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TECHNOLOGY AND ANTITRUST POLICIES IN A POLLUTING INDUSTRY

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Abstract:
We compare different combinations of technology and antitrust policies from a social welfare point of view in a non-tournament model of cost reducing R&D with spillovers, for the case of a homogeneous goods duopoly, where production produces pollution as a by-product, firms face an exogenous emissions tax and can also invest in abatement technologies. We show that for sufficiently polluting industries facing a loose environmental policy, cooperative R&D is not always welfare improving; a policy of subsidizing cooperative R&D is always welfare improving; allowing for mergers may be socially desirable; not regulating the industry at all may be welfare superior to a policy consisting of forbidding market collusion and subsidizing cooperative R&D.

Keywords: technology policy, antitrust, R&D cooperation, pollution

JEL Classification: Q28, L50, L40

1 Introduction

While the topic of technology policy in oligopolistic markets has been analyzed in several papers in theoretical industrial organization literature (for example Kamien, Muller and Zang, 1992; Vonortas, 1994; Poyago-Theotoky, 1995; Hinloopen, 1995 and Leahy and Neary, 1997, investigate the performance of instruments such as R&D subsidies or the relaxation of antitrust policies to allow and encourage cooperative R&D among firms), the relationship between technology policy and the environment has not yet been sufficiently investigated. Regarding this issue, Petrakis and Poyago-Theotoky (2002) investigate the potential adverse impact that technology policy might have on the environment whenever production activities generate pollution as a by-product, in a non-tournament model of R&D with spillovers and abatement in which firms face an exogenous emissions tax. They show first that

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under these circumstances the optimal R&D subsidy could be negative; second that social welfare under R&D cooperation could be lower than under R&D subsidization; and finally that a policy of tying-in the R&D subsidy to abatement activities increases social welfare.

In the present paper, in a similar setting to that of Petrakis and Poyago-Theotoky (2002), we compare different levels of public regulation of the market, namely forbidding both market collusion and cooperative R&D, forbidding market collusion but allowing for cooperative R&D, forbidding market collusion and subsidizing cooperative R&D,[1)] with the alternative of not regulating the industry at all, allowing firms to merge. Using the D'Aspremont and Jacquemin (1988) model adapted to encompass the environmental issue, we obtain the subgame perfect equilibrium for the different scenarios and then evaluate and compare them in terms of social welfare.

We show that, whenever the environmental damage produced by pollution is high enough and the environmental policy loose,[2)] first, in the absence of R&D subsidization, R&D competition may be socially preferred to R&D cooperation. This reverses the traditional result stating that cooperative R&D improves social welfare. The reason is that by cooperating, firms completely internalize the spillover effect of R&D, thus increasing total R&D investments, reducing unit costs and increasing total output and emissions. For sufficiently polluting industries, the negative effect of pollution is shown to offset the positive effect induced by the increase in R&D investments, reducing social welfare. On the other hand, when the technology policy consists of not only allowing but also subsidizing R&D alliances, cooperative R&D does always increase welfare. The reason is that the environmental problem may now be addressed through the subsidy whereas R&D cooperation allows the firms to completely internalize the spillover. In this sense, the two instruments (cooperative R&D and R&D subsidies) can be considered as complements instead of substitutes, as they have been usually considered in industrial organization literature.

Second, not regulating the industry at all (allowing cooperative behavior not only in R&D but also in the market, namely a merger) is very often welfare superior to any of the proposed policies, both in the presence of an exogenous emissions tax and under no environmental policy. The intuition is that whereas a merger, by reducing output,[3)] has a first order effect on pollution and thus helps to address the environmental problem, any of the proposed technology policies (allowing for cooperative R&D or subsidizing cooperative R&D) has a direct effect on R&D investments but only a second order effect on both output and pollution. Therefore, the positive effect of a merger on the environment is very often superior to the indirect effect produced by different technology policies. Notice that we obtain that allowing a merger

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1) Notice that it is very usual for governments and supranational institutions such as the European Union to encourage cooperation not only by allowing firms to cooperate in R&D but also by subsidizing their R&D costs when they participate in cooperative R&D projects. Therefore, differently from Petrakis and Poyago-Theotoky (2002) who compare cooperative R&D with R&D subsidies, we consider the possibility that the two policies are jointly implemented.

2) Petrakis and Poyago-Theotoky (2002) provide interesting examples of this case. Oil re-fineries and the food industry in Greece and the milk industry in Spain increase their productivity mainly due to technology policy measures while, at the same time, there is no clear environmental policy to regulate those particular industries.

3) If we are thinking of a duopolistic industry, a merger always reduces total industry output and thus total emissions. Under Cournot competition, however, if there are more than two firms in the industry, depending on the number of firms that stay out of the merger, total industry output could increase as a consequence of a merger, because the best response of the non-merging firms to an output reduction of the merging firms is to increase their output. On the other hand, under Bertrand competition, total output would always be reduced as a consequence of a merger.

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may be optimal (in a second best sense) even in a context in which no other efficiency gain is involved, and its only social value is given by the reduction in total emissions. On the other hand, observe that if both the environmental and the technology policy were decided by the same agency, the first best outcome would be implemented. Therefore, our results stress the importance of coordinating the two policies in order to achieve jointly the objectives of optimality in R&D investments and taking care of the environment.

The paper is organized as follows. Section 2 presents the model and describes the different scenarios, section 3 compares those scenarios in terms of social welfare and presents the results and section 4 closes the paper.

