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R&D cooperation with unit-elastic demand

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Abstract: The present paper shows that R&D cooperation leads to the monopoly outcome in terms of price and quantity if demand is unit-elastic. If the demand function exhibits an upper bound for the willingness to pay, R&D cooperation is inferior to a scenario in which firms cooperate both in their R&D and their output decision.

Keywords: R&D cooperation, spillovers, cartelization

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1. Introduction

Whether to promote research joint ventures (RJVs) or not is an important and heavily debated policy issue. Since the beginning of the 1980's, a shift in technology policy towards more cooperative R&D, both in Europe and the US, can be noticed (Röller et al. (2007)). In the US, the cornerstone in the change of technology policy was the passage of the National Cooperative Research Act (NCRA) in 1984. In a lively debate about this Act, Jorde and Teece (1990) argue that it is not sufficiently permissive. Shapiro and Willig (1990) however, warn that even joint ventures whose activities are confined to R&D may have anticompetitive effects. In the same manner Brodley (1990) points out that innovation collaboration can create anticompetitive risks. Also Martin (2002) utters concerns that firms which cooperate in one field might well cooperate in another one. Martin (1995) argues that "common assets create common interests". Firms that voluntarily form an RJV are also more likely to collude at the product market.

In the EU, the antitrust treatment of RJVs is based on a block exemption from Article 81 (ex 85) of the EC Treaty (for a discussion see Geroski (1993)). Furthermore, Articles 163 – 173 of the EC Treaty stipulate how to promote research activities and how to support efforts to cooperate. Multi-annual framework programmes are established to that aim. One target of the Lisbon strategy is to increase R&D expenditures to 3 % of GDP until 2010. A way to reach this ambitious goal is deemed to be R&D cooperation. As a consequence, cooperation is one of the main objectives in the Seventh Framework Programme, which entered into force in 2007.

From a theoretical point of view it is less clear whether R&D cooperation is always beneficial. The strategic investment game models put forth by D'Aspremont and Jacquemin (1988, 1990) (henceforth AJ) and by Kamien et al. (1992) (henceforth KMZ) show that whenever the spillover exceeds a certain "critical level", cooperative R&D levels are higher than non-

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6 cooperative ones. Consequently, cooperation in R&D is better than non-cooperation only for
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8 "high" spillovers. The aforementioned models and many of the subsequent ones are characterized
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10 by linear demand functions.
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13 We abolish this assumption and show that under certain conditions R&D cooperation
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15 directly leads to the monopoly outcome in terms of price and quantity. If demand is unit-elastic, a
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17 Cournot duopoly, in which firms cooperate in R&D and compete at the output market, leads to a
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19 price that approaches infinity and R&D expenditures that go to zero. The duopoly differs from
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21 the monopoly case only in terms of profits, which are lower in the duopoly case. If R&D
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23 spillovers are perfect, the cooperative and the non-cooperative choice of R&D expenditures
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25 coincide. Neither firm has an incentive to invest in R&D when spillovers are perfect, irrespective
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27 of whether they may cooperate or not. If the demand function exhibits an upper bound for the
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29 willingness to pay, duopoly prices and quantities under R&D cooperation correspond to that of
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31 the monopoly. However, R&D expenditures are lower than the cost minimizing amount of R&D
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33 expenditures. It is demonstrated that a scenario in which firms cooperate in R&D and compete in
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35 the quantity setting stage of the game is inferior to full cartelization.
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41 In a linear demand setting, Amir et al. (2002) show the potentially superior performance
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43 of a monopoly. Monopoly leads to a higher final cost reduction and higher industry profits
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45 compared to the case CJ of the KMZ model (i.e. cooperation in the R&D stage, with the spillover
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47 set to one, and competition at the output market). If the cost of R&D is low, it also results in a
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49 lower industry price and higher social welfare. Cabon-Dhersin (2007) also provides evidence that
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51 full cooperation (i.e. firms conduct R&D in a joint lab and collude in the product market) may be
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53 better than competition. The results derived by Amir et al. (2002) and Cabon-Dhersin (2007) rely
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55 on the assumption of a monopoly, i.e. a single R&D performing firm, or a joint lab, respectively.
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57 Trivially, spillovers do not play a role in these cases and duplication of fixed costs is eliminated.
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This fact and the use of a linear demand function constitutes an important difference to our model. Employing a a linear demand function Brod and Shivakumar (1997) demonstrate in an extended AJ framework that innovation effort and profits are higher in a regime where firms cooperate in both, the R&D and the output stage, than in a regime where firms cooperate in R&D only. Output and social welfare are, however, lower when output and R&D effort are chosen cooperatively than in the case where cooperation is restricted to R&D.

