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Subsidising Cooperative and Non-Cooperative R&D in Duopoly with Spillovers

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Abstract

Allowing firms to collude in R&D can raise the level of R&D investments but weakens authorities' control over monopoly power. In this paper an alternative (balanced budget) policy, that of subsidising R&D, is analysed. It is shown that subsidising R&D optimally raises social welfare and is more effective in promoting R&D investments than permitting R&D-cartels or RJVs. Also, subsidising non-cooperative R&D or subsidising an R&D-cartel leads to the same market outcomes. Abandoning anti-trust legislation concerning R&D, as is currently being done by the EC authorities, is not supported therefore by the analysis presented here. In stead, authorities should encourage firms to participate in RJVs and subsidise this agreement accordingly.

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1. Introduction

According to European legislation firms are not allowed to participate in cartels. However, in its Regulation 418/85 the European Commission granted a thirteen-year block exemption under Article 85 para.3 to collusion in research and development (R&D)[1]. This exemption is justified by the alleged effect of cooperative R&D in narrowing the fundamental gap between social and private incentives to invest in R&D[2].

Inspired by this practice a substantial literature has developed on R&D cooperation[3]. In particular Claude d'Aspremont and Alexis Jacquemin (1988, 1990) have developed a two-stage Cournot model with explicit technological spillovers to analyse collusive R&D. In the first stage firms determine their R&D investment. Given this investment, output is set in the second stage. Three different regimes are considered: first, no cooperation in either the first or the second stage; second, cooperation in R&D and competition in output; third, cooperation in both the first and the second stage. D'Aspremont and Jacquemin conclude that cooperation in R&D leads to an increase in R&D expenditures when spillovers are substantial, i.e. when a substantial part of each firm's R&D benefits flow without payment to competing firms. In case of small spillovers the outcome is reversed[4,5].

Implicitly d'Aspremont and Jacquemin consider only 'R&D-cartels': "agreements to coordinate R&D activities so as to maximize the sum of overall

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[1] See Jacquemin (1988) and Martin (1994) for a discussion of this policy.

[2] Katz and Ordover (1990) identify several forces which create the discrepancy between social and private incentives to conduct R&D. Also, depending on the industry, Bernstein and Nadri (1988) estimate the social rate of return to R&D capital to be 0.1 to 10 times the private rate of return.

[3] See a.o. Bozeman et al. (1986), Kamien and Zang (1993), Simpson and Vonortas (1994) and the other references in this paper.

[4] Suzumura (1992) explains these results as follows: "cooperation should reduce excessive duplication of R&D efforts in the presence of large spillovers. Note, however, that the R&D incentive of a single firm hinges squarely on the extent of appropriability of the R&D benefits, so that the presence of large R&D spillovers may drastically reduce the incentives for cost reduction(..). From this viewpoint, an enforceable agreement on cooperative R&D efforts seems to facilitate more commitments. The result of the net effect of the R&D cooperation hinges on the relative strength of these competing effects" (p.1308, footnote omitted). In case of large spillovers the latter effect outweighs the former leading in sum to increased R&D expenditures.

[5] The analysis of d'Aspremont and Jacquemin has been generalized in several ways (see Kamien et al. (1992) for an overview) without significant alternations to their conclusions.

profits" (Kamien et al. (1992, p.1294)). However, to understand all the economic aspects of cooperation in R&D we also have to consider research joint ventures (RJV): "agreements in which firms decide unilaterally on their R&D investments but the results of their R&D are fully shared" (Kamien et al. (1992, p.1294))[6]. Within RJVs spillovers are maximal while in R&D-cartels there is still room for duplicate research. If both contracts are agreed upon simultaneously, then firms are engaged in a 'RJV-cartel'.

Although it can be socially desirable to allow firms to collude in R&D by engaging in R&D-cartels or RJV-cartels, it remains a pursuit for additional social welfare with considerable risk. Firms are tempted to extend the R&D-collusion agreement to the production stage. This induces a social welfare loss because of increased market power.

An obvious alternative to abandoning anti-trust laws is to subsidise private R&D[7], a policy which is, in fact, conducted on a large scale[8]. Subsidising R&D may give rise to moral hazard (see Katz (1986) and Katz and Ordover (1990)), but does not weaken authorities' control over monopoly power. Also, Hall (1992) finds substantial empirical evidence for a positive elasticity of R&D investment with respect to cash flow. His sample reveals further that leverage ratios and R&D investments are strongly negatively correlated. Hall's findings indicate that subsidies may be more robust in stimulating R&D investments than allowing for any type of collusion.

