R&D-hindering collusion*

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November 4, 2008

Abstract

In an extended version of d'Aspremont and Jacquemin's (1988) R&D competition model we find a region where the game is a prisoner's dilemma: firms still invest in R&D but they would obtain a higher profit by not investing at all. In a repeated version of the game, we prove that firms implicitly tend to collude and refrain from investing in R&D, thus decreasing social welfare. When this happens, inviting firms to form a joint venture appears as a remedy to the lack of innovation efforts rather than the excess thereof.

JEL Classification: D43, L13, O31

Keywords: collusion, process innovation, social welfare

*We would like to thank Ricardo Cabral, Giorgio Zanarone and the seminar audience at the Universitat Autonoma de Barcelona, the VI IIOC (Arlington, May 16-18, 2008), SOEGW2 (Waterloo, June 11-15, 2008) and EARIE'08 (Toulouse, September 4-6, 2008) for useful comments and suggestions. The usual disclaimer applies.

1 Introduction

One of the main concerns for antitrust authorities is the detection and the subsequent elimination of anticompetitive practices adopted by firms to restrict the free play of competition in the market. Usually, there are three main areas of intervention: (i) prohibiting agreements between firms that restrict free trading and competition; (ii) banning abusive behaviour by a firm dominating a market, or anti-competitive practices that tend to lead to such a dominant position; (iii) supervising the mergers and acquisitions of large corporations, including some joint ventures. In this paper we focus on the first element, which includes in particular the repression of collusive agreements. In the United States, the Sherman Act, at Section 1, declares that "every contract, combination in the form of trust or otherwise, or conspiracy, in restraint of trade or commerce among the several States, or with foreign nations, is declared to be illegal. Every person who shall make any contract or engage in any combination or conspiracy hereby declared to be illegal shall be deemed guilty of a felony, and, on conviction thereof, shall be punished by fine". In the European Union, Article 81(1) of the Treaty states that all activities "which have as their object the prevention, restriction or distortion of competition within the common market" shall be prohibited. This provision covers a wide variety of behaviours, but the most obvious example of illegal conduct infringing Article 81(1) is a cartel between competitors.

However, certain types of cooperation are considered to be positive, especially when they stimulate firms' innovative activity by means of technology transfers and R&D cooperation. Both the American and the European antitrust regulations recognize such benefit and allow cooperative research. Since the passage of the NCRA (National Cooperative Research Act) in 1984, research joint venture in the United States were treated very permissively by the courts (Utton, 2003, Ch. 11). Article 81(3) of the EU Treaty provides the authorization for agreements which promote technical and economic progress.[1]

[1] The European Union is a major sponsor of research and development activities in many socio-economic areas. The aim is to promote R&D Joint Ventures among member states; this could reduce the excessive R&D costs. A successful collaboration is the Airbus commercial airline project, sponsored by France, Germany, UK and Spain, aimed at

As a matter of fact, collaboration in the R&D sector may breed collusion in the product market, thus restricting competition (see, *e.g.*, Geroski, 1993). The interplay between R&D promotion and antitrust enforcement is the most challenging policy area in Article 81 and many efforts have been recently carried out in this direction. Similarly, US law distinguishes between joint R&D and joint commercialization decisions; the former is legal, while the latter is illegal.

In the pathbreaking contributions of d'Aspremont and Jacquemin (1988, 1990) with firms investing in process innovation which generates spillovers, cooperative behaviour at the R&D level is welfare improving for relatively high spillover effects. Absent cooperative R&D, when spillovers are significant firms would tend to invest less resources in an activity which favours the rival as well. These results have been generalized to a wide class of oligopoly models by Suzumura (1992). Kamien et al. (1992) specify that R&D cooperation among firms (in particular R&D cartelization in their terminology) avoids the duplication of R&D efforts. Moreover, there exist circumstances where it is necessary to let firms share the burden of costly R&D efforts which otherwise would not be borne. In a nutshell, the bottom line of this literature is that the innovation process with high spillovers requires modification of the antitrust policy, although in practise we observe no serious attempts to restrict acceptable collaboration to those sectors of industry were spillovers are likely to be greatest.