2. The Model

We consider a homogeneous good duopoly. Market demand is given by $Q = a - P$, where a is a positive constant and $Q = q_1 + q_2$ and represents total industry output. Each firm can reduce its constant marginal cost of production either by investing in R&D or by capturing some know-how that spills over from rivals' R&D investments. Production produces pollution as a by-product. The firms face an exogenous emissions tax[4] t, but they can make abatement efforts in order to reduce their emissions and their tax burden. We assume that firm i's emissions associated with its production are given by $e_i = q_i - w_i$, $i = 1, 2$; where w_i represents firm i's abatement effort. The cost function is additively separable in production costs, R&D costs and abatement effort and is given by $c(q_i, x_i, x_j, w_i) = (c - x_i - \beta x_j)q_i + \frac{\gamma}{2}x_i^2 + \frac{w_i^2}{2}$, $i = 1, 2$, $i \neq j$, where c is a positive constant, $c > (x_i + \beta x_j)$, x_i represents firm i's R&D investment, $\beta \in [0, 1]$ measures the size of the spillover effect of R&D, γ represents the relative effectiveness of R&D (assumed to be high enough to guarantee interior solutions for R&D, output and welfare levels) and, finally $a > c + t$. The R&D and abatement cost functions are convex, implying decreasing returns on R&D and abatement efforts. Finally, we consider an environmental damage function assumed to be quadratic in the total level of emissions: $D(e_1, e_2) = \frac{d}{2}(e_1+e_2)^2$, where parameter d represents how fast environmental damage increases with emissions and is assumed to be $0 \leq d < 2$, which, together with the constraint on γ, guarantees interior solutions.

The timing of the game is as follows: first, taking the exogenous emissions tax t as given, the public agency decides the technology and antitrust policies in order to maximize social welfare, defined as the sum of consumer surplus and firms' profits, minus the environmental damage. Second, the firms decide their R&D investments either cooperatively (if allowed by the agency) or individually. Abatement efforts are decided by the firms at the third stage. Finally, in the last stage the firms either collude (if allowed by the agency) or compete à la Cournot in the market.

We solve the game by backwards induction for different set-ups, depending on the policy implemented by the national agency, and then we compare the different scenarios in terms of social welfare. We start with the unregulated scenario.

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4) Petrakis and Poyago-Theotoky (2002) use the same assumption, which they justify, for example, in cases where the emissions tax is set at supranational level, whereas the technology policy is set at national level, or when the environmental policy is set at national level, and the technology policy is industry specific and is designed by a different agency, which does not imply that the technology policy agency does not care about the environment.

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2.1 *Scenario 1: No Regulation*

Consider first a simple scenario with no technology or antitrust regulation. The firms face, however, an exogenous emissions tax t imposed by a supranational environmental agency. In that framework, the firms will choose to merge, thus deciding on R&D investments, abatement and output as a monopolist. Hence, at the third stage the firms choose outputs to maximize their joint profits conditional on R&D and abatement efforts:

$$\max_{q_1,q_2}\{(a-q_1-q_2)(q_1+q_2)-(c-x_1-\beta x_2)q_1-(c-x_2-\beta x_1)q_2-t(q_1+q_2-w_1-w_2)\} \quad (1)$$

Solving that programme we obtain the monopoly output, which, for the symmetric solution $x_1 = x_2 = x$, and $q_1 = q_2$, leads to:

$$\bar{q}_1=\bar{q}_2=\frac{1}{4}((a-c-t)+x(1+\beta)) \quad (2)$$

At the second stage of the game, the firms cooperatively choose abatement efforts in order to reduce their tax burden. They solve:

$$\underset{w_1,w_2}{\mathrm{Max}}\left\{(a-\bar{q}_1-\bar{q}_2)(\bar{q}_1+\bar{q}_2)-(c-(1+\beta)x)(\bar{q}_1+\bar{q}_2)-t(\bar{q}_1+\bar{q}_2-w_1-w_2)-\frac{w_1^2+w_2^2}{2}\right\} \quad (3)$$

The solution is given by $w_i^* = t$, $i = 1,2$, that is, the firms will undertake abatement activities as long as a positive tax on emissions is imposed and the optimal abatement level increases with the tax.

At the first stage of the game, under no technology policy, the firms choose their R&D levels cooperatively in order to internalize the spillover. We assume that, by cooperating, the firms increase the spillover parameter to its maximal value $\beta = 1$, which implies that there is full information sharing of the R&D results between the partners.[5] Therefore, at the first stage the firms choose their R&D investments to maximize joint profits:

$$\underset{x}{\mathrm{Max}}\{(a-\bar{q}_1-\bar{q}_2)(\bar{q}_1+\bar{q}_2)-(c-2x)(\bar{q}_1+\bar{q}_2)-\gamma x^2\} \quad (4)$$

where x denotes each firm's R&D investment. By substitution of the equilibrium outputs the program can be rewritten as follows:

$$\underset{x}{\mathrm{Max}}\left\{\left(\frac{a-c-t+2x}{2}\right)^2-\gamma x^2\right\} \quad (5)$$

The solution to this problem is:[6]

$$x^*=\frac{a-c-t}{2(\gamma-1)} \quad (6)$$

5) Poyago-Theotoky (1999) endogenizes the choice of the spillover parameter assuming that it can be interpreted as the disclosure rate. She shows that it is optimal for the partners to set $\beta = 1$.

6) The condition $\gamma > 1$ guarantees that the second order condition of the maximization problem is satisfied and that x^* is positive.