In this paper R&D-subsidies are analysed by introducing an active government into the d'Aspremont-Jacquemin model. Prior to the R&D-setting stage this government subsidises R&D optimally according to d'Aspremont and Jacquemin's social welfare function[9]. The main results of the analysis are that: (i) a government can increase social welfare through R&D-subsidies, (ii) subsidising non-collusive R&D optimally is more effective in raising R&D than

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[6] Kamien et al. (1992) do not give precisely this definition of a RJV but it can be extracted from their definitions of R&D competition and RJVs.

[7] See Spencer and Brander (1983).

[8] In 1985 the U.S., Germany and France respectively spent 13.3, 11.0 and 11.3 percent of their GNP on R&D subsidies. Japan subsidized R&D for 6.1% of GNP in 1983 (Ritzen(1990)).

[9] Suzumura (1992) questions this (first-best) welfare function since "the enforcement of the first-best arrangement may require considerable leverage on the government vis-à-vis private firms, something which may be hard to secure in reality" (p.1308). He then proposes a second-best welfare function presupposing that "the oligopolistic competition in the second stage quantity-games lies beyond the regulatory power of the nonomnipotent government" (p.1314).

permitting RJVs or R&D-cartels without subsidisation, (iii) subsidising non-cooperative R&D or subsidising R&D-cartels leads to the same market outcome (and social welfare)[10], (iv) yet only RJVs should be encouraged and subsidised. A subordinate result is that introducing R&D-subsidies ensures stability of the d'Aspremont-Jacquemin-games.

The organisation of this paper is as follows. In the next section the d'Aspremont-Jacquemin analysis is briefly described and some additional conclusions are drawn from their model. In Section 3 optimal subsidies are derived for the three d'Aspremont-Jacquemin games. Section 4 addresses the question wether authorities should subsidise R&D, allow firms to cooperate in R&D, or to subsidise cooperative R&D. Several conclusions are formulated in the last section.

2. Cooperative and non-cooperative R&D in duopoly with spillovers

D'Aspremont and Jacquemin (1988) consider a duopoly with linear demand, cost and production functions. R&D is cost reducing and R&D-costs are quadratic, reflecting the diminishing returns to R&D investments. Profits of a single firm equal

$$\pi_i(q_i,q_j,x_i,x_j) = (a-bQ)q_i-(A-x_i-\beta x_j)q_i-\gamma\frac{x_i^2}{2}, \quad i,j=1,2, \quad i\neq j, \qquad (1)$$

where Q ($=q_1+q_2$) is total production, x_i denotes R&D expenditures of firm i and β measures the spillover effect, $\beta\in[0,1]$. It is assumed that $a,b>0$, $Q\leq\frac{a}{b}$ and $A\geq x_i+\beta x_j$.

Table 1 summarizes all relevant variables resulting from solving completely the respective d'Aspremont and Jacquemin games[11]. Comparing the profits of a single firm for the respective games reveals that[12]

$$\pi_I^* < \pi_{II}^* < \pi_{III}^* \quad \forall\ \beta\in[0,\tfrac{1}{2})\cup(\tfrac{1}{2},1],$$

[10] In case of maximal spillovers this result reads as "subsidising RJVs or subsidising RJV-cartels lead to the same market outcome (and social welfare)".

[11] The solution concepts to these games can be found in d'Aspremont and Jacquemin (1988).

[12] For $\beta=½$ this ranking reads $\pi_I^* = \pi_{II}^* < \pi_{III}^*$.