In this paper we provide an alternative explanation for the attractiveness of joint R&D activity when spillovers are low, since it unlocks investments which would otherwise be reined in by (repeated) competition. As a consequence, an antitrust policy aiming at systematically preventing cooperation at the R&D level for relatively low levels of the spillover effect could turn out to be welfare-detrimental.

To make this point, we extend the classical d'Aspremont and Jacquemin (1988) model of cost-reducing R&D with spillovers to allow firms to refrain from investing in innovative activity. In particular, we add an additional stage to the d'Aspremont and Jacquemin (1988, 1990) (AJ henceforth) game where two firms decide whether to carry out an R&D effort or not, and

competing against Boeing.

maintain that antitrust regulations, based on AJ welfare analysis, hinder any R&D cartelization between firms when technological spillovers are small. We focus on the investment stage: if both firms invest, the remainder of the game develops along the same line as in AJ; otherwise, either no one invests or one invests and the other does not. By looking for subgame-perfect Nash equilibria, we find that the unique equilibrium remains the one identified by AJ with both firms investing in R&D.

Nonetheless, we discover a parameter region in which the game is a prisoner's dilemma, as firms would earn higher profits without investing. This region is defined by the interplay between two crucial parameters, one measuring the extent of technological spillover, the other the efficiency of the R&D activity. When the R&D activity is relatively efficient and spillovers are weak, investing in R&D entails a significant reduction in own marginal production cost which does not help improving the rival's productive performance. Firms are therefore keen on devoting resources to process R&D; this results into a huge increase in output which, eventually, lowers market price up to a level which is detrimental for firms' profits, as compared to the case where both firms abstain from investing.

We show that, in this region, if firms interact over time by playing the same game for an infinite number of periods (such as, for example, in Kesteloot and Veugelers, 1995), then the no-investment outcome can be sustained as an equilibrium of the repeated game. We obtain this result by adopting the optimal punishment approach (Abreu, 1986). Not surprisingly, the absence of process innovation investments implies a welfare loss as compared to the outcome of the one-shot game with both firms investing. In view of this, and taking into account that any form of research joint venture (either with full spillovers or not) is surely profit- and welfare-enhancing, the main policy implication of our analysis is that a public agency in charge of regulating R&D activities should promote the formation of RJVs whenever the technological conditions of the industry being inspected are such that firms may actually be refraining from carrying out any substantive R&D effort. Accordingly, the present model outlines joint investment as a remedy to the lack of R&D efforts, in contrast with the acquired view whereby it has been traditionally proposed as a means to mitigate effort duplication.

The paper is organized as follows. Section 2 presents the basic extension of the AJ model. Section 3 develops the analysis of the repeated game and outlines the main policy suggestion. Section 4 concludes.

2 The Model

The basic model we use is a slightly modified version of the well-known d'Aspremont and Jacquemin (1988) model of process R&D with spillovers. This model is a cornerstone of the analysis of research and development under oligopolistic competition, and we will sketch its structure only. Consider an industry with two operating firms, labeled 1 and 2. They sell a homogeneous good whose inverse demand function is

$$p = a - b(q_1 + q_2), \tag{1}$$

where q_1 (res. q_2) is the quantity produced by firm 1 (res. 2). Firms' technology is described by the following cost function:

$$C_i = (A - x_i - \beta x_j)q_i, i = 1, 2, i \neq j \tag{2}$$

The variables x_i and x_j are the R&D efforts exerted by firm i and j, A represents the *ex ante* unitary cost of production and, as usual, $\beta \in [0, 1]$ captures the extent of R&D spillovers. We adopt the same assumptions as AJ regarding the restriction on parameters a, A, b and β; additionally, we set $b = 1$. The R&D technology displays decreasing returns to scale, and the cost associated with a reduction of x_i in the unitary cost A is γx_i^2. Profits to firm i are:

$$\pi_i = pq_i - C_i - \gamma x_i^2. \tag{3}$$

AJ suppose a two-stage decision process in which agents first select their R&D effort and then the output level. They analyze this structure under three possible scenarios: in the first firms compete at both stages (we label it case "II"), in the second they collusively set the level of R&D effort, the production decisions remaining non-cooperative ("CC" in our notation); in the third case firms collude both at the R&D and production stages. We limit our attention to the first two cases, as the latter constitutes a clear infringement of the antitrust legislation.[2]