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Finally, by substitution of (6) into (2) we obtain the equilibrium industry output

$$Q^* = q_1^* + q_2^* = \frac{\gamma(a-c-t)}{2(\gamma-1)} \tag{7}$$

Next, we proceed to evaluate social welfare in equilibrium. Total welfare may be expressed as gross consumer surplus minus production costs minus R&D and abatement costs and minus environmental damage:[7)]

$$W^{CC} = \int_0^{Q^*}(a-z)dz - \left(c-2x^*\right)Q^* - \gamma\left(x^*\right)^2 - \left(w^*\right)^2 - \frac{d}{2}\left(Q^* - 2w^*\right)^2 \tag{8}$$

By direct substitution of the equilibrium values we obtain:

$$W^{CC} = \frac{\gamma(a-c-t)[(a-c)(3\gamma-2)+t(\gamma-2)]}{8(\gamma-1)^2} - t^2 - \\ - \frac{d}{2}\left(2t - \frac{2\gamma(a-c-t)}{4(\gamma-1)}\right)^2 \tag{9}$$

where the superscript *CC* denotes cooperation in both R&D and output.

2.2 *Scenario 2: Market Competition, Subsidized Cooperative R&D*

In this framework, the national agency forbids the firms to collude in the market, and implements a technology policy that consists of subsidizing their R&D costs whenever they cooperate in R&D. The subsidy rate is given by $s \in [-1, 1)$. A negative s would imply that the agency sets a tax on R&D. Therefore, at the fourth stage and given the R&D and abatement efforts of the previous stages, firm i solves:

$$\underset{q_i}{\text{Max}}\left(a - q_i - q_j\right)q_i - \left(c - x_i - \beta x_j\right)q_i - t\left(q_i - w_i\right),\ i = 1,2,\ i \neq j \tag{10}$$

We obtain in equilibrium:

$$\bar{q}_1 = \frac{1}{3}\left(a - c - t + x_1(2-\beta) + x_2(2\beta - 1)\right) \tag{11}$$

$$\bar{q}_2 = \frac{1}{3}\left(a - c - t + x_2(2-\beta) + x_1(2\beta - 1)\right) \tag{12}$$

At the third stage, each firm decides how much abatement to undertake, solving:

$$\underset{w_i}{\text{Max}}\left\{\left(a - \bar{q}_i - \bar{q}_j\right)\bar{q}_i - \left(c - x_i - \beta x_j\right)\bar{q}_i - t\left(\bar{q}_i - w_i\right) - \frac{w_i^2}{2}\right\},\ i = 1,2,\ i \neq j \tag{13}$$

The solution to this programme is given by $w_i^* = t;\ i = 1, 2$. At the second stage the firms jointly solve:

7) Notice that we do not subtract the environmental income in the welfare function. This may be explained by assuming that the emissions tax is imposed either by a national environmental agency or by an international agency that refunds it to the country through subsidies.

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$$\underset{x_1,x_2}{\text{Max}}\left\{(a-\bar{q}_1-\bar{q}_2)(\bar{q}_1+\bar{q}_2)-(c-x_1-\beta x_2)\bar{q}_1-(c-x_2-\beta x_1)\bar{q}_2-\frac{\gamma}{2}(1-s)x_1^2-\frac{\gamma}{2}(1-s)x_2^2\right\} \quad (14)$$

By direct substitution of the equilibrium outputs, taking into account that $\beta = 1$ we get:

$$\underset{x_1,x_2}{\text{Max}}\left\{\frac{2}{9}(a-c-t+x_1+x_2)^2-\frac{\gamma}{2}(1-s)(x_1^2+x_2^2)\right\} \quad (15)$$

Solving the maximization problem for x_1 and x_2 we obtain:[8)]

$$x_1^*=x_2^*=x^*=\frac{4(a-c-t)}{9\gamma(1-s)-8} \quad (16)$$

and by direct substitution of (16) in (11) and (12)

$$q_1^*=q_2^*=\frac{3\gamma(a-c-t)(1-s)}{9\gamma(1-s)-8} \quad (17)$$

At the first stage, the agency chooses the R&D subsidy (s) to maximize social welfare:

$$W^*=\int_0^{Q^*}(a-z)dz-(c-2x^*)2q^*-\gamma(x^*)^2-(w^*)^2-\frac{d}{2}\left(2(q^*-w^*)\right)^2 \quad (18)$$

By substituting the equilibrium values and solving the maximization problem with respect to s, we obtain the optimal subsidy

$$s^*=\frac{[3\gamma(1+8d)-8(1+2d)]t-6\gamma(a-c)(d-1)}{3\gamma[2(a-c)(2-d)+t(8d-1)]} \quad (19)$$

Notice that for $t = d = 0$; the optimal subsidy becomes $s^* = 1/2$. In the absence of environmental damage the optimal subsidy is always positive. Now, if $t = 0$ but $d > 0$, that is, production generates pollution, the subsidy becomes $s^*=\frac{1-d}{2-d}>(<)0$ as long as d < (>) 1. Observe that the optimal subsidy is decreasing in d, that is, as the environmental damage becomes greater the optimal R&D subsidy decreases. In fact, it becomes a tax for $d > 1$. A similar result is also obtained in Petrakis and Poyago-Theotoky (2002).