Table 1 Equilibrium Outcomes of the d'Aspremont-Jacquemin Games

	No Cooperation in R&D No Cooperation in Production	Cooperation in R&D No Cooperation in Production	Cooperation in R&D Cooperation in Production
x^{*a}	$\frac{(a-A)(2-\beta)}{4.5b\gamma-(2-\beta)(1+\beta)}$	$\frac{(a-A)(1+\beta)}{4.5b\gamma-(1+\beta)^2}$	$\frac{(a-A)(1+\beta)}{4b\gamma-(1+\beta)^2}$
Q^*	$\frac{3\gamma(a-A)}{4.5b\gamma-(2-\beta)(1+\beta)}$	$\frac{3\gamma(a-A)}{4.5b\gamma-(1+\beta)^2}$	$\frac{2\gamma(a-A)}{4b\gamma-(1+\beta)^2}$
π^*	$\frac{\gamma(a-A)^2[4.5b\gamma-(2-\beta)^2]}{2[4.5b\gamma-(2-\beta)(1-\beta)]^2}$	$\frac{\gamma(a-A)^2}{2[4.5b\gamma-(1+\beta)^2]}$	$\frac{\gamma(a-A)^2}{2[4b\gamma-(1+\beta)^2]}$
W^*	$\frac{\gamma(a-A)^2[9b\gamma-(2-\beta)^2]}{[4.5b\gamma-(2-\beta)(1+\beta)]^2}$	$\frac{\gamma(a-A)^2[9b\gamma-(1-\beta)^2]}{[4.5b\gamma-(1+\beta)^2]^2}$	$\frac{\gamma(a-A)^2[6b\gamma-(1-\beta)^2]}{[4b\gamma-(1-\beta)^2]^2}$

[a] R&D levels and profits concern a single firm.

where *I* denotes the fully non-cooperative game, *II* the game with only R&D collusion and *III* the full cooperation case. This comparison shows that irrespective of the spillover effect, firms will always want to collude in as many stages as possible.

From a social welfare point of view we have the following ranking[13]

$$W_I^* > W_{II}^* > W_{III}^* \quad \forall\ \beta \in [0, \frac{1}{2}),$$

$$W_{II}^* > W_I^* > W_{III}^* \quad \forall\ \beta \in (\frac{1}{2}, 1],$$

where W^* is defined as the sum of producers' and consumers' surplus.

Clearly, there is no need for relaxing anti-trust regulation when spillovers are small. Allowing for cooperation in R&D is only desirable in case of substantial spillovers. But even then the collusive R&D agreement needs to be monitored very closely since firms are tempted to extend the collusive arrangement to the production stage.

The cooperative R&D agreement considered by d'Aspremont and Jacquemin (1988) is that of a R&D-cartel. To analyse RJVs in their model, the

[13] For $\beta = ½$ we have as ranking $W_I^* = W_{II}^* > W_{III}^*$.

spillover parameter must be set to its maximum ($\beta = 1$). In that case the first game describes a RJV, while RJV-cartels are captured by the second game.

If asked for, RJVs or RJV-cartels can be enforced without objections from the industry since in all three games considered firms have an incentive to share the fruits of their R&D efforts[14]. Whether or not these agreements are desirable needs to be judged by their effect on social welfare. It turns out that RJVs are only desirable when pre-cooperative spillovers are not very large[15]. However, it is always socially beneficial to extend an existing R&D-cartel to a RJV-cartel[16].

On the other hand, we are led to conclude that firms should only be allowed to cooperate in R&D when pre-cooperative spillovers are large, and this collusive agreement should be that of a RJV-cartel. However, as already observed, this policy will evoke the danger of increased monopoly power since monopoly profits are within firms' reach. To the extent that spillover size indicates 'resemblance' between companies, and given that RJV-cartels are only desirable when spillovers are substantial, this threat is all the more real. Let us consider therefore another policy: that of subsidising private R&D.

3. R&D-subsidies in the d'Aspremont-Jacquemin-model

Following Spencer and Brander (1983) we introduce an R&D-subsidy, s, per unit of R&D. It is assumed that, in order to finance the total R&D-subsidy, firms are taxed for it (in the output stage). In other words, we consider a balanced-budget policy. By providing a R&D-subsidy, the government changes the cost structure of the R&D stage, and thus changes the set of actions (output and R&D expenditures) which are compatible with the two-stage Nash-Cournot equilibrium. (Firms cannot establish this alteration in cost structure themselves, since, by definition of a Nash-Cournot equilibrium, it is not in their interest to shift financial resources from the output stage to the R&D stage). However, the taxation in the output stage does not affect the equilibrium, since the appropriate tax is deducted from firms' profits after the Nash-Cournot equilibrium is computed. Therefore, differences in equilibrium profits and welfare with respect to the d'Aspremont-Jacquemin outcomes reflect only the influence of the subsidy.

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[14] Given the second order conditions it is true that $\partial \pi_i^* / \partial \beta > 0$ for $i = I, II, III$.