Henriques (1990) identifies the parametric regions for which the analysis proposed in AJ is stable in the sense of Seade (1980). Within our framework, this implies that we need to impose that:

$$\gamma > \frac{1}{3}(2-\beta)(1-\beta) \text{ when } \beta < 1/2;$$
$$\gamma > \frac{1}{9}(2-\beta)(1+\beta) \text{ when } \beta > 1/2.$$

Notice that once fulfilled these requirements, concavity of profits in R&D investments obtains, so that second-order conditions are satisfied.

Following AJ's analysis, process innovation investment in case II is given by:

$$x_i^{II} = \frac{(a-A)(2-\beta)}{9\gamma-(2-\beta)(1+\beta)}, \tag{4}$$

and the relative profit

$$\pi_i^{II} = \frac{\gamma(a-A)^2\left[9\gamma-(2-\beta)^2\right]}{\left[9\gamma-(2-\beta)(1+\beta)\right]^2}. \tag{5}$$

Similarly, investment in case CC is:

$$x_i^{CC} = \frac{(a-A)(1+\beta)}{9\gamma-(1+\beta)^2}, \tag{6}$$

and the profit

$$\pi_i^{CC} = \frac{\gamma(a-A)^2}{9\gamma-(1+\beta)^2}. \tag{7}$$

As for social welfare (which is defined, as usually as the sum of consumer surplus and firms' profits), in case II it writes

$$SW^{II} = \frac{2\gamma(a-A)^2\left[18\gamma-(2-\beta)^2\right]}{\left[9\gamma-(2-\beta)(1+\beta)\right]^2}; \tag{8}$$

[2]There are few exceptions, given that a cartel which improves the overall efficiency of the colluding firms could be allowed. Art. 81(3) of the EU Treaty is in favor of agreements which improve the production and distribution of the products. However, this is not the focus of our investigation as it is not specifically related to the R&D activity.

while in case CC:

$$SW^{CC} = \frac{2\gamma(a-A)^2[18\gamma - (1+\beta)^2]}{[9\gamma - (1+\beta)^2]^2} \tag{9}$$

and we know that $SW^{II} > SW^{CC}$ for $\beta < 1/2$. The antitrust authority would therefore tend to impede R&D cooperation when the sector under consideration is characterized by low levels of spillover.

2.1 The basic extension

We first extend this basic framework to allow firms to abstain from process innovation if they wish so. We consider the case where the extent of spillover is sufficiently low to justify the fact that explicit collusion in the R&D activity is forbidden by law. This amounts to saying that the fines imposed by the antitrust authority in case firms are caught colluding at the R&D stage are so high to make collusion unprofitable. Therefore, we retain the assumption that firms behave non-cooperatively at both stages to verify whether they decide to invest in process R&D. Three cases may emerge: (i) both firms invest; (ii) both firms do not invest; (iii) one firm invests while the other does not.

Case (i) has been analysed in the previous section, with optimal investment in R&D and profit respectively given by (6) and (7). As for the second case, identified by the superscript "00", if firms do not perform any R&D activity at the first stage then $x_1^{00} = x_2^{00} = 0$, and the model collapses on the classical Cournot duopoly with symmetric marginal costs.[3] At the symmetric subgame-perfect Nash equilibrium firms produce a quantity $q_i^{00} = (a-A)/3, i = 1, 2$ and enjoy a profit:

$$\pi_i^{00} = (a-A)^2/9. \tag{10}$$

Move now to case (iii) in which only one firm invests in R&D. Suppose that firm 1 invests and 2 does not; according to our notation, we use the

[3]In the ensuing analysis, the first letter in the apex refers to firm 1's action, the second to firm 2's one.