Finally, by substitution of the optimal subsidy in the output and R&D equilibrium levels and all these values in the welfare function, we obtain:

$$W^{SCN}=\frac{2\gamma(2-d)(a^2+c^2)+2c\gamma t(1-8d)+[20(1+2d)-\gamma(11+32d)]t^2}{9\gamma-8(2-d)}-\frac{2a\gamma[2c(2-d)+t(1-8d)]}{9\gamma-8(2-d)} \quad (20)$$

where the superscript *SCN* stands for subsidy to cooperative R&D and non-cooperative output decisions.

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8) The second order condition requires $\gamma>\frac{8}{9(1-s)}$, which also guarantees that R&D levels in equilibrium are positive.

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2.3 Scenario 3: Market Competition, Non-subsidized Cooperative R&D

In this scenario, the national agency forbids the firms to collude in the market, and allows them to cooperate in R&D, but no R&D subsidy is included in the technology policy. In this scenario, the market competition stage and the abatement decisions are exactly the same as in Scenario 2. Therefore, at the first stage the firms cooperatively decide their R&D investments ($\beta = 1$) to maximize joint profits:

$$\underset{x_1,x_2}{\text{Max}}\left\{\frac{2}{9}\left(a-c-t+x_1+x_2\right)^2-\frac{\gamma}{2}\left(x_1^2+x_2^2\right)\right\} \tag{21}$$

Solving the optimization problem and by subsequent substitution we obtain the equilibrium R&D and output levels:[9)]

$$x_1^* = x_2^* = x^* = \frac{4(a-c-t)}{9\gamma-8} \tag{22}$$

$$q_1^* = q_2^* = q^* = \frac{3\gamma(a-c-t)}{9\gamma-8} \tag{23}$$

Note that expressions (22) and (23) can be obtained directly from expressions (16) and (17) by setting $s = 0$.

Finally, social welfare in equilibrium is given by:

$$W^{CN} = \frac{2\gamma(a+c)^2(9\gamma(2-d)-8)+2\gamma t(a-c)+(24d(3\gamma-2)-(9\gamma+8))}{(8-9\gamma)^2} - \\ - \frac{t^2\left(11\gamma(9\gamma-16)+32d(2-3\gamma)^2+64\right)}{(8-9\gamma)^2} \tag{24}$$

where the superscript CN stands for cooperative R&D and non-cooperative market stage.

2.4 Scenario 4: No Cooperation, Subsidized R&D

Let us consider next a framework in which the national agency forbids any kind of cooperative behavior and implements a technology policy consisting of subsidizing R&D cost to firms. In this setting, the last two stages (the stages of output and abatement) are identical to those of Scenario 2. Thus, in the second stage the firms simultaneously solve:

$$\underset{x_i}{\text{Max}}\left\{\frac{1}{9}\left(a-c-t+(2-\beta)x_i+(2\beta-1)x_j\right)^2-(1-s)\frac{\gamma}{2}x_i^2\right\},\ i=1,2,\ i\neq j \tag{25}$$

Direct resolution of this programme results in the Nash equilibrium R&D levels, which are given by:[10)]

9) The second order conditions require $\gamma > 8/9$.

10) The second order conditions require $\gamma > \frac{2}{9(1-s)}\left[(\beta-2)^2+|1-2\beta||\beta-2|\right]$.

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$$x_1^* = x_2^* = x^* = \frac{2(a-c-t)(2-\beta)}{9\gamma(1-s)-2(2+\beta-\beta^2)}, \tag{26}$$

and, by substitution, we obtain the equilibrium outputs:

$$q_1^* = q_2^* = q^* = \frac{3\gamma(1-s)(a-c-t)}{9\gamma(1-s)-2(2+\beta-\beta^2)} \tag{27}$$

Finally, in the first stage the agency chooses the R&D subsidy *s* to maximize total welfare:

$$W^* = \int_0^{Q^*}(a-z)dz - (c-(1+\beta)x^*)2q^* - \gamma(x^*)^2 - (w^*)^2 - \frac{d}{2}(2(q^*-w^*))^2 \tag{28}$$

Substituting the equilibrium values and solving the maximization problem, we obtain the optimal subsidy:

$$s^* = \frac{6\gamma(a-c)[d-b(3-d)]}{3\gamma(1+b)[t(1-8d)-2(2-d)(a-c)]} - \\ - \frac{t[3\gamma(3+8d+b(8d-3))-2(2-b)(1+b)^2(1+2d)]}{3\gamma(1+b)[t(1-8d)-2(2-d)(a-c)]} \tag{29}$$

Finally, by substitution of the optimal subsidy, we obtain the equilibrium social welfare.

$$W^{SNN} = \frac{2\gamma(a-c)[(a-c)(2-d)+(8d-1)t]}{9\gamma-2(1+b)^2(2-d)} + \\ + \frac{t^2[5(1+b)^2(1+2d)-\gamma(11+32d)]}{9\gamma-2(1+b)^2(2-d)} \tag{30}$$

where the superscript *SNN* stands for subsidized R&D and non-cooperative R&D and output stages.

2.5 *Scenario 5: No Cooperation, Non-subsidized R&D*

In this scenario the agency forbids any kind of cooperation and no R&D subsidy is granted. Therefore, at the production stage and for the abatement decisions we can use the results of Scenario 3. At the second stage firm *i* will now choose its R&D investment to maximize:

$$\underset{x_i}{\text{Max}}\left\{\frac{1}{9}(a-c-t+(2-\beta)x_i+(2\beta-1)x_j)^2 - \frac{\gamma}{2}x_i^2\right\},\ i=1,2,\ i\neq j \tag{31}$$

Solving this for x_1 and x_2 and by subsequent substitution we obtain the R&D and output levels in equilibrium:[11)]

$$x_1^* = x_2^* = x^* = \frac{2(a-c-t)(2-\beta)}{9\gamma-2(2+\beta-\beta^2)} \tag{32}$$

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11) The second order conditions require $\gamma > \frac{2}{9}[(\beta-2)^2 + |1-2\beta||\beta-2|]$.