[15] RJVs increase social welfare when $\beta \leq 0.6$ since $W_I^* |_{\beta = 0.6} = W_I^* |_{\beta = 1}$, and on $\beta \in [0,1]$ the expression for social welfare follows a parabolic course.

[16] For $\beta \in [0,1]$ the partial derivative $\partial W_{II}^* / \partial \beta$ is positive.

Given the demand, production and cost structures of the d'Aspremont-Jacquemin-model, profits of a single firm with R&D-subsidies are

$$\pi_i(q_i,q_j;x_i,x_j,s) = (a-bQ)q_i - (A-x_i-\beta x_j)q_i - \gamma\frac{x_i^2}{2} + sx_i, \quad i,j=1,2,\ i\neq j. \tag{2}$$

Social welfare, defined as the sum of producers' and consumers' surplus, equals

$$W(Q,x) = (a-½bQ)Q - (A-(1+\beta)x)Q - \gamma x^2, \tag{3}$$

where $x = x_i$, $i=1,2$.

In the following three subsections the respective d'Aspremont-Jacquemin games will be solved within this R&D-subsidy setting, using the concept of sub-game perfect equilibrium.

<u>3.1 No cooperation in either R&D or output</u>[17]

Maximising (2) w.r.t. q_i for $i=1,2$, conditional on x_1, x_2 and s gives us the equilibrium quantity[18]

$$\hat{q}_i(x_i,x_j) = \frac{1}{3b}[(a-A)+(2-\beta)x_i+(2\beta-1)x_j], \quad i,j=1,2, \quad i\neq j. \tag{4}$$

At the preceding stage, in which firms determine their R&D investment, profits can be written as

$$\hat{\pi}(x_i,x_j;s) = \frac{1}{9b}[(a-A)+(2-\beta)x_i+(2\beta-1)x_j]^2 - \gamma\frac{x_i^2}{2} + sx_i, \quad i,j=1,2, \ i\neq j.$$

The equilibrium levels of R&D conditional on s, which follow from $\partial\hat{\pi}(x_i,x_j;s)/\partial x_i = 0$ for $i,j=1,2$, $i\neq j$, are[19]

$$\hat{x}_i(s) = \frac{(a-A)(2-\beta)+4.5bs}{4.5b\gamma-(2-\beta)(1+\beta)}, \quad i=1,2. \tag{5}$$

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[17] In all games we consider only symmetric equilibria.

[18] Variables marked with a hat are conditional equilibrium outcomes.

[19] The second order condition requires that $(2-\beta)^2 < 4.5b\gamma$.

As is to be expected, R&D-subsidies increase the equilibrium level of R&D investments. Also, for s equal to zero, (5) corresponds exactly to the d'Aspremont-Jacquemin expression[20].

Substituting (4) and (5) into (3) gives us social welfare conditional on the R&D-subsidy

$$\hat{W}(\hat{x}(s)) = \frac{4}{9b}[(a-A)+(1+\beta)\hat{x}(s)]^2 - \gamma\hat{x}(s)^2, \tag{6}$$

where $\hat{x}(s) = \hat{x}_i(s)$ for $i=1,2$. The final step involves calculating the optimal R&D-subsidy. Maximising (6) w.r.t. s gives[21,22]

$$s_I^* = \frac{3\gamma\beta(a-A)}{4.5b\gamma - 2(1+\beta)^2}. \tag{7}$$

Equation (7) states that the optimal R&D-subsidy is increasing in spillovers[23]. The incentive reducing effect of these externalities on R&D-investments is parried by an increasing subsidy. Indeed, without subsidies the derivative of $\hat{x}_i$ with respect to β is negative. With subsidies, this derivative is positive, as will be shown in the proof of Proposition 2.

3.2 Cooperation in R&D, competition in output

When firms cooperate in R&D but compete in output, equilibrium quantities are still given by (4). In the second stage firms maximise joint profits

$$\hat{\Pi}(x_i,x_j;s) = \hat{\pi}_1(x_i,x_j;s) + \hat{\pi}_2(x_i,x_j;s)$$

$$= \sum_{i=1}^{2}\left\{\frac{1}{9b}[(a-A)+(2-\beta)x_i+(2\beta-1)x_j]^2 - \gamma\frac{x_i^2}{2} + sx_i\right\}, \quad i \neq j.$$

[20] In fact, this is true for all expressions in all games.

