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Research Joint Ventures in an International Economy

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Abstract

D'Aspremont and Jacquemin's (1988) model is extended to study alternative configurations of research agreements in a two–country integrated world economy. Under unambiguous conditions on spillovers we show that: 1) Allowing national firms to cooperate in R&D confers them an advantage over foreign rivals, an effect similar to R&D subsidies. 2) In a policy game, each government would allow national cooperative agreements. 3) Contrary to other trade policies which lead to a "prisoners' dilemma" result, welfare in both countries increases when they both allow R&D cooperation. 4) Welfare is even higher if a generalized (international) coalition is formed.

I. Introduction.*

Cooperative research and development (R&D) agreements are not necessarily beneficial to the collectivity. On the positive side, they allow partner firms to internalise positive externalities such as spillovers of knowledge and to exploit possible synergies. This tends to increase both the level of R&D activities and their efficiency (duplications of innovative projects can be avoided and costs can be shared). On the negative side, if the firms which take part in the R&D agreement are rivals in the product market, cooperation in R&D investments tends to reduce competition since the profit-stealing incentive for R&D is missing.

In recent years studies on cooperative R&D ventures have examined the conditions under which they have a net beneficial effect. Katz (1986) shows that they are more likely to be welfare improving the lower the degree of product market competition and the higher the technological spillovers. D'Aspremont and Jacquemin (1988) analyse a simple model of duopoly and find that R&D cooperation at the precompetitive stage brings about higher R&D, output and welfare than the non-cooperative solution, provided that spillovers are high enough. A number of works have been built upon these two contributions. [For a recent survey, see Geroski (1993).]

The main result of these theoretical works is that if technological spillovers are high enough, pre-competitive R&D agreements improve welfare. This also provides the rationale to give cooperation in R&D a special treatment. While antitrust policies usually discourage every type of cooperation among firms, they have recently granted a special status to R&D ventures.[1]

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[1] We refer in particular to the block exemption under Article 85(3) of the Treaty of Rome granted by the EC Commission in 1985, and to the National Cooperative Research Act of 1984 in the US [see Jacquemin (1988) and

In this paper we deal with the international impact of such ventures. We present an example which extends work by d'Aspremont and Jacquemin (1988) in two ways. Firstly, while attention in this literature has been mainly focused on industry-wide R&D agreements, i.e. cooperative research involving all the firms operating in the industry [notable exceptions are Kamien and Zang (1993), Katz (1986) and Wu and De Bondt (1991)], we also consider alternative configurations (e.g. coalitions which do not cover the whole industry). Secondly, we set the analysis in an international economic framework, to analyse the strategic role that R&D agreements can play in international competition.

More specifically, we consider here an <u>integrated</u> two-country economy. A duopoly is assumed to exist in each country. A three-stage game is analysed. At the first stage, governments decide whether to allow national firms to cooperate in R&D activities or not. At the second stage, firms choose their level of R&D investments, assumed to be of a cost-reducing type. Technological spillovers in R&D activities are assumed: If firms do not cooperate, a part of their innovation output will leak to rival firms. If firms cooperate, they will share their innovation output. At the third stage, firms compete <u>non-cooperatively</u> on the integrated output market.

Under certain conditions on spillovers, it is shown that: (1) Allowing national firms to cooperate on R&D confers them an advantage in the international market, much in the same way as granting domestic firms an R&D subsidy gives them a strategic advantage in the literature on strategic trade policy [see eg. Brander and Spencer (1983)]. (2) At the equilibrium of the policy game played by the two national governments they both allow domestic firms to cooperate among themselves. (3) When the two national coalitions are formed, this does not result in a "prisoners' dilemma" outcome. Indeed, when the two countries authorise cooperative agreements, welfare gains arise for both of them. This is a result which distinguishes the R&D cooperative policy from other strategic trade policies like R&D subsidies.

Finally, we show that the same conditions ensure that industry-wide international cooperative agreements should be allowed. Were all the firms in the industry to cooperate in R&D activities at the pre-competitive stage, welfare would rise in both countries.

The plan of the paper is as follows. In section 2 we present the model. In section 3 we study the

Geroski (1993)].

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three alternative configurations about R&D investments which represent the basis of our analysis of the policy game: [i] fully non-cooperative case; [ii] R&D cooperation by two firms in one country whereas firms in the other country behave non-cooperatively; [iii] two R&D cooperative agreements with two national firms taking part in each of them. For each case we also analyse the incentives for the firms to take part in the R&D agreements. In other words, we check that firms do not have any incentive to defeat the R&D coalitions.Section 4 studies the Nash equilibrium of the whole game. Section 5 considers an extension where cooperation is allowed among all the firms in the industry. Section 6 concludes the paper.

2. The model.

In this section we present a homogeneous good (non-tournament) model of cost-reducing R&D with spillovers, which can be considered a variant of d'Aspremont and Jacquemin (1988). Unless explicitly specified, we use the standard assumptions first introduced by these authors. We consider the following scenario. The world is composed of two countries, A and B. When the game starts two firms are established in each country. We call A1, A2 the two firms located in country A and B1, B2 those located in country B.

The two countries are integrated so that firms face a single market whose consumers are represented by citizens of both countries.[2] A three-stage game is analysed. At period 0, governments decide whether to allow domestic firms to cooperate on R&D activities or not. At period 1, firms decide whether to cooperate (if it is allowed) or not, and choose the amount of investments to be devoted to R&D projects. At period 2, when costs incurred in the previous period have been sunk,

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[2] Note that in international trade a standard distinction exists between segmented and integrated markets. In the former case, firms set different prices in the different markets. In the latter, the price is unique (for instance, because of arbitraging of consumers). We choose the latter formulation for simplicity. Unlike Brander and Spencer (1983), where two firms sell their product to a third country, we need to analyse explicitly the impact of R&D agreements on consumer surplus, since we should take into account the possible negative effect of these agreements on output competition.

they decide on quantities to be brought to the market. Full non-cooperation is assumed at this stage of the game.

The inverse demand function of the world market is given by:

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

where a is a positive parameter, p is the market price and $Q = \Sigma q_i$ is the aggregate quantity sold by the four firms in the international market.