superscript ”IO”.[4] In this case the investment in R&D by firm 2 is $x_2^{I0} = 0$, and that by firm 1 is

$$x_1^{I0} = \frac{(a - A)(2 - \beta)}{9\gamma - (2 - \beta)^2}. \tag{11}$$

Quantities are $q_1^{I0} = 3\gamma(a - A)/\left[9\gamma - (2 - \beta)^2\right]$ and $q_2^{I0} = [3\gamma - (2 - \beta)(1 - \beta)](a - A)/\left[9\gamma - (2 - \beta)^2\right]$; finally, profits write:[5]

$$\pi_1^{I0} = \frac{\gamma(a - A)^2}{9\gamma - (2 - \beta)^2},\ \pi_2^{I0} = \frac{[3\gamma - (2 - \beta)(1 - \beta)]^2(a - A)^2}{[9\gamma - (2 - \beta)^2]^2}. \tag{12}$$

Notice that, by symmetry, in the case where firm 2 invests while firm 1 does not, $\pi_1^{0I} = \pi_2^{I0}$ and $\pi_1^{I0} = \pi_2^{0I}$.

Assume now that firms play, previously to the usual R&D investment-output game, a preliminary stage in which they decide whether or not to undertake any process innovation activity. If the firm decides to invest (choice “I”), it will select the R&D level according to the relevant case in the previous analysis; if the firms does not (choice “0”), it simply sets its research and development effort equal to zero. Invoking subgame perfection, one can describe the preliminary stage as the game depicted in Figure 1, which we call the *investment decision game (IDG).*

		Firm 2	
		0	I
Firm 1	0	$\pi_1^{00},\ \pi_2^{00}$	$\pi_1^{0I},\ \pi_2^{0I}$
	I	$\pi_1^{I0},\ \pi_2^{I0}$	$\pi_1^{II},\ \pi_2^{II}$

Figure 1: The investment decision game.

We can state the following:

[4]Clearly, by swapping the indexes one can describe the symmetric situation, indicated as ”$0I$”.

[5]Henriques-Seade conditions for the baseline case in which firms invest positive amounts in R&D (case II) are sufficient for ensuring a well-behaved problem in the asymmetric case.

Lemma 1 *(i) The IDG admits a unique Nash equilibrium in pure strategies given by (I,I). (ii) Let* $\beta \leq 0.2$*: the game is a Prisoner's Dilemma for* $\gamma \leq (2+3\beta-\beta^3)/(27\beta)$.

Proof. (i) Standard comparisons among profits show that $\pi_i^{II} > \pi_1^{0I} = \pi_2^{I0}$ and $\pi_i^{00} < \pi_1^{I0} = \pi_2^{0I}$. (ii) $\pi_i^{00} \geq \pi_i^{II}$ iff $\gamma \leq \widetilde{\gamma} = (2+3\beta-\beta^3)/(27\beta)$; such a condition satisfies stability when $\beta \leq 0.2$. ■

At equilibrium, firms always invest in cost-reducing technology, even if there exists a parameter region where they would gain a higher profit by not investing at all. In particular, this happens when γ is relatively low and $\beta \leq 0.2$, hence when R&D activity is relatively efficient and it does not give rise to an intense spillover effect. This seems counterintuitive at a first sight, as firms' investment effort apparently pays off in terms both of the reduction in the own unitary cost of production and of the limited extent of technological spillovers accruing to the rival. However, the above result can be explained by the fact that the combination of the two favourable effects pushes firms to invest too much. Indeed, in the parameter region under study, a relatively small investment in R&D entails a huge reduction in marginal production costs and therefore a significant increase in output which, in turn, lowers market price. The overall effect is a fierce competition which turns out to be detrimental for firms' profits as compared to the case where both firms abstain from investing.

In addition, notice that $\partial\widetilde{\gamma}/\partial\beta < 0$ for all β: the lower the rate at which R&D spills to the rival, the higher the threshold value of γ below which the game is a prisoner's dilemma. Stated differently, the higher the relative cost-advantage acquired through R&D, the higher is the maximum unit cost of R&D below which the equilibrium where both firms invest is Pareto-dominated, from the firms' standpoint, by the scenario where both firms do not invest.

Figure 2 diagrammatically identifies the region (labeled **P**) in the space (β, γ) where the game is a Prisoner's Dilemma.