[21] Variables marked with a star are unconditional equilibrium outcomes.

[22] The second order condition requires that $2(1+\beta)^2 < 4.5b\gamma$. Note that this ensures (see (7)) that the optimal R&D-subsidy is positive.

[23] $\partial s_I^*/\partial\beta = 3\gamma(a-A)[4.5b\gamma - 2(1-\beta^2)]/[4.5b\gamma - 2(1-\beta)^2]^2$ which is positive $\forall \beta \in [0,1]$.

The symmetric equilibrium level of R&D conditional on s is given by[24]

$$\hat{x}(s) = \frac{(a-A)(1+\beta)+4.5bs}{4.5b\gamma-(1+\beta)^2}. \tag{8}$$

Comparing (8) with (5) we see that, in the case of equal per unit R&D-subsidies, R&D-cartelisation leads to increased R&D investments when spill-overs are large (i.e. $\beta > \frac{1}{2}$). The opposite holds for small spillovers. This confirms (again) the validity of d'Aspremont and Jacquemin's result. However, R&D-subsidies need not be equal under different forms of cooperation. Indeed, they turn out to be different, the implications of which are analysed in the next section.

Social welfare conditional on the optimal R&D level is given by (6) with $\hat{x}(s)$ given by (8). Maximizing this expression welfare with respect to s leads to[25]

$$s_{II}^{*} = \frac{\gamma(a-A)(1+\beta)}{4.5b\gamma-2(1+\beta)^2}. \tag{9}$$

Comparing s_I^* with s_{II}^* shows that the latter exceeds the former for $\beta < \frac{1}{2}$ while for large spillovers the opposite holds.

3.3 Cooperation in both R&D and output

If firms act as a monopoly they maximise joint profits

$$\pi(q_1,q_2;x_1,x_2,s) = (a-bQ)Q-AQ+(x_1+\beta x_2)q_1+(x_2+\beta x_1)q_2-\sum_{i=1}^{2}\left\{\gamma\frac{x_i^2}{2}-sx_i\right\},$$

in the first stage. The symmetric solution for the output stage, conditional on x ($= x_1 = x_2$) and s, is

$$\hat{q}_i(x) = \frac{(a-A)+(1+\beta)x}{4b}, \quad i=1,2. \tag{10}$$

Joint profits are now given by

[24] The second order condition requires that $(1-\beta)^2 < 4.5b\gamma$.

[25] The second order condition requires that $2(1-\beta)^2 < 4.5b\gamma$. Again this implies that the optimal R&D-subsidy is positive.

$$\hat{\pi}(x;s) = \frac{1}{4b}[(a-A)+(1+\beta)x]^2 - \gamma x^2 + 2sx.$$

The optimal level of R&D turns out to be[26]

$$\hat{x}(s) = \frac{(a-A)(1+\beta)+4bs}{4b\gamma-(1+\beta)^2}. \tag{11}$$

Given (10) and (11) social welfare can be written as

$$\hat{W}(\hat{x}(s)) = \frac{3}{8b}[(a-A)+(1+\beta)\hat{x}(s)]^2 - \gamma\hat{x}(s)^2. \tag{12}$$

Maximising (12) with respect to s leads to[27]

$$s^*_{III} = \frac{\gamma(a-A)(1+\beta)}{8b\gamma-3(1+\beta)^2}. \tag{13}$$

According to (13), there are also social incentives to subsidize R&D in the monopoly case. This confirms the findings of d'Aspremont and Jacquemin that (in the absence of R&D subsidies) the social planner's level of R&D is never realised by any market form.

3.4 Stability

Henriques (1990) shows that, for the fully non-cooperative game, the second order condition associated with the R&D stage is not sufficient to ensure stability in this stage. The R&D reaction functions cross correctly if $|\partial x_i/\partial x_j| < 1$ for $i,j=1,2$, $i\neq j$, i.e. (Henriques (1990,p.639))

$$\left|\frac{(2-\beta)(2\beta-1)}{4.5b\gamma-(2-\beta)^2}\right| < 1.$$

Rearranging this stability condition leads to

[26] The second order condition states $(1+\beta)^2 < 4b\gamma$.