The firms in the industry are perfectly symmetrical. In particular, they have the following marginal costs c_i:

$$c_i (x_i, x_{-i}) = C - (x_i + \Sigma_{j \neq i} \beta_j x_j) \qquad i = A_1, A_2, B_1, B_2; \; i \neq j.$$

$$0 < C < a; \quad C \geq (x_i + \Sigma_{j \neq i} \beta_j x_j); \quad Q \leq a; \tag{2}$$

where C is a positive parameter, x_i is the level of R&D investments performed by firm i and x_{-i} the vector of R&D outputs x_j carried out by its rivals.[3] The parameter β_j denotes the degree of spillovers occurring in the production of innovations. We assume that the degree of spillovers depends on whether the firms cooperate among themselves or not, as follows:

$\beta_j = \overline{\beta}$ if firm j participates in an R&D agreement with firm i.

$\beta_j = \underline{\beta}$ if firm j does not participate in an R&D agreement with firm i, where in general it would be: $1 \geq \overline{\beta} \geq \underline{\beta} \geq 0$.[4] This amounts to saying that the knowledge produced by firm i which spills over a firm j is larger when firms i and j share their decisions on R&D rather than when they do not cooperate on investments in R&D. For simplicity, throughout the paper we take $\overline{\beta} = 1$, implying that firms which cooperate on R&D agreements share their information completely.[5] This corresponds to the case of Research Joint Ventures, for example [see Kamien et al. (1992)].

The spillover $\underline{\beta}$ represents a "technological leakage" parameter, i.e. the degree of knowledge that

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[3]For a treatment of R&D cooperative agreements where firms engage in quality-improving rather than cost-reducing R&D see Motta (1992b).

[4] This assumption is borrowed from Katz (1986), whereas d'Aspremont and Jacquemin (1988) assume $\overline{\beta} = \underline{\beta}$, which does not allow for any synergy among cooperating firms. Note that d'Aspremont and Jacquemin's objective was to show that R&D cooperation can be welfare-improving. When $\overline{\beta} > \underline{\beta}$ their main result would have obviously been reinforced.

[5] In Motta (1992a) similar results to those proved here are obtained through numerical solutions under the assumption that $\underline{\beta} \leq \overline{\beta} \leq 1$.

flows involuntarily from one firm to another. This parameter is likely to be higher the less protected are technological innovations (if patents are not easily enforced, or if they do not ensure complete protection from imitators) and the easier is "reverse engineering".[6]

Firms also incur costs of R&D according to the following:

$$F_i (x_i) = g \ x_i^2/2 \qquad\qquad g>0. \qquad\qquad\qquad (3)$$

The quadratic cost function reflects the existence of diminishing marginal returns to R&D expenditures, a standard assumption.

For simplicity, neither transportation nor other additional costs of selling the good abroad are considered.

A feature of the present paper is that we deal with the possibilities that (i) only a subset of the firms coordinate their decisions on R&D and (ii) more than one agreement is made within the industry.[7] This is the object of the next section.

3. The equilibrium solutions for the alternative R&D configurations.

In this section we study different scenarios occurring at the R&D stage of the game, according to different hypotheses on R&D configurations that can arise among the four firms, and under the hypothesis that firms anticipate the outcome of the output stage of the game. Three main cases are considered: [1] Non-cooperation; [2] Firms from country B cooperate on R&D expenditures while country A's firms do not coordinate their decisions ("unilateral cooperation" case); [3] A coalition is formed in each country: the two national firms cooperate on R&D between them, while acting non-cooperatively with respect to firms in the other country ("retaliation").[8] .

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[6] See Geroski (1993) for a discussion of technological, pecuniary and environmental externalities in R&D.

[7]Katz (1986) considers the case where k<n firms cooperate in a unique R&D agreement, but only under the assumption that β =0. Wu and De Bondt (1991) assume instead that $\beta= \bar{\beta}$.

[8]The name "retaliation" is chosen for evocative reasons. It is not a rigorous terminology in that we do not analyse here a dynamic game: governments make contemporaneous decisions on the policy on R&D agreements.

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The policy game played by national governments (section 4) will be built upon the results obtained in the present section.

Whatever the type of coalition considered, throughout the paper we maintain the assumption that firms compete non-cooperatively at the second stage of the game.

For each of the four cases considered above we seek a sub-game perfect equilibrium in R&D investment levels x and quantities q. We use the standard backward technique and begin by finding the Cournot-Nash solution of the last stage of the game.

Output sub-game.

The standard Cournot problem for <u>given</u> levels of R&D invested by firms gives the following equilibrium output:

$$q_i = (a - 4c_i + \Sigma c_j) / 5; \qquad\qquad (4)$$

By substituting we can find equilibrium prices and net profits at the first stage of the game, as:

$$\pi_i = (a - 4c_i + \Sigma c_j)^2 / 25 - g\, x_i^2/2 \qquad (i,j=A1, A2, B1, B2;\ i \neq j). \qquad (5)$$

Note that this outcome is common to all the different R&D configurations above. Starting from (5) we can then compute the solutions for the whole game under the different scenarios.

3.1 Non-cooperative equilibrium.

In this case there is no cooperation on R&D expenditures among the firms. The average costs they face at the output stage are:

$$c_i = C - x_i - \beta \Sigma_j x_j \qquad i,j=A1,A2, B1,B2;\ i \neq j. \qquad (6)$$

By substituting (6) into the profit expression (5), differentiating with respect to R&D investments x_i and solving the system of resulting F.O.C.'s we obtain (focusing on the symmetric equilibrium $x_i = x_j = x_{nc}$, where the index "nc" is used to denote the non-cooperative solution):

$$x_{nc} = 2\,(4 - 3\beta) / (-8 + 25g - 18\beta + 18\beta^2) \qquad nc=A1,A2,B1,B2 \qquad (7)$$

where (a-C) has been normalised to 1. Expression (7) gives equilibrium R&D investments when decisions on research and development are taken non-cooperatively by the four firms in the industry.

For second order conditions to be satisfied we require: $g > 2(4-3\underline{\beta})^2/25$.

