645,09	645,09	645,09
0,29	415,85	415,85	415,85	**112,92**	108,18	108,18	**655,64**	**655,64**	644,56
0,27	415,29	415,29	**426,33**	107,88	107,88	107,88	**657,44**	**657,44**	643,88
0,1	412,64	412,64	**428,04**	106,39	106,39	106,39	**659,41**	**659,41**	640,75
0,03	411,39	411,39	**428,80**	105,69	105,69	105,69	**660,28**	**660,28**	639,28

Table 2: Firm's profits determined on the simulation experiments made.

In table 2 we can observe that firms with the same initial parameters attain a different profitable situation, as 7^{th} and 8^{th} have higher profits (655.64>644.56) than the 9^{th} firm, as well as the less efficient firm (112.92>108.18) has higher profits than the other equally inefficient firms. Profits, as noticed before, for all firms tend to decrease when they are not in a RJV. For example, firm number 1 with marginal cost of 10 has firstly a profit of 419.84 (spillover=0.75) and it diminishes till 411.39 (spillover = 0.03). The same happens to the other firms. But, when they join the network, because of the gains in R&D cooperation, their profits tend to increase. For example, firm number 3 earns 415.85 when spillover equals 0.29

but when it joins the network, for spillover values of 0.27 and less, its profits boost to 426.33 and more. This is one of the possible trends that RJV firm profits take, but is not the only one, as in other experiments RJV firms see their profits decrease. Nevertheless, their profits are still higher than the ones from companies outside the RJV with the same production conditions.

Concerning the R&D output, we can notice that it has a propensity to increase as a result of a diminishing spillover (Table 3). Nevertheless, if some firms start a cooperation arrangement their R&D output decreases, as a result of the full knowledge sharing benefit that the network agreement provides. As they will share all the research they make, they will not spend so many resources on R&D production and then their in-house R&D output decreases. We also see that R&D output decreases with the entrance in the network but it still increases if the spillover decreases outside the network. This happens because firms will have to invest more so that they can maintain themselves producing in the market, and also because their investment will almost not flow to other firms outside the network. Since the spillover is low, which decreases free riding behaviour, firms that would invest less in R&D are obliged to increase their R&D output.

	Firms								
Spillovers	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**
0,75	0,06	0,06	0,06	0,03	0,03	0,03	0,08	0,08	0,08
0,5	0,10	0,10	0,10	0,05	0,05	0,05	0,13	0,13	0,13
0,3	0,14	0,14	0,14	0,07	0,07	0,07	0,17	0,17	0,17
0,29	0,14	0,14	0,14	**0,06**	0,07	0,07	**0,13**	**0,13**	0,17
0,27	0,14	0,14	**0,11**	0,07	0,07	0,07	**0,14**	**0,14**	0,17
0,1	0,17	0,17	**0,13**	0,09	0,09	0,09	**0,16**	**0,16**	0,21
0,03	0,18	0,18	**0,14**	0,09	0,09	0,09	**0,18**	**0,18**	0,22

Table 3: Firm's R&D output determined on the simulation experiments made.

We then can clearly demonstrate that it augments when the spillover drops. As we can state by looking again at firm 1, we can observe that its output, when the spillover is 0.75, is much higher than when the spillover is 0.03. It also happens to firm 5 although the total output is lower than the total output of firm one (0.06>0.03 once spillover is 0.75 and 0,18>0.09 once spillover is 0.03).

Finally, regarding the output produced we see that it depends on the type of firms existing in the group, more precisely, the asymmetry between firms' marginal cost of production (Table 4). In fact, when there are firms with different levels of efficiency, those that are more productive normally tend to increase their output while the less efficient ones see their output reduced. Increasing production costs as a result of less knowledge exchange (spillover) leads to less capacity to produce output for companies with low productive skills. However, this situation changes if a network arises. If this happens, cooperating firms produce more than in a non-cooperation scenario, mainly if compared with other firms with the same parameter background.