[27] The second order condition requires that $3(1-\beta)^2 < 8b\gamma$. As in the previous two games this condition ensures a positive R&D-subsidy.

$$3(2-\beta)(1-\beta) < 4.5b\gamma,\ \forall\beta\in[0,\frac{1}{2}), \tag{14a}$$

$$(2-\beta)(1+\beta) < 4.5b\gamma,\ \forall\beta\in(\frac{1}{2},1]. \tag{14b}$$

Combining both conditions implies $4.5b\gamma > 6$. But the second order condition for deriving the optimal subsidy in the non-collusive game gives $4.5b\gamma > 8$. Therefore, introducing optimal R&D-subsidies ensures stability of the fully non-cooperative game.

4. To what avail?

Should a government provide R&D-subsidies, should it allow individual firms to cooperate in R&D, or should it do both? To answer these questions we first examine whether or not R&D-subsidies are socially desirable. In Proposition 1 it is shown that they are. Second, the impact of subsidising R&D is compared with allowing firms to cooperate in R&D. It appears that in general the former policy is more effective than the latter in promoting private R&D investments. This statement is formalised in Proposition 2. Third, the optimal 'policy mix' is derived. For a number of reasons, which will be explained below, we conclude that a government should subsidise RJVs and firms should not be allowed to cooperate in R&D.

Considering the effect of optimal R&D subsidies leads to the following proposition, the proof of which is given in the appendix.

PROPOSITION 1

For all three games considered, irrespective of the spillover effect, (i) the optimal R&D-subsidy is positive and (ii) subsidising R&D optimally increases the level of R&D, output and social welfare, but lowers net profits.

According to Proposition 1, providing optimal R&D-subsidies (for which firms are taxed) increases consumers' surplus but lowers producers' surplus. The former effect dominates the latter with the net result that social welfare increases. There is however an upper limit to subsidizing R&D beyond which the level of R&D increases too much, which, compared to the zero subsidy case, results in a social welfare loss. Since the social welfare function is quadratic in

s, this limit is equal to two times the respective optimal R&D-subsidies. Moreover, these subsidies are functions of unknown parameters, in particular of the spillover effect. Given that spillover effects are never known exactly, R&D-subsidies should be provided with care[28].

It could be argued that firms are not interested in R&D-subsidies since it lowers their net profits. But if a government wants to increase social welfare it can always tax firms and set R&D-subsidies accordingly. Given the nature of a Cournot-Nash equilibrium, firms' best responses are then given by the equilibria as computed in the previous section.

To the extent that authorities evaluate all instruments available to foster investments in R&D, we have to compare both policy options considered here.

PROPOSITION 2

To promote private R&D, subsidising non-collusive R&D optimally is more effective than permitting R&D-cartels or allowing firms to engage in RJVs without subsidisation.

PROOF

Comparing the equilibrium level of non-cooperative, subsidised R&D, $\hat{x}_I(s_I^*)$, with the non-subsidised R&D investment in the R&D-cartel, $\hat{x}_{II}(0)$, we have $\forall\beta\in[0,1]$ that

$$\hat{x}_I(s_I^*) = \hat{x}_{II}(0)\{1 + \frac{4.5b\gamma}{4.5b\gamma - 2(1+\beta)^2}\}.$$

The second order condition for deriving the optimal subsidy in the fully non-cooperative game ensures that the expression in brackets is positive. The partial derivative of non-collusive subsidised R&D with respect to β equals

$$\frac{\partial\hat{x}_I(s_I^*)}{\partial\beta} = \frac{2(a-A)[4.5b\gamma + 2(1+\beta)^2]}{[4.5b\gamma - 2(1+\beta)^2]^2}$$

and is positive $\forall\beta\in[0,1]$. Then, realizing that

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[28] All optimal subsidies are increasing in β. Therefore, there is no danger in under estimating the spillover effect, but over estimated spillover effects could lead to socially harmful R&D-subsidies.

$$\hat{x}_I(s_I^*)\,|_{\beta=0} > \hat{x}_I(0)\,|_{\beta=1}$$

completes the proof, since $\hat{x}_I(0)\,|_{\beta=1}$ is the non-subsidised equilibrium R&D investment in a RJV.

■

Subsidising non-cooperative R&D not only leaves the control of monopoly power with the authorities, it is also more efficient in raising private R&D than allowing firms to participate in R&D-cartels or RJVs. This observation raises serious doubts as to the abandoning of anti-trust enforcement by the EC authorities concerning private R&D.