Other related papers stem from Suzumura (1992) and Kline (2000), which allow for more general demand functions. Kline (2000) distinguishes between two types of externalities from R&D: the "rival cost effect" and the "rival revenue effect". Suzumura (1992) shows that if spillovers are "large enough", the "rival cost effect" dominates the "rival revenue effect" and an RJV improves R&D efforts and social welfare. Thus, Suzumura (1992) carries out a robustness study and shows that the results obtained by AJ (1988, 1990) hold for a wider class of concave inverse demand functions. Kline (2000), however, criticizes Suzumura (1992) for ruling out the cost paradox and shows that R&D cooperation might lead to lower R&D expenditures than non-cooperation (i.e. the "rival revenue effect" dominates the "rival cost effect") if certain conditions on demand and cost are satisfied. The case of a unit-elastic demand analyzed in this paper is a special case of the conditions stated by Kline (2000), where the cost-paradox is not excluded. The present analysis complements Kline's (2000) results as it calculates actual levels of R&D expenditures whereas Kline makes comparisons only at the margin. The overall aim of the present paper is to fuel the debate about the appropriate antitrust treatment of research joint ventures.

The rest of the paper is organized as follows: In Section 2 the model is described, followed by a comparison of non-cooperative and cooperative R&D levels. Section 3 contains an

extension of the model for "kinked" demand functions. Finally, policy conclusions are drawn in Section 4.

2. The model

Consider an industry with two identical firms, firm 1 and firm 2, producing the same product and facing an inverse demand function of

$$p = \sigma(q_1 + q_2)^{-1/\varepsilon}. \quad (1)$$

The variables q_1 and q_2 denote the output of the respective firm and p the product price. σ is a positive parameter that measures market size. The positive parameter ε denotes the constant price elasticity of demand.

Firm i 's constant unit cost of production c_i depends on x_i , firm i 's and firm j 's R&D expenditures, in the following way

$$c(x_i) = \beta(x_i + \theta x_j)^{-\alpha} \quad i, j = 1, 2; i \neq j. \quad (2)$$

with $\alpha, \beta > 0$ and θ denoting the spillover parameter $0 \leq \theta \leq 1$. Note that the cost function reflects diminishing returns to R&D expenditures and that the employed functional forms resemble that introduced by Dasgupta and Stiglitz (1980).

Assume that firms play a two-stage game, in which they simultaneously choose R&D expenditures in the first stage. Given the R&D expenditure levels, firms simultaneously and non-cooperatively decide how much to produce in the second stage of the game. The game is solved by backward induction, looking for the subgame perfect Nash equilibria. In the case of R&D cooperation firms choose R&D expenditure levels cooperatively in order to maximize joint profits.

Second stage quantities for given levels of R&D expenditures are derived from the profit function

$$\pi_i = \left(\sigma (q_1 + q_2)^{-1/\varepsilon} - \beta (x_i + \theta x_j)^{-\alpha} \right) q_i - x_i \quad i, j = 1, 2; i \neq j. \quad (3)$$

The first order conditions for the second stage maximization problem are given by

$$\frac{\partial \pi_i}{\partial q_i} = \frac{\sigma}{\varepsilon} (q_1 + q_2)^{-(1+\varepsilon)/\varepsilon} \left((\varepsilon - 1) q_i + \varepsilon q_j \right) - \beta (x_i + \theta x_j)^{-\alpha} = 0, \quad i, j = 1, 2; i \neq j. \quad (4)$$