	Firms								
Spillovers	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**
0,75	20,54	20,54	20,54	10,54	10,54	10,54	25,55	25,55	25,55
0,5	20,56	20,55	20,56	10,54	10,54	10,54	25,57	25,57	25,57
0,3	20,56	20,56	20,56	10,50	10,51	10,51	25,58	25,58	25,58
0,29	20,51	20,51	20,51	**10,64**	10,46	10,46	**25,64**	**25,64**	25,53
0,27	20,50	20,50	**20,68**	10,45	10,45	10,45	**25,68**	**25,68**	25,52
0,1	20,47	20,47	**20,73**	10,39	10,39	10,39	**25,73**	**25,73**	25,50
0,03	20,45	20,45	**20,76**	10,37	10,37	10,37	**25,76**	**25,76**	25,49

Table 4: Firm's output determined on the simulation experiments made.

By examining the behaviour of output values, we realize that it normally tends to increase when there is no network formation, although some less efficient firms may face a decrease on output created. After a RJV arises there is a decrease on output produced by firms outside the network and a continuous increase on output from RJV firms. Thus, by looking to the example, when the spillover falls from 0.75 to 0.50 the output rise for all firms, but in the next phase the output continues to increase for the more efficient firms but it decreases for the less efficient firms. For example, we see that, firstly, firms 1, 4 and 7 produce more output (20.56>20.54; 10.54>10.54; 25.57>25.55), but when the spillover is 0.3, for instance the output produced is for firm one, four and seven 20.56 (<20.56), 10.50(<10.54) and 25.58(>25.57), respectively.

When some firms initiate a cooperative network their output increase and it is higher than the one produced by non-cooperating firms with the same production efficiency. As we see above, by joining the network, firms 4, 7 and 8 produce more output than before. And as for the last two, they continue to increase their output for lower spillover values. This exemplifies what was said above about how firms' output change with the spillover.

3.3.2. Numerical results for different entering decision criteria

Companies inside the network have, in this algorithm, the last word on letting or not outside firms to enter the network. Three different entering criteria were defined that turned different numerical results mostly significant on network stability, as it was explained in section 3.1.

All the parameters referred above maintain the same properties. The main difference between decision criteria is the number of companies that are allowed to enter the network. In some experiments the number of firms inside the network is higher when two different criteria are compared.

Generally it is possible to visualize which criterion is more flexible and make easier the entrance of new companies inside the RJV. As we can see in figure 7, the spillover necessary to make a network arise is higher for criterion 2, followed by criterion 1 and then 3, the least advantageous criterion. We may note that when considering the third criterion, which assumes that the profit of the leader firm must not decrease with the entrance of a new member, only in four experiments there was a network formed. On the other hand in the experiments with the second criterion, where the profit of the entering firm is higher than the network average profit, there is always a network formed. Therefore, circumstances necessary to generate a RJV are less tough in the second criterion than for the other possible criteria.

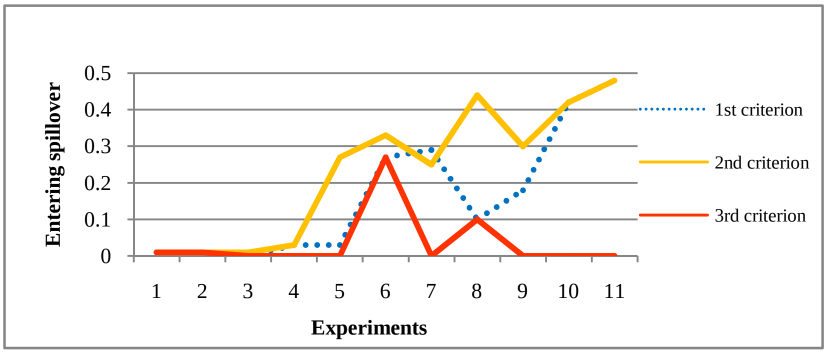

Figure 7: Spillover value needed to form a network for each criterion

Regarding the first criterion used, where the inside companies only let a new firm to enter if the average network profit increases after its incoming, there is a high tendency to arise a cooperative network. By considering different levels of spillover (Table 5), we may conclude that with this kind of decision, the number of firms in the network is usually of 2 and 3:

Network Formation			
Experiments	**Costs (1st to 9th firm)**	**Spillover**	**Number of**
1	10,20,30,40,50,60,70,80,90	0,01	2
2	10,10,10,40,50,60,90,90,90	0,01	2
4	40,40,50,50,60,60,70,80,90	0,03	3
5	80,80,80,80,80,90,90,90,90	0,03	3
6	90,80,70,60,50,40,30,20,10	0,27	4
7	10,10,10,20,20,20,5,5,5	0,29	3
8	20,20,20,20,20,20,5,5,5	0,1	3
9	1.5,3,4.5,6,7.5,9,10.5,12,13.5	0,18	2
10	3,3,3,3,3,13.5,13.5,13.5,13.5	0,42	3
11	13.5,13.5,13.5,13.5,3,3,3,3,3	0,48	3

Table 5: Spillover and number of firms in the network when using the first entering criterion

About the second decision criterion, where a firm outside the network only enters if its initial profit is superior to the network average profit, it presents a bigger number of cases where network take place. In the experiments made with this criterion, firms enter on a cooperative network more easily. The number of companies inside the network is higher than in the previous criterion for almost experiments made: there were usually four or more companies inside the RJV (Table 6):

Network Formation			
Experiments	Costs (1st to 9th firm)	Spillover	Number of firms
1	10,20,30,40,50,60,70,80,90	0,01	2
2	10,10,10,40,50,60,90,90,90	0,01	3
3	5,40,40,40,40,40,40,40,90	0,01	5
4	40,40,50,50,60,60,70,80,90	0,03	4
5	80,80,80,80,80,90,90,90,90	0,27	4
6	90,80,70,60,50,40,30,20,10	0,33	4
7	10,10,10,20,20,20,5,5,5	0,25	4
8	20,20,20,20,20,20,5,5,5	0,44	4
9	1.5,3,4.5,6,7.5,9,10.5,12,13.5	0,3	4
10	3,3,3,3,3,13.5,13.5,13.5,13.5	0,42	5
11	13.5,13.5,13.5,13.5,3,3,3,3,3	0,48	4

Table 6: Spillover and number of firms in the network when using the second criterion

The last criterion is the one with worse results in what respects the network formation (Table 7). New firms can only enter the network if the company having the maximum profit maintains the profit at the same value or increases it while the newcomer enters. With this harsh criterion, as referred above, only in four cases there is network formation. In table 7 below we see how network formation works under this criterion for experiments where network arises.

Network Formation			
Experiments	Costs (1st to 9th firm)	Spillover	Number of firms
1	10,20,30,40,50,60,70,80,90	0,01	2
2	10,10,10,40,50,60,90,90,90	0,01	2
6	90,80,70,60,50,40,30,20,10	0,27	4
8	20,20,20,20,20,20,5,5,5	0,1	3

Table 7: Spillover and number of firms in the network when using the third criterion

We made some statistical tests in order to corroborate the relationships and the effects of the variables in the experiments. One–way ANOVA has been computed, considering the effect of several values of the marginal cost (here used as a factor/qualitative variable), over the profit of the firms. The overall null hypothesis has been rejected at 0.05 level of significance, meaning that different marginal costs produce different levels of profits in the firms. Post-hoc multiple comparisons tests (Tuckey HSD) have been performed and we were able to conclude that lower marginal costs are associated with higher profits.

We have also compared the profits between networked and non networked firms. The result of the Mann-Whitney test is that statistically significant at 0.05 level of significance, showing that there are differences between firms: firms in networks have higher profits than those outside the networks.

4. Final remarks

In this study, we analyzed the membership in R&D cooperation networks and its impact on some economic indicators. Our main research hypothesis was that the membership in cooperation networks is related to the degree of the knowledge spillover. We first developed an analytical model where we considered that production costs were symmetric between all companies in the market. We then used numerical simulations to find the solution for the equilibrium of R&D output, proceeding in the next moment with computational simulations in order to verify our hypothesis. The conclusions obtained were that the profit of firms in the network is higher than the corresponding profit outside the network. Additionally, from our computational exercise, we may conclude that an increase of the R&D spillover outside the RJV will make firms benefit from other firms' knowledge, and, therefore, increase their profits. We also observed that as the R&D cost (γ) increases, each firm's profit also increases, but with a higher effect on the RJV firms than for the case of no cooperation. Finally, we observed that as the number of firms in the market increases, the R&D output decreases due to the fact that the spillover is greater for larger number of firms in the market and the need for R&D output is inferior.