To compose the optimal 'policy mix', we have to evaluate the effect of allowing firms to form R&D-cartels, RJVs or RJV-cartels, combined with subsidising these agreements optimally. Table 2 summarizes all relevant variables resulting from solving the respective games of the previous section[29].

PROPOSITION 3

Subsidising non-cooperative R&D or subsidising a R&D-cartel leads to the same market outcome and social welfare.

Proposition 3 states that encouraging R&D investments by allowing firms to participate in R&D-cartels and in addition subsidising this agreement, has the same effect as subsidising non-cooperative R&D. Since Proposition 3 holds for all values of β, it is in particular valid for $\beta=1$, i.e. optimally subsidising a RJV leads to the same increase in R&D as optimally subsidising a RJV-cartel.

As derived in the proof of Proposition 2, subsidised non-collusive R&D is increasing in β, with the result that subsidised RJVs (or subsidised RJV-cartels), which imply $\beta=1$, give rise to the highest level of private R&D[30].

It remains to see whether, in terms of social welfare, subsidised RJVs (or subsidised RJV-cartels) are the optimal solution. To answer this question we first note that

$$W_I^{*s} = W_{II}^{*s} > W_{III}^{*s}, \quad \forall \beta \in [0,1].$$

[29] Note that equilibrium profits are less the corresponding subsidy amount since firms are assumed to be taxed for the R&D-subsidy in the third stage.

[30] Note that $x_I^{*s}\,|_{\beta=1} = x_{II}^{*s}\,|_{\beta=1} > x_{III}^{*s}, \quad \forall \beta \in [0,1]$.

Table 2 Optimal Subsidies, R&D, Total Output, Profits and Welfare[a]

	No Cooperation in R&D No Cooperation in Production	Cooperation in R&D No Cooperation in Production	Cooperation in R&D Cooperation in Production
s^{*}	$\frac{3\gamma\beta(a-A)}{4.5b\gamma-2(1+\beta)^2}$	$\frac{\gamma(a-A)(1-\beta)}{4.5b\gamma-2(1-\beta)^2}$	$\frac{\gamma(a-A)(1+\beta)}{8b\gamma-3(1+\beta)^2}$
x^{*s}	$\frac{2(a-A)(1+\beta)}{4.5b\gamma-2(1+\beta)^2}$		$\frac{3(a-A)(1-\beta)}{8b\gamma-3(1-\beta)^2}$
Q^{*s}	$\frac{3\gamma(a-A)}{4.5b\gamma-2(1-\beta)^2}$		$\frac{4\gamma(a-A)}{8b\gamma-3(1-\beta)^2}$
$\pi^{*s\,b}$	$\frac{\gamma(a-A)^2[4.5b\gamma-4(1-\beta)^2]}{2[4.5b\gamma-2(1+\beta)^2]^2}$		$\frac{\gamma(a-A)^2[16b\gamma-9(1+\beta)^2]}{2[8b\gamma-3(1-\beta)^2]^2}$
W^{*s}	$\frac{2\gamma(a-A)^2}{4.5b\gamma-2(1-\beta)^2}$		$\frac{3\gamma(a-A)^2}{8b\gamma-3(1+\beta)^2}$

[a] Subsidies, R&D-levels and profits concern a single firm.
[b] Profits are less the corresponding amount of R&D-subsidy.

A subsidised monopoly is never desirable. Yet firms are always in pursuit of this market form since

$$\pi_I^{*s} = \pi_{II}^{*s} < \pi_{III}^{*s}, \ \forall \beta \in [0,1].$$

So again the danger of increased monopoly power, due to collusion in R&D, is apparent. And since there is no difference between W_I^{*s} and W_{II}^{*s}, there is no reason for allowing firms to cooperate in R&D. Finally, note that W_I^{*s} is rising in β[31]. Therefore, the optimal policy is for the authorities to encourage firms to form RJVs and subsidise this agreement accordingly.

[31] $\partial W_I^{*s}/\partial\beta$ is positive $\forall \beta \in [0,1]$.