Finally, one can evaluate the welfare in the case where no firm invests:

$$SW^{00} = \frac{4}{9}(a-A)^2. \tag{13}$$

For future reference notice that, by comparing equations (8), (9) and (13), the following inequalities hold in **P**:

$$SW^{II} > SW^{CC} > SW^{00} \tag{14}$$

In principle there should be no need for the antitrust authority to intervene in favour of joint R&D promotion given that firms, when they play non-cooperatively, set the investment level as in case II and in this case social welfare reaches its highest level.

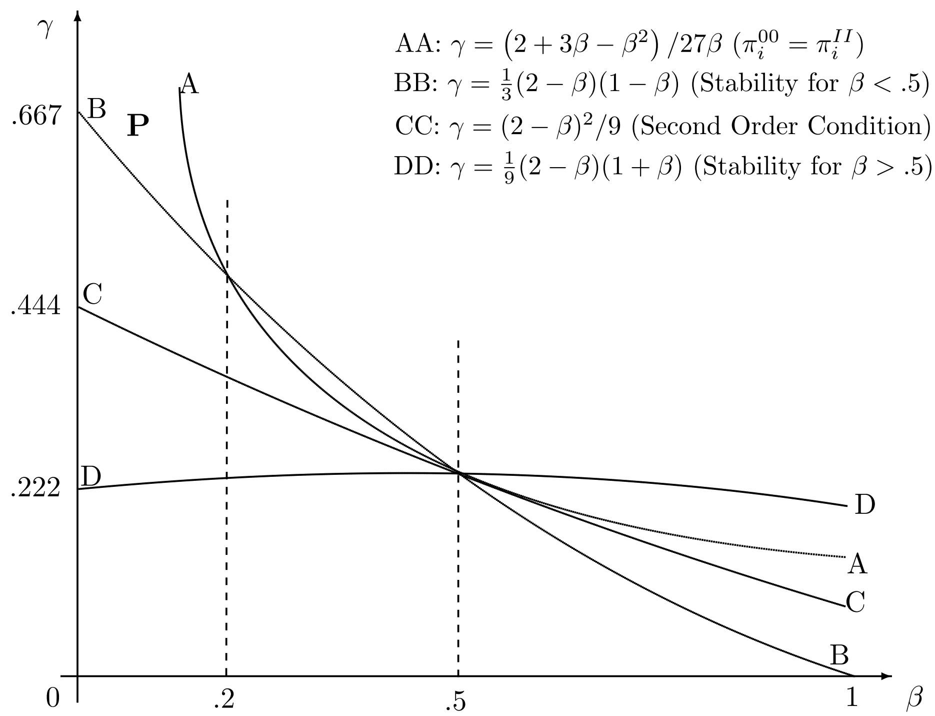

Figure 2: The Prisoner's Dilemma (region P).

3 The repeated game

In the previous section we added a preliminary stage to the standard Cournot oligopoly game with process-innovating R&D *à la* d'Aspremont-Jacquemin and unveiled a parameter region where the game is a Prisoner's Dilemma. From now on we limit our attention to such a region, *i.e.* in all the ensuing analysis we impose $(\beta, \gamma) \in \mathbf{P}$. In the one-shot version of the game the existence of the Dilemma is immaterial as firms always play the investment strategy. Furthermore, non-cooperative behavior at both stages leads to the socially second best outcome (see d'Aspremont and Jacquemin 1988, 1990). This last remark would furthermore support the antitrust policy prescription to forbid collusive R&D agreements in region P.

The picture changes if one allows firms to interact over time. Imagine firms repeat the *IDG* described in Figure 1 for an infinite number of periods $t = 0, \ldots, \infty$ and let $\delta \in (0, 1)$ be the discount factor common to both firms. Assume that firms plan their moves following the "optimal punishments" theorem (Abreu, 1986). In the remainder, given the *ex ante* full symmetry across firms, we will look for a symmetric subgame perfect solution of the supergame, and we will drop the indices identifying firms i and j as long as this does not generate confusion.