It is straightforward to check that $\partial x_{nc}/\partial\underline{\beta}<0$: The higher the spillover rate $\underline{\beta}$, the lower the R&D investments made by the firms since a decrease in the degree of appropriability of the innovations reduces the incentive for the firms to carry out research projects.

By using (7) we are then able to obtain the expression for price and profits at the non-cooperative equilibrium, as follows:

$$p_{nc}= 2 - 20\, g\, /\, (-8 + 25g - 18\underline{\beta} + 18\underline{\beta}^2) \qquad nc=A1,A2,B1,B2 \qquad (8)$$

$$\pi_{nc}= g\, (-32 + 25g + 48\,\underline{\beta} - 18\underline{\beta}^2)\, /\, [(-8 + 25g - 18\underline{\beta} + 18\underline{\beta}^2)^2] \qquad nc=A1,A2,B1,B2 \qquad (9)$$

3.2 R&D cooperation among country B's firms.

The hypothesis we consider in this section is that country B's firms set a cooperative agreement on R&D investments, both agreeing to do R&D at the same level x_B, whereas country A's firms do not. This means that the degree of spillovers occurring between firms located in country B is $\bar{\beta}=1$ (B's firms share their knowledge), while the relevant spillovers with respect to the knowledge involuntarily flowing from firms of a country to their rivals located abroad and within country A's firms is $\underline{\beta}$. In formal terms we have:

$$c_B = C - x_B\,(1+ \bar{\beta}) - \underline{\beta}\, \Sigma_i\, x_{Ai} \qquad i=1,\,2;\; B=B1,B2. \qquad (10)$$

$$c_{Ai} = C - x_{Ai} - \underline{\beta}\,(2x_B+x_{Aj}) \qquad i,j=1,\,2;\; i\neq j;\; B=B1,B2. \qquad (10')$$

Recalling that we assume perfect information by the players (in particular, country A's firms know that the firms in the other country set a common level of R&D investments x_B), we can write the profit functions, differentiate them, and solve the system of FOC's (under the hypothesis of symmetry $x_{Ai}=x_{Aj}$) to obtain:

$$x_B= 2\,[6-4\underline{\beta}]\,(-8+5g+14\underline{\beta}-6\underline{\beta}^2)\, /\, [f(g,\underline{\beta})] \qquad (11)$$

$$x_A= 2\,[4-3\underline{\beta}]\,(-24+40\underline{\beta}-16\underline{\beta}^2+5g)\, /\, [f(g,\underline{\beta})] \qquad (11')$$

where: $[f(g,\underline{\beta})] = 192-80\underline{\beta}-560\underline{\beta}^2+640\underline{\beta}^3-192\underline{\beta}^4-480g+610g\underline{\beta}-190g\underline{\beta}^2+125g^2$.

Second order conditions for B's firms require: $g>2[6-4\underline{\beta}]^2/25$; for A's firms: $g>2[4-3\underline{\beta}]^2/25$.

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Throughout the paper we will focus on the case where g>72/25. This is a sufficient condition for the second order conditions in the different coalition configurations to be always satisfied. We will also restrict our attention to ß>.28. This is to avoid the study of corner solutions (with $x_A=0$). We can then establish the following:

Proposition 1. If $g \geq 72/25$ and.$28 \leq \beta \leq 1$, then $x_B > x_A > 0$.

Proof. See Appendix.

Note that $x_B > x_A$ because the full exchange of information occurring in a cooperative research venture represents a stronger incentive to carry out research for the cooperating firms B than for the remaining firms, which are not able to internalise the spillovers. In other words, this encourages national firms to carry out more R&D and thus to become more competitive vis-a-vis foreign rivals.

By using (11)-(11') one can then find price and net profits at the "unilateral cooperation" equilibrium with country B's firms cooperating on R&D investments and country A's firms behaving non-cooperatively at the R&D decision stage:

$$p_{UC} = 2 \ (192-80\underline{\beta}-560\underline{\beta}^2+640\underline{\beta}^3-192\underline{\beta}^4-320g+340g\underline{\beta}-80g\underline{\beta}^2+75g^2) \ / \ [f(g,\underline{\beta})] \qquad (12)$$

$$\pi_B = g \ (-8+5g+14\underline{\beta}-6\underline{\beta}^2)^2 \ (-72+25g+96\underline{\beta}-32\underline{\beta}^2) \ / \ [f(g,\underline{\beta})]^2 \qquad (13)$$

$$\pi_A = g \ (-24+5g+40\underline{\beta}-16\underline{\beta}^2)^2 \ (-32+25g+48\underline{\beta}-18\underline{\beta}^2) \ / \ [f(g,\underline{\beta})]^2 \qquad (13')$$

It could be shown that $\pi_B > \pi_A$ unless the value of the spillover parameter $\underline{\beta}$ becomes very high. This is due to the high level of R&D investments carried out by the cooperating firms B.[9] Since a large part of it spills over to firms A, they are able to decrease their costs without incurring the large R&D expenses of firms B. The cooperating firms B provide then a public good to the other members of the industry in the form of increased knowledge.[10]

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[9]When $\underline{\beta} = 1 = \bar{\beta}$, π_B is smaller than π_A. This is consistent with the result that outsiders' profits are always (weakly) larger than profits earned by participants in the R&D cartel obtained by Wu and De Bondt (1991) under the assumption $\bar{\beta}=\underline{\beta}$.

[10]This suggests an analogy with the literature on cartels and horizontal mergers. Salant et al. (1983) show that in the presence of a homogeneous good and competition à la Cournot, members of a cartel might earn lower profits than at the fully non-cooperative equilibrium. This result comes from the fact that cartel members reduce their output to offer high

This brings us to the problem of the incentive to form an R&D coalition in our model. So far we have just assumed that country B's firms cooperate if they have the possibility to do it, namely that when the national government decides to permit R&D cooperative agreements, the domestic firms exploit this opportunity. We shall now check if this is true, or if instead firms B do not have any incentive to set the cooperative agreement. To do so we shall use a concept proposed by d'Aspremont et al. (1983): A coalition is called "stable" when it is both *internally* and *externally* stable, that is when members do not have an incentive to defeat the coalition and at the same time outsiders do not have an incentive to join it.