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$$q_1^* = q_2^* = q^* = \frac{3\gamma(a-c-t)}{9\gamma - 2(2+\beta-\beta^2)} \tag{33}$$

Note that expressions (32) and (33) can be obtained directly from expressions (26) and (27) by setting $s = 0$.

Finally, we obtain total welfare in equilibrium, which is given by:

$$W^{NN} = \frac{6\gamma(a-c-t)\left[2(a-t)(2+\beta-\beta^2)-9\gamma c\right]-2\gamma(a-c-t)^2\left[2(2-\beta)^2+9\gamma\right]}{\left[2(2+\beta-\beta^2)-9\gamma\right]^2}+$$
$$+\frac{6a\gamma(a-c-t)}{9\gamma-2(2+\beta-\beta^2)}-t^2-\frac{d}{2}\left(\frac{6\gamma(a-c-t)}{9\gamma-2(2+\beta-\beta^2)}-2t\right)^2 \tag{34}$$

where the superscript *NN* stands for non-cooperative R&D and non-cooperative output stage.

3. Welfare Comparison

We shall proceed in this section to compare the different scenarios in terms of social welfare.[12] The following proposition compares social welfare under Scenarios 3 and 5, that is, W^{CN} and W^{NN}, with the goal of analyzing whether R&D cooperation is always welfare superior to R&D competition, as is usually believed in industrial organization literature. As we will see below, in the absence of R&D subsidies, that result may be reversed.

Proposition 1 *Given an exogenous emissions tax t, for* $0 \le t < f_{35}(\beta)$ *a threshold value* $d_{35}(t, \beta)$ *always exists such that for* $d > d_{35}(t, \beta)$*,* $W^{CN} < W^{NN}$*. On the other hand, for* $t \ge f_{35}(\beta)$*,* $W^{CN} < W^{NN}$ *never holds.*

Proof of Proposition 1

In order to obtain the result we compare social welfare under Scenarios 3 and 5, that is, W^{CN} and W^{NN}. From the difference between them we solve for d obtaining the critical value function:

$$d_{35}(t,\beta)=\frac{\beta\left[32040-2021t+\beta\left(-23121+916t-2\beta(\beta-2)(414+11t)\right)\right]}{6\left[2+\beta(\beta-1)\right]\left[-1701+626t+\beta(\beta-1)(-81+47t)\right]}+$$
$$+\frac{1242(t-28)}{6\left[2+\beta(\beta-1)\right]\left[-1701+626t+\beta(\beta-1)(-81+47t)\right]} \tag{35}$$

This function is plotted in Figure 1. For values of d such that $0 < d_{35}(t, \beta) < d < 2$, we have $W^{CN} < W^{NN}$. We have cut the "*d*" axis in $d = 2$, given that we impose that constraint on the model in order to guarantee interior solutions. This makes an additional constraint on t appear: in order for $d_{35}(t, \beta)$ to be lower than two, t has to be lower than the following function

$$\mathrm{f}(\beta)=\frac{9\left[84+\beta(4\beta-23)\right]\left[8+\beta(15+4\beta)\right]}{13782+\beta\left[-6619+2\beta\left(4144+293(\beta-2)\beta\right)\right]} \tag{36}$$

12) In order to simplify and make the results depend only on the most relevant parameters (β, d, t), we set the other three parameters at the following values: $a = 10$; $c = 1$; $\gamma = 3$. In this way, we are able to obtain tractable expressions in the comparisons of welfare. The particular values we have chosen are such that interior solutions for the different scenarios are guaranteed. However, we have also made some simulations in order to check the importance, if any, of changing these parameters and we have seen that the qualitative results are not sensitive at all to such changes.

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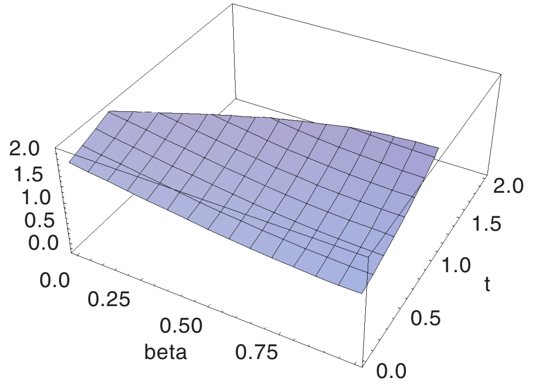
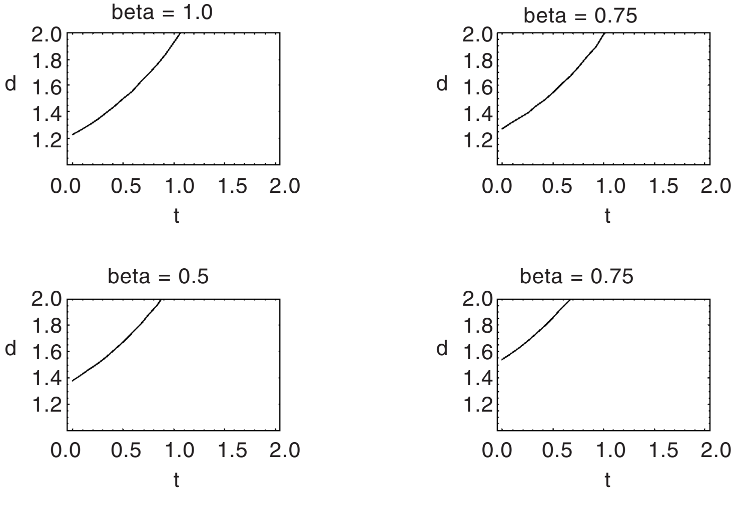
As can be seen in Figure 1, given a value of β, for high enough values of *t*, in particular for $t > f(\beta)$, no critical value *d* lower than two exists, implying that in that case $W^{CN} > W^{NN}$ holds.