Closed-form solutions do not exist for arbitrary values of the demand elasticity ε . However, they are straightforward to calculate for the special case $\varepsilon = 1$, a case also considered for instance in Aghion et al. (2001). In this case, equilibrium quantities read

$$q_i^* = \frac{\sigma (x_i + \theta x_j)^{2\alpha} (\theta x_i + x_j)^\alpha}{\beta \left((x_i + \theta x_j)^\alpha + (\theta x_i + x_j)^\alpha \right)^2}, \quad i, j = 1, 2; i \neq j. \quad (5)$$

Note that the quantities are well defined for a demand elasticity of 1. A symmetric equilibrium of the quantity setting stage exists even for inelastic demand as long as ε is greater than 1/2. The equilibrium price is also a function of R&D expenditures and reads

$$p^* = \beta \left((x_i + \theta x_j)^{-\alpha} + (\theta x_i + x_j)^{-\alpha} \right), \quad i, j = 1, 2; i \neq j. \quad (6)$$

Inserting q_i^* (equation (5)) in the profit function (equation (3)) yields the reduced-form profit functions

$$\pi_i^* (x_i, x_j) = \frac{\sigma (x_i + \theta x_j)^{2\alpha}}{\left((x_i + \theta x_j)^\alpha + (\theta x_i + x_j)^\alpha \right)^2} - x_i, \quad i, j = 1, 2; i \neq j. \quad (7)$$

2.1 Non-cooperative R&D

Differentiating the reduced-form profit function with respect to x_i and solving for an equilibrium with symmetric R&D expenditures x^N yields³

$$x^N = \frac{\alpha\sigma(1-\theta)}{4(1+\theta)}. \quad (8)$$

Observe that effective R&D expenditures $(x_i + \theta x_j)$ are equal to $\alpha\sigma(1-\theta)/4$ and that individual and effective R&D expenditures are strictly decreasing as the spillover parameter θ rises. This result reflects the findings by Spence (1984), who showed that (in the symmetric case) a firm's R&D intensity is a decreasing function of the extent of spillovers. In the present case however, x^N approaches zero, as θ approaches one. With unit elastic demand, a perfect spillover would lead firms not to invest in R&D at all. We want to emphasize that this result is in sharp contrast to most of the existing strategic investment game models. In particular, the models by AJ (1988, 1990) and KMZ (1992) yield a positive amount of R&D effort for firms acting noncooperatively and a perfect spillover. The intuition behind the break down of R&D activities under unit-elastic demand with perfect spillovers might be explained as follows: If $\theta=1$, any investment in R&D leads to cost reductions of equal size for both, the investing firm and the rival. Consequently, a given percentage increase in R&D investment implies a larger percentage decrease in prices than in operating costs. As total revenue is constant under unit elastic demand, output must increase to the same extent as prices decrease. It follows that output is increasing

³ We assume that a symmetric, interior equilibrium for the whole game exists as long as $\theta < 1$. A sufficient condition ensuring this by satisfying the second-order conditions globally is $\alpha \leq 1/2$. A proof is available from the authors upon request. For $\theta = 1$, we obtain the boundary case of zero R&D expenditures.

faster than costs decrease. This leads, in turn, to higher total costs. Higher total costs together with constant revenue would result in less profit than without R&D investment.