Firms start by not investing $(x^0 = 0)$ in the first period and stick to this decision until one of the two detects a deviation. If a deviation from the collusive path $\left(x^d\left(0\right)\right)$ is detected at period t, both firms switch to the punishment action (defined as x^p) in period $t+1$. In period $t+2$, if both firms have played x^p in the previous period, they revert to the collusive path again $(x^0 = 0)$, otherwise (i.e., if at least one of them deviates from the optimal punishment by playing the best reply against it, $x^d\left(x^p\right)$), they continue with the punishment. Following Abreu (1986), we state the following conditions guaranteeing that x^0 and x^p identify a subgame-perfect Nash Equilibrium of the repeated IDG.[6]

$$\begin{aligned} \pi(x^d\left(0\right), x^0) - \pi(x^0, x^0) &\leq \delta[\pi(x^0, x^0) - \pi(x^p, x^p)], \qquad (15) \\ \pi(x^d\left(x^p\right), x^p) - \pi(x^p, x^p) &\leq \delta[\pi(x^0, x^0) - \pi(x^p, x^p)], \qquad (16) \end{aligned}$$

where per period profit of either firm is a function of both its own and its rival's instantaneous investment decisions. In particular, $\pi(x^0, x^0) = \pi^{00}$ and

[6] Abreu's "optimal punishments" could be substituted for by Nash punishments in the line of Friedman's (1971) "grim triggers strategies". However, the stability of the agreement (as measured by the threshold level for the discount factor) would be lower in this case. Calculations are available upon request.

$\pi(x^d(0), x^0) = \pi_1^{I0} = \pi_2^{0I}$, as in (10) and (12), respectively. Inequality (15) identifies the condition that must be met for the stability of the collusive path, while inequality (16) identifies the condition for the implementation of the symmetric one-shot punishment to be incentive compatible.

On the basis of symmetry in the optimal punishments, one can easily find that

$$\begin{aligned}\pi(x^p, x^p) &= \frac{1}{9}[a - A + x^p(1+\beta)]^2 - \gamma(x^p)^2, &(17)\\ \pi(x^d(x^p), x^p) &= \frac{\gamma[a - A - x^p(1-2\beta)]^2}{9\gamma - (2-\beta)^2}. &(18)\end{aligned}$$

Conditions (15) and (16), reformulated as strict equalities, define a system of two equations in two unknowns (x^p and δ) whose solutions represent the optimal punishment and the smallest value of the discount factor compatible with the collusive outcome of the repeated IDG.

From (15), we have

$$\delta \geq \frac{\pi(x^d(0), x^0) - \pi^{00}}{\pi^{00} - \pi(x^p, x^p)} \triangleq \widetilde{\delta}, \tag{19}$$

whereby

$$\widetilde{\delta} = \frac{(a-A)(2-\beta)^2}{x^p[9\gamma - (2-\beta)^2]\left\{x^p[9\gamma - (1+\beta)^2] - 2(a-A)(1+\beta)\right\}}, \tag{20}$$

that can be plugged into (16), to be solved as a strict equality w.r.t. x^p. This yields two solutions, the first is $x_-^p = 0$, and the second:

$$x_+^p = \frac{2(a-A)(2-\beta)}{9\gamma - (2-\beta)(1+\beta)}. \tag{21}$$

Notice that x_-^p coincides with the collusive action and therefore cannot candidate as the optimal punishment. We select x_+^p as the punishment investment level (incidentally, stability conditions guarantee the positivity of such investment). By substituting x_+^p into (20) one obtains the minimum level for the discount factor compatible with the collusive outcome:

$$\tilde{\delta}^* = \frac{(2-\beta)[9\gamma - (2-\beta)(1+\beta)]^2}{36\gamma[9\gamma - (2-\beta)^2](1-2\beta)}, \tag{22}$$

which is included in the interval $[0, 1]$ if $(\beta, \gamma) \in \mathbf{P}$. To complete the discussion of the optimal punishment investments (see the Appendix for the details), we should note that firm's profit during the punishment period, $\pi(x^p, x^p)$, is non-positive in a relevant parameter range. The security-level condition therefore requires that, in this interval, the discounted value of payoff generated by the (continuation) game starting from the punishment period is positive for firm $i = 1, 2$:

$$\pi(x^p, x^p) + \pi^{00} \sum_{t=1}^{\infty} \delta^t \geq 0. \tag{23}$$

In the Appendix we prove that (23) holds. We can therefore state the following.