In the situation studied here, where firms from country A cannot cooperate in R&D, each firm from country B knows that either it strikes an agreement with the co-national firm, which yields a profit π_B, or it defeats the agreement by falling back to the fully non-cooperative situation, where it would gain profits π_{nc}. By comparing these two profits we obtain:

Proposition 2. If $g \geq 72/25$ and $.28 \leq \beta \leq 1$, then $\pi_B > \pi_{nc}$.

Proof. See Appendix.

The fact that π_{nc} is smaller than π_B ensures internal stability, i.e. that country B's firms do have a private incentive to form a R&D cooperative agreement. Since we restrict possible cooperation to firms located in the same country and since we assume a duopoly in each country, we do not need to check for external stability. The same reasoning applies to all the cases treated under the hypothesis that authorities only allow for domestic R&D joint ventures. We make use of the external stability criterion in section 5, where international agreements are studied. Private interest in the R&D agreement also means that a government does not have to encourage the R&D agreements with subsidies or other monetary incentives.

3.3 The case of "retaliation": domestic R&D cooperation in both countries.

prices in the industry. In other words, they incur the costs of offering a public good (high prices) whose benefit goes mainly to the remaining firms operating in the industry.

In this paragraph we consider the case where both countries A and B allow domestic firms to make a cooperative agreement in R&D. We call this case "retaliation" for simplicity as well as for evocative reasons, although it should be clear that the decision of permitting R&D agreements is made simultaneously by the two governments. Since $\bar{\beta}=1$ all the knowledge produced by a firm Ai (resp. Bi) goes to firm Aj (resp. Bj), but only a fraction $\underline{\beta}$ spills over firms located in country B (resp. A).

$$c_A = C - 2 x_A - 2 \underline{\beta} x_B \tag{14}$$

$$c_B = C - 2 x_B - 2 \underline{\beta} x_A \tag{14'}$$

By restricting attention to the symmetric equilibrium $x_A=x_B=x_R$, we find the equilibrium solution:

$$x_R=2 (6-4\underline{\beta}) / (-24 + 25g - 8\underline{\beta} + 16\underline{\beta}^2) \tag{15}$$

Second order conditions for this to be a maximum are $g>2[6-4\underline{\beta}]^2/25$, always satisfied under our assumption $g>72/25$. Profits earned by the firms are:

$$\pi_R=g (-72 + 25g +96\underline{\beta} -32\underline{\beta}^2)/ (-24 + 25g - 8\underline{\beta} + 16\underline{\beta}^2)^2 \tag{16}$$

The main effect of the simultaneous cooperative agreements is to stimulate competition between the two national groups. Since both of them find an incentive to raise their R&D levels, this results in an increase of R&D investments with respect to the non-cooperative situation ($x_R > x_{nc}$).[11] When comparing profits arising in this case with those relative to the non-cooperative solution, it can be shown (the proof can be obtained upon request) that $\underline{\beta} >.5$ is a sufficient condition for $\pi_R > \pi_{nc}$. Indeed, when spillovers from one group of firms to the other become important the cost-reduction effect due to the externality outweighs the negative effect of the increased spending in R&D.

As in the previous section 3.2, we have to check that the configuration analysed here, with a coalition in each country, is stable in the sense that firms from a country do not have an incentive to withdraw from their domestic R&D coalition subject to firms of the other country cooperating on R&D.

Profits from cooperation when there exists a R&D coalition by foreign firms are given by π_R. If a firm defeats the domestic coalition, it will get π_A (the profit earned by a firm when firms abroad have

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[11] The inequality $x_R > x_{nc}$ is solved for $g>(4/25)(\underline{\beta}-1)(2\underline{\beta}-3)(3\underline{\beta}-4)/(2-\underline{\beta})$. Since this value is negative, the inequality is always satisfied.

a R&D joint venture). The following proposition confirms that the configuration with two coalitions is stable.

Proposition 3. If $g \geq 72/25$ and $.28 \leq \beta \leq 1$, then $\pi_R > \pi_A$.

Proof. See Appendix.

4. The policy game played by the governments.

In this section we look for an equilibrium of the whole game by solving the first (policy) stage of the game, under the assumption that governments anticipate the outcome of later stages. Table 1 summarises the payoff matrix. Governments can either allow domestic firms to cooperate with each other or not. Their objective function is the welfare of the country, defined as:

$$W_i = 2\pi_i + CS_i \qquad (i=A, B, R, NC) \qquad (17)$$

Note first of all that the indices used are the same as in section 3. So, W_i, π_i, CS_i are respectively welfare, firms' profits and consumer surplus under the assumptions that the government does not allow domestic firms to cooperate (A) while the other does (B) - or vice versa; that both governments allow domestic firms to carry out R&D agreements (R); that neither allows them (NC). Consumer surplus is computed in the usual way. Finally, note that no additional term enters the welfare function. In particular, no subsidy or monetary help is given to firms in the case governments decide to allow R&D ventures.

By making use of the equilibrium solutions found in section 3 we can then compute welfare associated to each case of the payoff matrix (see Table 1). It is straightforward that both countries choosing a policy which permits domestic R&D cooperation is a Nash equilibrium if $W_B > W_{NC}$ and $W_R > W_A$. The following propositions establish this result.

Proposition 4. If $g \geq 72/25$ and $.28 \leq \beta \leq 1$, then $W_B > W_{nc}$.

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Proof. See appendix.

Proposition 5. If g≥72/25 and.28≤β≤1, then $W_R > W_A$.

Proof. See appendix.

At the Nash equilibrium, both governments will then choose an antitrust policy which allows national firms to cooperate between them, and the resulting payoff for both of them will be W_R. We can now summarise our game and in particular explain why R&D cooperation among national firms can be seen as a very particular case of strategic trade policy.

Research joint ventures encourage domestic firms to carry out more R&D and will make them more competitive in the international market. The reduction in their costs makes their outputs larger and their profits higher. This will result in a welfare improvement for the country ($W_B > W_{NC}$), also due to the price cut which is brought about by the output expansion.