Figure 1
Critical Value d_{35}



Proposition 1 shows that when we take into account the environmental impact produced indirectly by R&D investments through its positive effect on output and emissions, cooperative R&D, contrary to the traditional belief, may result in lower social welfare than non-cooperative R&D, whenever the environmental damage is great (parameter *d* is high enough) and the exogenous environmental policy is loose (*t* is low). The intuition is clear: when the firms jointly decide on R&D investments, they completely internalize the spillover effect, making R&D investments more profitable, which leads to higher R&D, lower production costs, and thus higher levels of output and pollution. As Proposition 1 shows, when the emissions tax is low and the environmental damage high enough, the negative effect dominates, leading to a reduction in social welfare. When the emissions tax is higher, however, a higher pro-

Figure 2
Critical Values d_{35} for Different Values of β



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portion of the environmental externality is corrected directly by the tax and the positive effect of cooperation on welfare dominates, making R&D cooperation welfare improving. Figure 2 displays the critical value function $d_{35}(t)$ for different values of the spillover parameter β. In the area above the function, cooperative R&D reduces social welfare relative to non-cooperative R&D. As can be seen, when the spillover parameter increases that region also increases. The reason is that a higher β means that the advantage of increasing the spillover parameter to its maximal value that the firms achieve when they cooperate in R&D is smaller and, therefore, the region where cooperative R&D is not welfare improving increases.

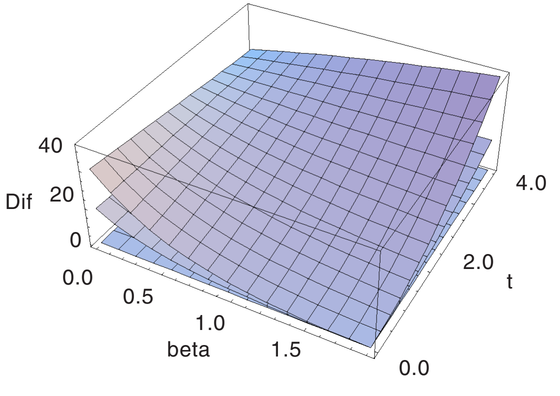
Petrakis and Poyago-Theotoky (2002) show that a technology policy consisting of allowing for cooperative R&D may be socially worse than the alternative policy of subsidizing R&D, which is also an interesting result. We are not, however, comparing two different technology policies. Our result states that cooperative R&D can reduce social welfare relative to non-cooperative R&D. Notice, however, that this result has been obtained in a setting in which no subsidies on R&D are granted. The only technology policy decision to be taken is whether or not to allow for cooperative R&D. The following proposition will make the same comparison, but now the technology policy will consist of a subsidy to cooperative R&D. As we will see below, under that scenario, cooperative R&D is always welfare improving.

Proposition 2 *For any positive emissions tax t guaranteeing interior solutions,* $W^{SCN} > W^{SNN}$ *always holds.*

Proof of Proposition 2

In order to obtain the result we have merely to compare welfare under Scenarios 2 and 4. It can be seen that, regardless of β and for all $t > 0$ guaranteeing interior solutions, $W^{SCN} > W^{SNN}$ always holds. The difference $W^{SCN} - W^{SNN}$ is plotted in Figure 3 for β = 0.3 (upper surface) and β = 0.8 (lower surface). As can be seen, the difference is positive regardless of β. In fact, as β decreases, cooperation becomes socially more desirable and, thus, the difference becomes greater. In the extreme case β = 1, the difference becomes zero and coincides with the lowest (zero) surface in Figure 3.

Figure 3
Difference between W^{SCN} and W^{SNN}



The above proposition shows that when the technology policy consists of a subsidy (or tax) on cooperative R&D, it is not possible for R&D cooperation to reduce social welfare relative to non-cooperative R&D. The reason is that, in this scenario, the environmental problem can be addressed by the national agency by correctly

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choosing the subsidy (or tax) to be imposed on the firms that cooperate in R&D and, in that way, whereas cooperation allows the firms to completely internalize the spillover, the environmental issue is controlled through the subsidy/tax on R&D. Proposition 2 suggests that in the presence of environmental externalities of production, it may be optimal not only to allow for R&D cooperation but also to encourage it through R&D subsidization, a policy which is frequently used in the EU.

Our next proposition compares social welfare under Scenarios 1 and 3 in order to find out whether allowing a merger, by reducing output and emissions, may be welfare superior to the scenario where only R&D cooperation is allowed.