5. Conclusions

Subsidising R&D, for which firms are taxed, should be considered as a serious alternative to abandoning anti-trust laws to stimulate private R&D investments. This policy preserves not only the control over monopoly power with the authorities, but is also more effective in promoting R&D investments than permitting R&D-cartels or RJVs. Moreover, providing optimal R&D-subsidies leads to an increase in social welfare. Also, subsidising non-cooperative R&D or subsidising a R&D-cartel leads to the same market outcome (and welfare). In particular, subsidising a RJV or subsidising a RJV-cartel leads to the same market outcome (and welfare). According to the analysis presented here, the authorities should encourage and subsidise RJVs.

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Appendix. Proof of Proposition 1

part (i)

The second order conditions associated with deriving the optimal R&D-subsidies guarantee that the denominators of the respective subsidies are positive. By restrictions on the parameters of the model ($\gamma>0, a>A$ and $\beta\in[0,1]$) the same is true for the respective numerators.

part (ii)

R&D

The levels of R&D for the respective games can be written as

$$x_I^{*s} = x_I^{*}\left\{1 + \frac{27b\beta\gamma}{2[4.5b\gamma - 2(1+\beta)^2](2-\beta)}\right\},$$

$$x_{II}^{*s} = x_{II}^{*}\left\{1 + \frac{4.5b\gamma}{4.5b\gamma - 2(1+\beta)^2}\right\},$$

$$\hat{x}_{III}^{*s} = x_{III}^{*}\left\{1 + \frac{4b\gamma}{8b\gamma - 3(1+\beta)^2}\right\}.$$

The second order conditions assure that the expressions in brackets exceed one.

Output

The differences between optimal-subsidy total output and zero-subsidy total output for the respective games are given by

$$Q_I^{*s} - Q_I^* = \frac{9\gamma(a-A)\beta(1+\beta)}{[4.5b\gamma - 2(1+\beta)^2][4.5b\gamma - (2-\beta)(1+\beta)]} > 0,$$

$$Q_{II}^{*s} - Q_{II}^* = \frac{3\gamma(a-A)(1+\beta)^2}{[4.5b\gamma - 2(1+\beta)^2][4.5b\gamma - (1+\beta)^2]} > 0,$$

$$Q_{III}^{*s} - Q_{III}^* = \frac{2\gamma(a-A)(1+\beta)^2}{[8b\gamma - 3(1+\beta)^2][4b\gamma - (1+\beta)^2]} > 0.$$

The inequalities hold for $\beta \in (0,1]$.

Welfare

The differences between optimal-subsidy social welfare and zero-subsidy social welfare for the respective games are given by

$$W_I^{*s} - W_I^* = \frac{9\gamma(a-A)^2 4.5b\gamma\beta^2}{[4.5b\gamma - 2(1+\beta)^2][4.5b\gamma - (2-\beta)(1+\beta)]^2} > 0,$$

$$W_{II}^{*s} - W_{II}^* = \frac{\gamma(a-A)^2 4.5b\gamma(1+\beta)^2}{[4.5b\gamma - 2(1+\beta)^2][4.5b\gamma - (1+\beta)^2]^2} > 0,$$

$$W_{III}^{*s} - W_{III}^* = \frac{\gamma(a-A)^2 2b\gamma(1+\beta)^2}{[8b\gamma - 3(1+\beta)^2][4b\gamma - (1+\beta)^2]^2} > 0.$$

The inequalities hold for $\beta \in (0,1]$.

Profits

The differences between optimal-subsidy profits and zero-subsidy profits for the respective games are given by

$$\pi_I^{*s} - \pi_I^{*} = -\frac{3\gamma(a-A)^2 4.5b\gamma\beta[4.5b\gamma(2-\beta)+(5\beta-4)(1+\beta)^2]}{2[4.5b\gamma-2(1+\beta)^2]^2[4.5b\gamma-(2-\beta)(1+\beta)]^2} < 0,$$

$$\pi_{II}^{*s} - \pi_{II}^{*} = -\frac{\gamma(a-A)^2 4.5b\gamma(1+\beta)^2}{[4.5b\gamma-2(1+\beta)^2]^2[4.5b\gamma-(1+\beta)^2]} < 0,$$

$$\pi_{III}^{*s} - \pi_{III}^{*} = -\frac{\gamma(a-A)^2 4b\gamma(1+\beta)^2}{2[4b\gamma-(1+\beta)^2][8b\gamma-3(1+\beta)^2]^2} < 0.$$

The inequalities hold for $\beta \in (0,1]$.

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