Proposition 1 *Let the optimal punishment level be x^p_+ and let $\delta \geq \tilde{\delta}^*$. At the equilibrium of the repeated IDG with optimal punishments firms do not carry out any R&D investment.*

As a consequence, in the repeated version of the game, there exist a discount factor above which firms stick to the collusive outcome and decide to not invest in R&D. In the interval under consideration, where $(\beta, \gamma) \in \mathbf{P}$, this would imply a consistent reduction of social welfare as compared to the non-cooperative one-shot behaviour, as it can be ascertained by comparing SW^{II} and SW^{00} (see 14). In particular, firms prefer to soften competition by reducing (indeed eliminating altogether) process innovation, thus limiting the increase in output that a lower marginal cost would drive. The negative impact on consumption is not compensated by the higher firms' profits, so that the overall welfare effect is negative. This can be summarized as follows.

Corollary 1 *The industry-level investment in R&D at the equilibrium of the repeated IDG is socially suboptimal.*

In this situation a benevolent social planner faces a delicate issue: firms stick to a collusive result without engaging in an explicit collusive behavior, that is to say they do not set their investments as prescribed by (6). As the collusive agreement is implicit, it becomes extremely difficult for the antitrust authority to prove the existence of such an agreement and therefore to intervene and restore the non-collusive outcome. Indeed, it may well be impossible to prove in court that firms do not invest at all because of a collusive agreement. The reason is that, while we are accustomed to think of cartels that increase prices or decrease outputs, in the present case the outcome is observationally equivalent to a standard textbook exposition of the basic Cournot duopoly model, where marginal cost is exogenously give, or equivalently R&D is assumed away. Accordingly, it would be just impossible to collect any evidence of a collusive supergame which, in fact, is not taking place. In principle, the antitrust agency could imagine what is going on, but she would have no practical instrument to corroborate her guess.

While usually we think of situations where a remedy to effort duplication is needed, here the opposite issue arises, namely the absence of any R&D effort whatsoever. Our aim, in the remainder, is to illustrate that an organizational design for R&D activities that has been considered so far as a solution to excess investment can also be a solution to its absence. This instrument cannot be an R&D cartel (the CC outcome envisaged above) as, for low spillover levels, the regulator would prefer the II outcome, which is precisely what firms avoid playing through the implicit collusion we have just outlined. This perspective would be a paradoxical one, where the antitrust authority suspects that firms are colluding but is completely unable to obtain any evidence that they do so, and the regulator invites firms to collude on R&D being aware that this would be welfare-inferior to the fully non-cooperative subgame perfect equilibrium leading to II.

With these considerations in mind, we propose the alternative routes consisting of either one or the other form of RJV that have been widely investigated in the existing literature: the first is a setup where firms carry out independent R&D efforts, but the spillover is set equal to one; the second is a setup where firms jointly invest in a single lab and split equally the related cost.

In the first, we have $C_i = (A - x_i - x_j)q_i$, $i = 1, 2$, $i \neq j$ and firm i chooses x_i to maximise

$$\pi_i\,(SL) = \frac{(a - A + x_i + x_j)}{9} - \gamma x_i^2, \tag{24}$$

where SL stands for *separate labs*. This yields:

$$x_i(SL) = \frac{a-A}{9\gamma-2}; \pi_i(SL) = \frac{(a-A)^2(9\gamma-1)\gamma}{(9\gamma-2)^2} \text{ for } i,j=1,2;$$

$$SW(SL) = \frac{2(a-A)^2(18\gamma-1)\gamma}{(9\gamma-2)^2}. \tag{25}$$

In the second, $C_i = (A - x_i - x_j)q_i$ for $i = 1,2$ $i \neq j$ again, but x_1 and x_2 are chosen so as to jointly maximise

$$\pi(JL) \triangleq \pi_1(JL) + \pi_2(JL) = \frac{2}{9}(a - A + x_1 + x_2)^2 - \gamma(x_1 + x_2)^2, \tag{26}$$

with JL standing for *joint lab*. In this case, the equilibrium investment, profits and welfare are:

$$x_i(JL) = \frac{2(a-A)}{9\gamma-4}; \pi_i(JL) = \frac{(a-A)^2\gamma}{9\gamma-4}, \text{ for } i=1,2;$$

$$SW(JL) = \frac{4(a-A)^2(9\gamma-2)\gamma}{(9\gamma-4)^2}. \tag{27}$$

It is then a matter of straightforward calculations to check that the following holds:

Proposition 2 *In the parameter region* $\boldsymbol{P}$ *where a prisoner's dilemma arises,* $\pi_i(JL) > \pi_i(SL) > \pi_i^{00}\left(> \pi^{II}\right)$, *and* $SW(SL) > SW(JL) > \left(SW^{II} >\right) SW^{00}$.

4 Conclusion

In this paper, we departed from the classical d'Aspremont and Jacquemin (1988) model of process R&D with spillovers by letting firms the option to invest an amount of R&D equal to zero. By using a supergame constructed on this extension, we have shown that a regulator should be aware of the possibility that firms endogenously refrain from investing altogether. In particular, in parametric regions where an antitrust regulation based on AJ analysis would prevent collusive R&D, it may be worth for firms to avoid a harsh competition in the product market by limiting (eliminating, indeed) the step of technological improvement. This outcome turns out to be socially suboptimal. In addition, since the absence of R&D investment by firms do not derive from joint (instantaneous) profit maximization, it may prove difficult for an antitrust authority to sanction such a behavior, and to improve the industry efficiency. To cope with this issue, we have proposed a simple solution consisting in promoting R&D joint ventures as a means of achieving technological progress in situations where firms' incentives may indeed point in the opposite direction.

APPENDIX

Let $(\beta, \gamma) \in \mathbf{P}$. Firm i's profit in the punishment period is

$$\pi(x_+^p, x_+^p) = \frac{(a-A)^2[81\gamma^2 - 54\gamma(2-\beta)(1-\beta) + (2-\beta)^2](1+\beta)^2}{9[9\gamma - (2-\beta)(1+\beta)]^2}. \quad (28)$$

The above expression is positive for values of γ external to the interval

$$[\frac{3\beta(\beta-3) + 2[(3 - \sqrt{(\beta-2)^3(2\beta-1)}]}{9}, \frac{3\beta(\beta-3) + 2[(3 + \sqrt{(\beta-2)^3(2\beta-1)}]}{9}] \quad (29)$$

The lower bound of the interval lies always below the threshold for γ which insures stability. The upper bound, on the contrary, cuts the region where the game is both stable and a dilemma. This implies that one should check the security level of the game, that is to say, verify that the value of the continuation game after a deviation

$$\pi(x^p, x^p) + \pi^{00} \sum_{t=1}^{\infty} \delta^t =$$

$$= \frac{324(a-A)^2\gamma^2(2\beta-1)[3\gamma + (2-\beta)(\beta-1)]^2}{[9\gamma - (2-\beta)(1-\beta)]^2[81\gamma^2(7\beta-2) - 18\gamma(2-\beta^2(5\beta-1) - (\beta-2)^3(1+\beta)^2]} \quad (30)$$

is positive.

The numerator of (30) is negative in the relevant parametric region, so we focus our attention on the denominator. The sign of the denominator of (30) coincides with the sign of its second term, for the first is always positive. Standard calculations show that this term is negative (so that 30 is positive) for values of γ external to the interval

$$[\frac{5\beta^3 - 21\beta^2 + 24\beta - 4 + 2\sqrt{2\beta^2 + 5\beta + 2}}{9(7\beta - 2)}, \frac{5\beta^3 - 21\beta^2 + 24\beta - 4 - 2\sqrt{2\beta^2 + 5\beta + 2}}{9(7\beta - 2)}]. \tag{31}$$

It is easy to see that for $\beta < 0.2$ the lower bound of the interval is negative, while the second is smaller than the threshold for stability. This implies that, when the *IDG* game is stable, the value of (30) is positive.

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