Proposition 3 *Given an exogenous emissions tax t, for* $0 \leq t < t_{13}$ *a threshold value* $d_{13}(t)$ *always exists such that for* $d > d_{13}(t)$, $W^{CC} > W^{CN}$. *On the other hand, for* $t \geq t_{13}$, $W^{CC} > W^{CN}$ *never holds.*

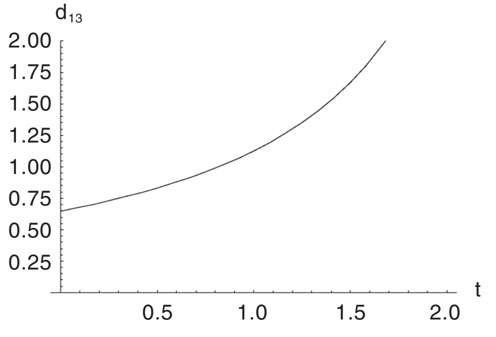
Proof of Proposition 3

Directly comparing social welfare under Scenarios 1 and 3, we obtain the difference $W^{CC} - W^{CN}$ and, solving that difference for d, we obtain the critical value function:

$$d_{13}(t) = \frac{3753 + 343t}{5(1161 - 433t)}$$

Next, we have to look for the conditions that guarantee that the critical value function is lower than two. This constraint is satisfied whenever $t < t_{13} = 7857/4673$. On the other hand, for $t \geq t_{13} = 7857/4673$, $W^{CC} - W^{CN} < 0$ always holds. Figure 4 plots the critical value function $d_{13}(t)$. The vertical axis has been cut in $d = 2$ in order to satisfy the constraint $0 \leq d < 2$.

Figure 4
Critical Value *d*13



The above proposition shows that whenever the environmental damage produced by an industry is great enough (parameter d is high enough), allowing the firms to merge and cooperate not only in R&D but also in abatement and output is welfare superior to allowing them to cooperate only in R&D. The intuition is the following: a merger, by reducing total output, has a first order effect on pollution and, thus, on social welfare. This positive effect on welfare may offset the negative effect of the reduction in market competition produced by the merger whenever the environmental policy is loose enough (t is low enough) and the environmental damage great enough (d high enough). Notice that the above result has been obtained in a setting with no subsidies on cooperative R&D. Figure 5 plots the difference $W^{CC} - W^{CN}$ as a function of d and t. As can be seen, for high enough values of d and low enough values of t the difference becomes positive, which means that a merger is welfare improving.

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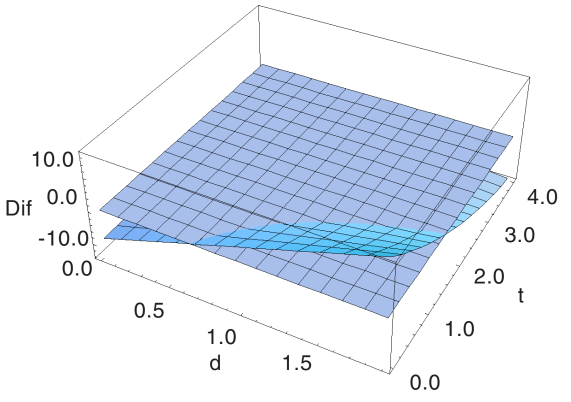
Figure 5
Difference between W^{CC} and W^{CN}



The next proposition compares welfare under Scenarios 1 and 2 in order to check whether the inclusion of a subsidy to R&D cooperation in the technology policy changes the result of the previous proposition.

Proposition 4 *Given an exogenous emissions tax t, for* $0 \leq t < t_{12}$*, a threshold value* $d_{12}(t)$ *always exists such that for* $d > d_{12}(t)$ *,* $W^{CC} > W^{SCN}$*. On the other hand, for* $t \geq t_{12}$*,* $W^{CC} > W^{SCN}$ *never holds.*

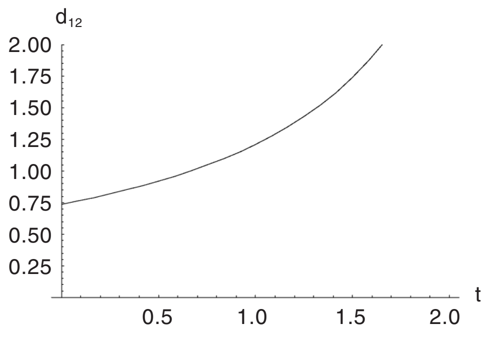
Proof of Proposition 4

Directly comparing social welfare under Scenarios 1 and 2, we obtain $W^{CC} - W^{SCN}$, and solving that difference for d, we obtain the critical value function:

$$d_{12}(t) = \frac{21141 - 8586t + 181t^2 + 3(t-9)\sqrt{216513 - 128466t + 16977t^2}}{16(27 - 11t^2)} \quad (37)$$

Next, we have to look for the conditions that guarantee that the critical value function is lower than two. This constraint is satisfied whenever $t < t_{12} = 81/49$. On the other hand, for $t \geq t_{12} = 81/49$, $W^{CC} - W^{SCN} < 0$ always holds. Figure 6 plots the critical value function $d_{12}(t)$*:* The vertical axis has been cut at the value two in order to satisfy the constraint $0 \leq d < 2$.