So far the story is very similar to that told by strategic trade policies like R&D subsidies, which are granted to domestic firms to make them more aggressive in the world market. However, it should be noticed that the policy of allowing R&D cooperation among national firms is not harmful to the foreign country, as the following shows.

Proposition 6. If g≥72/25 and.28≤β≤1, then $W_A > W_{nc}$.

Proof. See appendix.

In other words, and unlike the usual strategic policies such as R&D subsidies, higher profits at home are not necessarily at the expense of lower welfare abroad, which shows that a R&D cooperation policy (unlike subsidies) is not necessarily of a "beggar-thy-neighbour" type.

A first possible consequence of this result is that it may reduce the likelihood that the foreign government would react against such an R&D cooperative policy. But if a response existed (indeed both countries decide to allow R&D cooperation in the game studied above), both countries turn out to be even better off ($W_R > W_{NC}$) with respect to the situation where none of them allow R&D agreements, as established by the following.

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Proposition 7. If g≥72/25 and.28≤β≤1, then $W_R > W_{nc}$.

Proof. See appendix.

This means that - contrary to what happens with other strategic trade policies - the game played here does not give rise to a prisoner's dilemma outcome.

This result comes from the existence of positive externalities related to the R&D activity. The acknowledgement of these externalities brings us to the possible question of whether it would be advisable to allow industry-wide international cooperation. This is the object of the next section.

5. An extension: International R&D cooperation.

In this section we consider agreements among firms of different nationalities. We start with the case where all the four firms adopt a cooperative agreement on R&D decisions while acting non-cooperatively at the output stage of the game. Given that cooperation is now extended to all the firms operating in the industry, the unique spillover parameter existing among the firms is given by the "exchange information" rate $\bar{\beta}=1$. Denoting as x_C the common levels of R&D, common production costs are given by the following:

$$c_C = C - x_C (1 + 3\,\bar{\beta}) \qquad (18)$$

We can then obtain the equilibrium solution that, properly rearranged, can be written as

$$x_C = 8/(-32 + 25g) \qquad (19)$$

Second order conditions are satisfied if g>32/25. Profits are equal to:

$$\pi_C = g/(-32 + 25g) \qquad (20)$$

The next proposition shows that welfare is higher under full cooperation among all four firms than in the situation where two simultaneous cooperative agreements existed in the industry.[12]

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[12]One can also show that R&D investments, profits and welfare are higher under the case of full cooperation than under full non-cooperation, independently of the value of β.

Proposition 8. If $g \geq 72/25$ and $.28 \leq \beta \leq 1$, then $W_C > W_R$.

Proof. See appendix.

Therefore, were firms to make an industry-wide agreement, welfare would turn out to be higher for both countries. We have however to check that firms would implement the agreement. It is possible that such an industry-wide agreement would not be stable, in the sense that firms may have an incentive to defeat it (since we consider a coalition among all the firms in the economy, we do not need to check if there exists external stability).

Call "D" the firm which considers deviating from the coalition, while "ND" refers to the other three firms.

$$c_{ND} = C - 3 x_{ND} - \beta x_D \qquad (21)$$

$$c_D = C - x_D - 3 \beta x_{ND} \qquad (21')$$

Some standard calculations reveal that equilibrium outputs are:

$$x_{ND} = 2(6-3\beta) (-8+5g+14\beta-6\beta^2)/ \mu(g,\beta) \qquad (22)$$

$$x_D = 2(4-3\beta) (-36+5g+54\beta-18\beta^2)/ \mu(g,\beta) \qquad (22')$$

where $\mu(g,\beta)=(288-360\beta-180\beta^2+360\beta^3-108\beta^4-520g+600g\beta-180g\beta^2+125g^2)$.

It is easy to check that the function $\mu(g,\beta)$ is positive for the parameter values assumed here. One can also easily check that $x_{ND} > 0$ for $g \geq 72/25$ and $.28 \leq \beta \leq 1$. Instead, $x_D \geq 0$ only for $(-36+5g+54\beta-18\beta^2) \geq 0$. This means that under our restrictions on parameter values the deviant firm is not always able to sell. In particular, a sufficient condition for $x_D \geq 0$ is that $g \geq 72/25$ and $\beta \geq .475$. If the spillover is not high enough, the cooperating firms are much more competitive than the firm which does not participate in the agreement. However, the higher the proportion of R&D investments which spills over to the non-member firm, the more competitive the latter becomes. In the limit, if $\beta=1$ the deviant firm has the same production technology as the firms taking part in the coalition, but spends much less for R&D activities. This gives an intuition of why a firm may benefit from deviating from an industry-wide coalition in research activities, for high spillover values.

From the output values one can then compute the profits obtained by the deviating firm as:

$$\pi_D = g (-32+25g+48\beta-18\beta^2) (-36+5g+54\beta-18\beta^2)^2/ (\mu(g,\beta))^2 \qquad (23)$$

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A firm will not have any incentive to deviate from the agreement when the profits obtained by free-riding (the other three firms still cooperating) are lower than those obtained by taking part in the R&D agreement. The following proposition establishes this stability condition.

Proposition 9. If $g \geq 72/25$ and $.28 \leq \beta \leq .93$, then $\pi_C > \pi_D$.

Proof. See appendix.

When parameters fall within the values spelled out by Proposition 9, the industry-wide agreement is carried out by the firms. In turn, this brings about a higher welfare for both countries than in the case where they were allowing national R&D agreements only, as stated by Proposition 8.

However, this is not enough to conclude that under our assumptions on parameter values the countries had better promote R&D cooperation among both national and foreign firms. Indeed, we should see what happens when the industry-wide agreement is not stable. Does a three-firm R&D agreement represent a stable coalition when $\underline{\beta} > .93$? And if so, is welfare resulting from this situation higher than in the case where national governments promote only domestic cooperation?