2.2 Cooperative R&D

Under R&D cooperation firms choose R&D activities cooperatively in order to maximize joint profits. In the quantity setting stage, firms play a non-cooperative game. The objective function is

$$\max_{x_1, x_2} (\pi_1^*(x_1, x_2) + \pi_2^*(x_2, x_1)) = \frac{\sigma \left((x_1 + \theta x_2)^{2\alpha} + (x_2 + \theta x_1)^{2\alpha} \right)}{\left((x_1 + \theta x_2)^\alpha + (\theta x_1 + x_2)^\alpha \right)^2} - x_1 - x_2. \quad (9)$$

The derivative of this expression with respect to x_1 reads

$$\frac{\partial (\pi_1^* + \pi_2^*)}{\partial x_1} = \frac{2\alpha\sigma(1-\theta^2)x_2 \left((x_1 + \theta x_2)^\alpha - (x_2 + \theta x_1)^\alpha \right)}{\left((x_1 + \theta x_2)^{1-\alpha} (\theta x_1 + x_2)^{1-\alpha} \left((x_1 + \theta x_2)^\alpha + (\theta x_1 + x_2)^\alpha \right) \right)^3} - 1. \quad (10)$$

Again we solve for an equilibrium with symmetric R&D expenditures. If one assumes that $x_1 = x_2 = x^C$, the first expression on the r.h.s of (10) becomes 0, and the value of the derivative is equal to -1 . As a consequence, the R&D expenditures of firms facing a unit-elastic demand function and allowed to cooperate in R&D would converge to zero in the limit. Firms would invest as little as possible to ensure that they can realize the constant revenue. The same holds true for a monopolist. Given any level of marginal costs it is optimal that output approaches zero. Therefore, R&D investment should also approach zero, since zero output causes zero variable costs. The result for the monopoly case is also shown and discussed for instance in Aghion et al. (2001), p. 472.

While aggregate output and aggregate R&D expenditure is the same for the two market structures, the joint profit of the duopolists is smaller than that of the monopolist. Due to

competition at the second stage of the game, profit for each duopolist approaches $\sigma/4$ as R&D expenditures go to 0. Therefore, joint profits are just half of the monopoly profit. Note here that in the case with symmetric R&D expenditures x^C joint profits can be simplified to

$$\pi_1^* + \pi_2^* = \frac{\sigma}{2} - 2x^C. \quad (11)$$

Observe that the zero investment result in R&D in case of R&D cooperation is independent of the spillover level. The economics behind this result resembles the perfect spillover case discussed above: Given some initial R&D level, increasing R&D expenditures would decrease prices proportionally more than costs. Given revenue, the related increase in output leads to higher costs and therefore to lower profits.

The zero investment result is again in stark contrast to the existing literature. For a survey of this literature refer to De Bondt (1996). Strategic investment game models with linear demand usually result in a critical spillover level, above (below) which R&D cooperation yields higher (lower) R&D efforts than non-cooperation. This outcome is due to a free-rider effect, which becomes worse the higher is the spillover level.

3. Extension: Demand with finite maximum willingness to pay

While it is demonstrated in Section 2 that R&D cooperation might lead to the monopoly outcome in terms of both, R&D expenditures and final output, we present in the following an example that does not rely on limit arguments. To that aim, assume that consumers are characterized by a maximum finite willingness to pay that is equal to the parameter σ .⁴ As a

⁴ Note that we could also introduce an upper bound \bar{c} for the marginal costs c , if firms spend nothing on R&D at all. The subsequent results hold, if $\bar{c} > \sigma$ for $x_i = 0$. The definition made in equation (2) then applies for

consequence, the demand curve exhibits a flat part at a price of σ and a kink at an aggregate output of one (remember that we assumed $\varepsilon = 1$). This extension leaves the equilibrium of the game with R&D competition unchanged as long as

$$\sigma > \frac{2^{\frac{1}{1+\alpha}} \beta^{\frac{1}{1+\alpha}}}{(\alpha(1-\theta))^{\alpha/(1+\alpha)}}. \quad (12)$$

This condition is derived by plugging in equilibrium R&D expenditures from equation (8) into equation (5) and then setting $2q_i^* > 1$. We assume that this condition holds. It ensures that price and quantity in the equilibrium without R&D cooperation are different from the monopoly price and quantity.