However, has referred above, all firms entered in the network independently of the environment they face in the market, which does not agree with empirical evidence. So, in order to get more realistic results, a new approach was attempted by introducing cost asymmetry. By doing this we could find that a network, for some level of spillover, would arise but without all companies entering it. Only some would be able to join together and benefit from R&D cooperation. They benefited from higher profits and from R&D of other companies which reduced their production costs and they also produced more output. Nevertheless, networks also depended on how companies manage the RJV. The formation and maintenance of a network depended on what were the entrance and exit decisions defined by firms. As seen before, there were types of decisions that leaded to easier network formation and others did not. Depending on what were the minimum requirements for companies to belong to the network the easiest or more difficult, networks were arranged.

By comparing the two approaches – symmetric *vs.* asymmetric production costs - we reached the conclusion that the second one was more close to reality. In both cases the number of firms in the network kept stable but on the first model companies entered into the network regarding any kind of situation while in the second model there was entrance only for some levels of spillover and in only some circumstances making the simulation more alike to reality firms' behaviour.

But, whatever the approach was, the gains to companies that joined the network were higher, as R&D cooperation was a way of improving efficiency on companies that joined the RJV. And its impact on profits was showed vital to their performance on the model.

In spite of exhibiting some limitations (e.g. by considering only asymmetry in production costs, and excluding asymmetric spillovers between firms), this research could be improved in some directions. One possibility is to introduce endogenous spillovers between firms, that is, the level of spillover among firms could depend on their location, the R&D investment made by each firms, etc... Another possibility is to consider vertical links between asymmetric firms (suppliers-buyers) with both horizontal and vertical spillovers.

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Appendices

Appendix 1: Algorithm - Part I

CoopR - Repeated Cooperation Game

Initialization: set up of simulation parameters a, b (equations 1 and 2), beta (equations 3 and others); Marginal costs C (equation 3), R&D costs γ (equation 5); The outputs Q and q and R&D investment X are set up as vectors with Normal distributions (equations 3, 4 and 6); The individual profit □i and the networks' profit have been set up respectively in 2 and zero.

Repetition of the Game (Cycle)

Repeat for all generations {

Repeat for all firms in the market {

2.1. Compute investment in R&D

2.2. Compute individual profit

2.3. Compute network profit

2.4. Compute possible profits by considering the entrance in the network or the exit of a firm of the network

2.5. Cooperation decision: test conditions (7), (8),(9) to verify if new firms enter in the network or if there are firms that want to get out of the network

2.6. Output decision (qi*)

Appendix 2: Algorithm - Part II

Coop1R - Repeated Cooperation Game

Initialization: set up of simulation parameters a, b (equations 1 and 2), beta (equations 3 and others); Marginal costs C (equation 3), R&D costs γ (equation 5); The outputs Q and q and R&D investment X are set up as vectors with Normal distributions (equations 3, 4 and 6); The individual profit πi and the networks' profit have been set up respectively in 2 and zero.

Repetition of the Game (Cycle)

Repeat for all generations {

2. Repeat for all firms in the market { (for each set of equations that represents each number of possible members of the network)

2.1. Compute investment in R&D

2.2. Compute individual profit

2.3. Compute network profit

2.4. Output decision (qi*)

2.5. Compute possible profits by considering the entrance in the network or the exit of a firm of the network

2.6. Cooperation decision: test conditions (7), (8) and (9) to verify if new firms enter in the network or if there are firms that want to get out of the network

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Faculdade de Economia da Universidade do Porto
Rua Dr. Roberto Frias, 4200-464 Porto | Tel. 225 571 100
Tel. 225571100 | www.fep.up.pt