As for the first question, we should check that for $\underline{\beta} > .93$ the coalition between three firms is stable. To do so we must prove: (a) that the coalition is externally stable, i.e. the firm out of the agreement does not wish to enter. This is already done since we have seen that $\pi_D > \pi_C$ (the profits earned by staying out of the coalition are higher than by entering it); (b) that the coalition is also internally stable, i.e., that a member firm - which earns a profit π_{ND} - does not want to defeat the agreement. If it did so, it would earn π_A, that is the profit earned by a firm which is not engaged in any R&D venture when two rivals are cooperating.[13] Proposition 10 shows that $\pi_A < \pi_{ND}$, which

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[13] Here we are focusing on the case where a firm decides only between staying in the existing coalition or leaving it. There is also another possibility, that is that the firm leaves the 3-firm coalition to form a rival coalition with the outsider firm. It is not clear what happens in this case. On the one hand, the latter firm does not have an incentive to form such a coalition since $\pi_D > \pi_R$ for $\beta \geq .93$. On the other hand, if a firm defeats the coalition, the outsider's profits would be $\pi_A < \pi_R$ which would reestablish an incentive to form a rival coalition. Therefore, to analyze rigorously this case we should specify additional rules of the game and in particular the order of the moves, which is beyond the purpose of the present section. The main point here is that if a 3-firm coalition arises then welfare is higher, as

implies that the three-firm coalition is stable.

Proposition 10. If g≥72/25 and.28≤β≤1, then $\pi_{ND} > \pi_A$.

Proof. See appendix.

As a second step we have to check that welfare when there is three-firm R&D cooperation is higher than when the authorities in the two countries allow cooperative ventures only among domestic firms. The odd-number coalition brings in an asymmetry. Consumer surplus is the same in both countries but two cooperating firms are located in one country, while a cooperating firm and the outsider are located in the other country. To see that both countries have an incentive in promoting cooperative R&D with foreign firms, we have therefore to check that: $W_{3,1} = 2\pi_{ND} + CS_{3,1} > W_R$, and that $W'_{3,1} = \pi_{ND} + \pi_D + CS_{3,1} > W_R$, where the index (3,1) refers to the case of cooperation among three firms.

Proposition 11. If g≥72/25 and.28≤β≤1, then $W_{3,1} > W_R$, and $W'_{3,1} > W_R$,

Proof. See appendix.

This completes our argument that R&D joint ventures among three or four members is welfare improving for both countries.

6. Discussion.

We have shown in this paper that allowing R&D cooperation among national firms may be seen as a type of strategic trade policy. The particular features of a such a policy should be emphasized. First, it does not necessarily harm foreign countries. Because of the role played by spillovers we also have that at the equilibrium of the policy game both governments allow for national research joint

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Proposition 11 shows.

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ventures and this in turn leads to a welfare improvement with respect to the case where firms cannot cooperate. Further, our analysis suggests that governments should allow firms to strike R&D agreements not only with domestic, but also with foreign firms.

The reader should be aware of the simplifying assumptions that we have used. We have provided here a simple example without any pretension of generality. Even with specific functional forms and the simplest (mainly standard) assumptions, the analysis attains immediately a high level of complexity.

Works on R&D cooperation under Bertrand competition tend to confirm the main results obtained under the Cournot competition hypothesis used here [see e.g. De Bondt and Veugelers (1991)]. One may then expect some robustness of the results obtained but this still has to be checked.

It should also be recalled that we make the hypothesis that the number of firms is given. One would then wish to study the robustness of the results when n_1 and n_2 firms are assumed in the two countries and, even better, when free entry is allowed.[14]

Another assumption that should be relaxed is that $\bar{\beta} = 1$ when firms cooperate in R&D. As already explained above, we believe it reasonable to assume that firms which decide to form a research agreement share all their knowledge, as is normally the case for research joint ventures.[15] Nonetheless, it can be proved that under the other extreme assumption on spillovers, $\bar{\beta} = \underline{\beta}$, a sufficient condition for all the propositions from 1 to 8 to hold good is that $\underline{\beta} > .5$ (details are available from the author upon request). However, section 5 would not make sense under this alternative assumption since a coalition of four is never stable and a coalition of three is stable only when spillovers are very close to 1.

Other qualifications apply to our analysis. The first, and more important, is that it is not clear that allowing R&D cooperation at the pre-competitive stage would not help the firms to establish contacts

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[14]The effect of cooperative R&D agreements on the number of firms which can operate in an industry has been studied in Motta (1992b), in the context of a vertical product differentiation model.

[15]Of course, one would like to have a model where the degree of information shared by partners is endogenous, but this is far beyond the scope of the present paper. See also Jacquemin (1988) for the difficulties of reaching cooperative agreements. They range from communication problems and different companies' objectives to fears that a partner could benefit from the cooperation more than the firm itself, thus reducing its competitivity on the product market.

used to relax market competition. A policy of exemption of R&D agreements from the antitrust laws, like in the EC, probably calls for a more active role of the authorities to check that this does not degenerate into full cooperation among the partners. Another important point is that theoretical work, like the present one, identify conditions, mainly on spillovers, under which cooperative agreements are welfare improving. Whether in the real world the level of spillovers is such that they would satisfy these conditions is an empirical matter.

Despite all the necessary caveats, we feel that the present paper gives some real economic insights about the issues studied. We have showed that such R&D cooperative agreements might be used as a policy to improve the international position of domestic firms. Indeed, this seems to fit quite well with many of the R&D programs implemented by the more industrialized countries. Katz and Ordover (1990) review three large-scale research consortia in semiconductors and computers: Sematech and the Microelectronics and Computer Corporation in the US, and the Very Large Scale Integration consortium in Japan. They indicate that one of the reasons which prompted public authorities to form these national cooperative ventures was that they "perceived a need to increase the effectiveness of R&D programs to improve the international competitiveness of domestic firms" (p.174).

The EC treatment of R&D ventures responds to a similar motivation. Regulation 418/85, adopted in 1985, grants a block exemption from Article 85 of the Treaty of Rome (which forbids agreements among competitors) to R&D agreements. It has been widely emphasised that one of the main reasons behind such an exemption was the willingness to increase European competitiveness in world markets, especially in high technology industries (see eg. Goyder (1992)).