Both, monopoly and R&D cooperation would lead to a price of σ and an aggregate output of one. To see this, remember the arguments from Section 2.2, which imply that aggregate output cannot be larger than 1. If output were greater than 1, we would be on the unit-elastic part of the demand curve. For this range of the demand curve we have seen that increasing output or R&D expenditures lead to a contradiction. On the other hand, aggregate output cannot be less than one. For output levels smaller than one, the price elasticity is infinite as the demand curve is flat. As is well known, even a monopolist acts as a price taker in such a case.

Therefore, one obtains the result that R&D cooperation is sufficient for a duopoly, which competes in the final stage of the game, to implement the monopoly solution in terms of output and price. The joint profit, however, is smaller. To see this point, we derive equilibrium R&D expenditures under R&D cooperation. Again looking for a symmetric equilibrium, we solve for

lower marginal costs. This assumption simply implies that firms need to invest in research in order to serve the market.

\bar{x} , the maximum value of R&D expenditures, which is compatible with both firms producing an output of 1/2 each. Setting the quantity q_i^* in (5) equal to 1/2 and imposing symmetry yields

$$\bar{x} = \frac{2^{1/\alpha} \beta^{1/\alpha}}{(1+\theta) \sigma^{1/\alpha}}. \quad (13)$$

For values of $x > \bar{x}$, firms would produce a total output of more than one in the second stage of the game due to lower marginal costs. As noted above, this can never be optimal. Therefore, \bar{x} is a binding constraint for the R&D expenditures of the firms. However, \bar{x} is smaller than the level of R&D expenditures minimizing costs with an output of 1/2. This can be seen by differentiating $\pi_1 + \pi_2$ as defined in equation (3) with respect to x_1 and x_2 , imposing that individual outputs are 1/2. The resulting value is

$$\hat{x} = \frac{1}{1+\theta} \left(\frac{\alpha\beta(1+\theta)}{2} \right)^{\frac{1}{1+\alpha}}. \quad (14)$$

As we assume that equation (12) holds, \bar{x} is always smaller than the cost minimizing level \hat{x} . This yields another surprising result: R&D cooperation with non-cooperation in the quantity setting stage is inferior to full cartelization! While output and prices are identical, sole R&D cooperation leads to higher average costs and lower R&D expenditures than full cartelization. Given the same prices, the smaller markup of price over marginal costs in the R&D cooperation case indicates inefficiency since output could be produced at lower costs.

4. Policy conclusions

Our findings lend support to De Fraja's and Silipo's (2002) request for a case by case approach in the antitrust treatment of research joint ventures. In a different framework (a vertical differentiation model) they establish that – depending on the parameter combination – each R&D regime may yield the highest level of welfare. For this reason, they argue that it is problematic to

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give ready and fast rules as "always allow research joint ventures as long as there is no market collusion". Cabon-Dhersin (2007) makes a plea for a case-by-case analysis, too. Our results point in the same direction.

We show that full cartelization might perform better than R&D cooperation only. Consequently, one can draw the policy conclusion that it is more sensible not to allow R&D cooperation for the development of products with inelastic demand. In this case, firms might use R&D cooperation to restrict innovation rather than to promote technological progress. If authorities are not able to preclude cooperation in such a situation, full cartelization of the participants of a cooperative agreement would even be preferable to R&D cooperation only.

In this respect our result is in contrast to Brod and Shivakumar (1997). They claim that if antitrust authorities view consumer surplus and social welfare as important, antitrust protection should not be granted to cooperative production. Martin (1995) is even more restrictive and argues that already the formation of an RJV may be detrimental.

To summarize, we want to stress that the desirability of RJVs is still under discussion. At the one hand, some consider R&D cooperation already as too far-reaching. At the other hand, it is shown that in particular cases monopoly leads to the highest level of R&D effort and welfare. Which regime performs better is sensitive amongst others to the type of model used (strategic investment game, patent race, differentiation model), the demand structure (most models assume linear demand), the kind (technological or informational) and level of the spillover parameter and the degree of product substitutability. An endogenous spillover would probably also change the outcomes. As a consequence, we support De Fraja and Silipo's (2002) view that no general rule applicable to all proposed RJVs can be deduced from the existing literature.

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