Figure 6
Critical Value d_{12}



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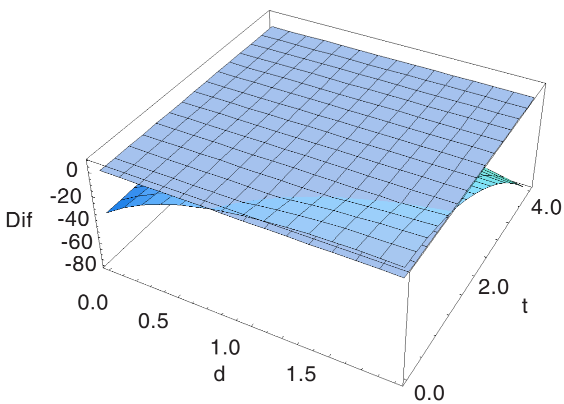
As the above proposition shows, even when the technology policy includes a subsidy to R&D cooperation, whenever the environmental damage produced by an industry is great enough (parameter *d* is high enough) and the environmental policy loose enough, not regulating the industry at all, allowing the firms to merge, is very often welfare superior to a policy of subsidizing cooperative R&D and forbidding collusion. This is a surprising result given that, in this scenario, the national agency may address the environmental problem by choosing the right subsidy/tax on R&D. However, the technology policy has only a second-order effect on emissions (the indirect effect that a change in R&D investments has on output and pollution) whereas again, market collusion has a first order effect on output and pollution. It results that for low values of *t* and high values of *d*, the latter policy is welfare superior to the former. Figure 7 plots the difference $W^{CC} - W^{SCN}$ as a function of *d* and *t*. The difference becomes positive for high enough values of *d* and low enough values of *t*.

Figure 7
Difference between W^{CC} and W^{SCN}



4. Conclusions

While the topic of technology policy in oligopolistic markets has been analyzed in several papers in the industrial organization literature, the relationship between technology policy and the environment has not yet been sufficiently investigated. In this paper we have investigated how some traditional results may change when we introduce the environmental issue into a classical non-tournament model of cooperative R&D with spillovers. In particular, we compare different combinations of technology and antitrust policies from a social point of view, namely allowing for R&D cooperation between rival firms, encouraging R&D cooperation through the subsidization of R&D costs of the cooperating firms and also the combination of those technology policies with an antitrust policy forbidding mergers. We analyze the case of a homogeneous goods duopoly that produces pollution as a by-product of production, faces an exogenous emissions tax imposed by a supranational institution and invests in cost reducing R&D that generates spillovers and also in abatement technologies. In this framework, we show that not regulating the industry at all may be welfare superior to different combinations of technology and antitrust regulation. In particular, when production generates pollution, technology policies that stimulate R&D, reducing production costs and increasing total output result in more emissi-

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ons. We show that when the environmental damage produced by pollution is great and the environmental policy loose, first, allowing for cooperative R&D could be welfare reducing. However, when the technology policy is based on subsidizing cooperative R&D, that result never holds. The reason is that the environmental problem can be addressed by correctly choosing the subsidy (or tax) to be imposed on the firms that cooperate in R&D and, in that way, whereas cooperation allows the firms to completely internalize the spillover, the environmental issue is controlled through the subsidy/tax on R&D. In this sense, the two instruments (R&D cooperation and R&D subsidies) can be seen as complements instead of substitutes, as stated usually in the relevant literature.

Second, we show that a merger, by reducing industry output, can increase welfare through its positive effect on the environment. This result holds even assuming that the positive environmental effect is the only efficiency gain produced by the merger. However, observe that this result arises in a context in which the environmental policy is decided by a different agency than the technology and antitrust policies. Of course, if the same agency could coordinate both policies, the first best outcome would be implemented. Therefore, our results stress the importance of coordinating these two policies in order to achieve jointly the objectives of optimality in R&D investments and taking care of the environment.

Finally, we show that, in our context, not regulating the industry at all may be welfare superior to a policy consisting of subsidizing R&D cooperation and forbidding market collusion. The idea is that whereas the technology policy has only a second-order effect on pollution, a merger directly affects both output and pollution and its positive effect may offset its negative effect on competition.

References

D'Aspremont, C., Jacquemin, A. (1988), "Cooperative and Non-cooperative R&D in Duopoly with Spillovers." *American Economic Review*, 78, pp. 1133-1137.

Hinloopen, J. (1995), "Cooperative R&D versus R&D Subsidies: Cournot and Bertrand Duopolies." Florence, European University Institute, Working Paper ECO 95/26.

Farrell, J., Shapiro, C. (1990), "Horizontal Mergers and Equilibrium Analysis." *American Economic Review,* 80, pp. 107-126.

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

Leahy, D., Neary, J. (1997), "Public Policy towards R&D in Oligopolistic Industries." *American Economic Review,* 87, pp. 642-662.

Levin, D. (1990), "Horizontal Mergers: the 50-per cent Benchmark." *American Economic Review*, 80, pp. 1238-1245.

McAfee, R., Williams, M. A. (1992), "Horizontal Mergers and Antitrust Policy." *Journal of Industrial Economics*, 40, pp. 181-187.

Petrakis, E., Poyago-Theotoky, J. (2002), "Technology Policy in an Oligopoly with Spillovers and Pollution." *Australian Economic Papers*, 41(1), pp. 37-52.

Poyago-Theotoky, J. (1995), "Equilibrium and Optimal Size of a Research Joint Venture in an Oligopoly with Spillovers." *Journal of Industrial Economics*, 43, pp. 209-226.

——————— (1999), "A Note on Endogenous Spillovers in a Nontournament R&D Duopoly." *Review of Industrial Organization*, 15, pp. 253-262.

Vonortas, N. (1994), "Inter-firm Cooperation with Imperfectly Appropriate Research." *International Journal of Industrial Organization*, 12, pp. 413–435.

Williamson, O. (1968), "Economies as an Antitrust Defense: the Welfare Trade-offs." *American Economic Review*, 58, pp. 18-36.