The fact that European, US and Japanese governments have all promoted research agreements among domestic firms is consistent with the story we tell in this paper, where each country finds it optimal to allow such agreements. We also suggest that R&D ventures are not necessarily harmful to non-participating firms because of the externalities involved. Such a claim is certainly more difficult to check (measuring externalities and the overall effect on welfare of such measures involves all sorts of difficulty). However, we can make two observations which point to such a result. The first is that R&D cooperative ventures are normally allowed, or promoted, at the pre-competitive stages where spillovers β are larger (see e.g. Katz and Ordover (1990)). In turn, this raises the possibility that

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<u>Appendix</u>

In this appendix we prove the results stated in the text. Our recurrent problem will be to solve a constrained optimization program of the following type:

minimize $[F(g,\beta)]$ subject to: $g \leq 72/25$, $\underline{\beta} \geq .28$, and $\underline{\beta} \leq 1$.

To do so, we shall write the Lagrangean:

$$L = - [F(g,\underline{\beta})] - \lambda_g (- g + 72/25) - \lambda_1 (-\underline{\beta} + .28) - \lambda_2 (\underline{\beta} - 1) \tag{A1}$$

Proposition 1. If g≥72/25 and .28≤ß≤1, then $x_B > x_A > 0$.

Proof. The expressions of x_A and x_B are given by (11) and (11'). In both cases, the denominator is given by: $[f(g,ß)] = 192-80ß-560ß^2+640ß^3-192ß^4-480g+610gß-190gß^2+125g^2$.

Our first step is to show that the denominator is positive. We then solve the program (A1) where $F(g,ß)] = f(g,ß)$. The solution of this problem is given by: $ß=.28$, $g=72/25$, $\lambda_g =395.9$, $\lambda_1 =1190.4$, $\lambda_2 =0$. It is easy to check that $f(g=72/25, ß=.28)>0$. Hence, the function will only take non-negative values in the domain studied here.

The second step is to check that $x_A>0$. This is true iff $(-24+40ß-16ß^2+5g) >0$. By applying again the Kuhn-Tucker conditions in the way shown above, it is easy to check that the minimum of this function is attained where $ß=.28$, $g=72/25$, $\lambda_g =5$, $\lambda_1 =31.04$, $\lambda_2 =0$. Since at its minimum the function has a positive value, we can conclude that $x_A>0$.

The last step is to check the sign of the expression: $x_B-x_A = 2 (48-116ß+92ß^2-24ß^3+10g-5ß g)/ [f(g,ß)]$. By using the same method it is easy to verify that the numerator is positive, since it reaches a minimum in $ß=1$, $g=72/25$ (with $\lambda_g =5$, $\lambda_1 =0$, $\lambda_2 =18.4$), where the function attains a positive value.   (QED)

Proposition 2. If g≥72/25 and .28≤ß≤1, then $\pi_B > \pi_{nc}$.

First we write the difference between these two profit functions as:

$\pi_B - \pi_{nc} = g \{ (-8+5g+14ß-6ß^2)^2 (-72+25g+96ß-32ß^2) [(-8 + 25g - 18ß+ 18ß^2)^2] -$

$(-32 + 25g + 48 ß- 18ß^2)[f(g,ß)]^2 \} / \{ [f(g,ß)]^2 [(-8 + 25g - 18ß+ 18ß^2)^2] \}$

Since the denominator is positive, we just have to check the sign of the numerator. By applying the Kuhn-Tucker conditions, we find that the minimum is $ß=1$, $g=72/25$ (with $\lambda_g =1.47(10^6)$, $\lambda_1 =0$, $\lambda_2 =5.21(10^6)$). Since the numerator is positive at its minimum, the function is positive everywhere.   (QED)

Proposition 3. If g≥72/25 and .28≤ß≤1, then $\pi_R > \pi_A$.

Proof. We first write the difference of profits as:

$\pi_R-\pi_A= g \{ (-72 + 25g +96ß -32ß^2) [f(g,ß)]^2 - (-24+5g+40ß-16ß^2)^2 (-32+25g+48ß-18ß^2) (-24 + 25g - 8ß + 16ß^2)^2 \} / \{ (-24 + 25g - 8ß + 16ß^2)^2 [f(g,ß)]^2 \}$

By using the method that should be clear by now, it is possible to see that the Kuhn-Tucker conditions are satisfied by: $\beta=.28$, $g=72/25$, $\lambda_g =2.85(10^6)$, $\lambda_1 =8.06(10^6)$, $\lambda_2 =0$. In this point $\pi_R-\pi_A>0$, which proves our proposition. (QED)

Proposition 4. If $g\geq72/25$ and $.28\leq\beta\leq1$, then $W_B>W_{nc}$.

We have already shown in Proposition 2 that profits are higher when the country's firms cooperate and rivals do not, than under a situation of full no-cooperation. Therefore, we just have to show that $CS_B\geq CS_{nc}$. To do so, it is enough to check that a higher quantity is brought onto the market when domestic firms engage in cooperative agreements in R&D (recall that markets are integrated and that national consumption is half the international one). This amounts to showing that:

$Q_B>Q_{nc} <=> 2 x_B+2x_A - 4x_{nc} > 0 <=> (20 (8 - 5\beta + \beta^2) g (-8 + 14 \beta - 6 \beta^2+ 5 g)) / ((-8 - 18 \beta + 18 \beta^2+ 25 g) [f(g,\beta)]) > 0$.

By using the usual method it is then easy to show that both denominator and numerator are positive, as a quick inspection of the expression above also reveals. (QED)

Proposition 5. If $g\geq72/25$ and $.28\leq\beta\leq1$, then $W_R>W_A$.

Since Proposition 3 already shows that $\pi_R>\pi_A$, we just need to show that $Q_R>Q_A <=> 4x_R - (2x_B+2x_A) > 0 <=> (20 (8 - 5\beta + \beta^2) g (-24 + 40 \beta - 16 \beta^2+ 5 g)) / ((-24 - 8 \beta + 16 \beta^2+ 25 g) [f(g,\beta)]) > 0$.

All the terms are positive under the constraints of our problem. (QED)

Proposition 6. If $g\geq72/25$ and $.28\leq\beta\leq1$, then $W_A>W_{nc}$.

By using the simple definition of welfare as the sum of producer and consumer surplus, it is straightforward to compute welfare in the different cases as a function of the two parameters g and β.

$$W_A= \{200g^2(-16 + 27\beta - 11 \beta^2 + 5g)^2) + (2g (-24 + 40\beta - 16\beta^2 + 5g)^2 (-32 + 48\beta - 18\beta^2 + 25g) \} / [f(g,\beta)]^2 \qquad (A2)$$

$$W_{nc}=2g (-32 + 48 \beta - 18 \beta^2 + 125 g) / (-8 - 18 \beta + 18 \beta^2 + 25g)^2 \qquad (A3)$$

To check that $W_A-W_{nc}>0$, it is then enough to study the sign of the numerator, since the common denominator of this expression is positive. It turns out that the numerator has a solution to the

constrained optimization problem where $\underline{\beta}=.28$, $g=72/25$, $\lambda_g=3.45(10^6)$, $\lambda_1=5.46(10^6)$, $\lambda_2=0$. In correspondence of this point of minimum the numerator is positive. The function W_A-W_{nc} is therefore bigger than zero under our assumptions on parameters values. (QED)

Proposition 7. If $g\geq72/25$ and $.28\leq\beta\leq1$, then $W_R>W_{nc}$.

Since expression (A3) already gives the welfare function when no cooperation occurs among all the firms, we just need to compute welfare under the hypothesis that two different national coalitions form in the integrated market. It is easily checked that:

$$W_R= 2g\,(-72 + 96\,\underline{\beta} - 32\,\underline{\beta}^2 + 125\,g)) / (-24 - 8\,\underline{\beta} + 16\,\underline{\beta}^2 + 25g)^2; \qquad (A4)$$

One has then just to build the function W_R-W_{nc} and check its sign. After noting that the common denominator is always positive, one can then check that the minimum of the numerator is attained where $\underline{\beta}=1$, $g=72/25$ (the values of the multipliers which solve the Lagrangean are: $\lambda_g=122(10^3)$, $\lambda_1=0$, $\lambda_2=28928$) and that the function is positive in this point. (QED)

Proposition 8. If $g\geq72/25$ and $.28\leq\beta\leq1$, then $W_C>W_R$.

Welfare under the hypothesis of full cooperation among all the four firms in the industry is:

$$W_C= 2\,g\,(-32 + 125\,g) / (-32 + 25\,g)^2 \qquad (A5)$$

We can write the numerator of the difference as:

$$2g\{\,(-72+96\underline{\beta}-32\underline{\beta}^2+125\,g)\,(-32 + 25\,g)^2 - (-32 + 125\,g)\,(-24\,-8\underline{\beta}+16\underline{\beta}^2+25g)^2\,\} \qquad (A6)$$

The solution of the constrained optimization problem is given by $\underline{\beta}=.367$, $g=72/25$, $\lambda_g=26906.4$, $\lambda_1=0$, $\lambda_2=0$. Since at this point of minimum the function is positive, we conclude it is positive everywhere in the domain analyzed. (QED)

Proposition 9. If $g\geq72/25$ and $.28\leq\beta\leq.93$, then $\pi_C>\pi_D$.

Expressions (20) and (23) gives profits under these two cases. The common denominator of the resulting difference $\pi_C-\pi_D$ is positive. The numerator has a minimum which is given by $\underline{\beta}=.93$, $g=72/25$ (the multipliers are: $\lambda_g=3859.86$, $\lambda_1=0$, $\lambda_2=109261$). At the minimum the function is positive, which proves the proposition. (QED)

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Proposition 10. If g≥72/25 and .28≤ß≤1, then $\pi_{ND} > \pi_A$.

The profits obtained by a firm participating in a R&D venture of three is given by:

$$\pi_{ND} = g \ (-72+25g+72\underline{ß}-18\underline{ß}^2) \ (-8+5g+14\underline{ß}-6\underline{ß}^2)^2 / \ (\mu(g,\underline{ß}))^2 \tag{A7}$$

The profits obtained by an outsider when a R&D agreement between two firms is carried out is given by expression (13'). As usual, we have to write down $\pi_{ND} - \pi_A$ and check its sign, which - since the common denominator is positive - amounts to studying the sign of the numerator, under the above constraints on the parameters. The values which satisfy the Kuhn-Tucker consitions and which give the minimum of the numerator are: $\underline{ß}=1$, $g=72/25$, $\lambda_g=5.11 \ (10^6)$, $\lambda_1 =0$, $\lambda_2 =5.14 \ (10^8)$. The numerator is positive at the minimum, which completes the proof. (QED)

Proposition 11. If g≥72/25 and .28≤ß≤1, then $W_{3,1} > W_R$, and $W'_{3,1} > W_R$,

The profits obtained by the firms when a R&D coalition of three is made are already written in the text; it is possible to verify that consumer surplus in this case is given by:

$$CS_{3,1} = 200g^2 \ (-15+5g+24\underline{ß}-9\underline{ß}^2) \ ^2 / \ (\mu(g,\underline{ß}))^2 \tag{A8}$$

At this point, one has all the necessary elements to compute $W_{3,1}$ and $W'_{3,1}$, and write down

the expressions $(W_{3,1} - W_R)$ and $(W'_{3,1} - W_R)$. It is possible (but lengthy) to check through the usual procedure that the denominators of both functions are positive, and the numerators reach a minimum where the solutions to the associated constrained optimization program are respectively :

$\underline{ß}=.28$, $g=72/25$, $\lambda_g=3.523 \ (10^6)$, $\lambda_1 =4.456 \ (10^6)$, $\lambda_2 =0$ and

$\underline{ß}=.558$, $g=72/25$, $\lambda_g=1.112 \ (10^7)$, $\lambda_1 =0$, $\lambda_2 =0$.

In both cases the functions are positive at the minimum, confirming the proposition. (QED)

Table 1 - Payoff matrix for the governments' policy game.

| | Country 1 | |
Country 2	Not allow R&D Coop.	Allow R&D Cooperation
Not allow R&D Coop.	W_{NC}, W_{NC}	W_A, W_B
Allow R&D Cooperation	W_B, W_A	W_R, W_R

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