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Product market competition, R&D, and welfare

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Summary

We compare the subgame perfect equilibrium emerging in four regimes of research and development (R&D) competition between duopolists: (i) full competition, (ii) coordination of research strategies, (iii) joint venture with cross licensing of patents, and (iv) full collusion in R&D and the product market. The outcome of the firms' interaction depends on the interplay of the degree of product market competition, the similarity of the research strategies, and the cost of R&D, relatively to market size. Our main result is that each of the four regimes can, for plausible parameter combinations, yield the highest level of welfare. Therefore it is problematic to draw general rules applicable to all proposed research joint ventures.

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1. Introduction

An increasingly important facet of industrial policy is the attitude taken towards cooperation in research and development (R&D) among firms.

One important feature of R&D is the possibility of spillovers: one firm's research activity may have positive effects on another firm's

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innovation activity. Recent literature has pointed out how spillovers may affect adversely the incentive to invest in R&D: knowing that my investment will help my product market competitors will generally weaken my incentive to invest. d'Aspremont and Jacquemin (1988) discuss how cooperative R&D agreements between otherwise competing firms may help firms internalise these externalities, resulting in improvements in the level of social welfare. Their work studies cost reducing activities, and is extended to the case of more than two firms and more general demand and cost assumptions by Suzumura (1992), and to quality enhancing R&D by Motta (1992). These papers obtain results analogous to d'Aspremont and Jacquemin (1988).

The literature has identified two types of spillovers, often implicitly: information spillovers and technological spillovers.† In the former case, the research projects undertaken by the two firms are perfect substitutes, and a fraction of one firm's findings benefits directly the other firm. This happens because, although firms endeavour to keep their research secret, industrial espionage, personnel poaching, scientists' absentmindedness and analogous phenomena cannot be kept below a certain level. When firms join in a research joint venture, all the information possessed by one firm is revealed to all the participants.‡ With technological spillovers, on the other hand, the issue is not secrecy, but simply the fact that one firm's success in pursuing an advancement in one field may be adapted to a similar field. In this case, the research projects of the firms are less than perfect substitutes. This may happen in situations where several possible ways of achieving a certain goal are theoretically available and progress in one of these ways affects the probability of success of alternative methods.§

While in practice both types of spillovers will be present, it is useful to keep them conceptually distinct. The existing literature has concentrated on information spillovers: in the models cited

† On the distinction between technological and informational spillovers as well as for a comprehensive review of the literature on spillovers and innovative activity, see De Bondt (1996).

‡ Consider, as an example, the race to discover superconductors. Each firm tests a range of materials and conditions, and the knowledge of the results of experimental tests conducted by one firm is valuable to the research programme of competing firms. The presence of spillovers implies that not all results can be kept secret.

§ For example: the cure for a given disease may, in theory, be possible either via traditional antibiotic methods, or via genetic engineering: one firm may be pursuing the first and a certain advancement in one technique may suggest a solution for problems encountered in different techniques. Digital and analogue transmission of data is another example: suppose a certain type of transmission of data is being attempted by one firm via analogue methods, by another via digital methods. Advancement in one technique may, or may not help the firm attempting the other technique.

above, other things equal, if a joint venture is formed, the amount of knowledge available to each firm is increased by the knowledge possessed by its competitors. By contrast, in our model, we study technological spillovers. When the spillovers are technological, the fact that firms cooperate does not imply that another firm's research is as useful as one's own. I may know all your discoveries and experiments, but this may not be of as much use to me as it is to you.† We take the extreme case in which joint ventures do not determine directly any increase in knowledge: the amount of knowledge of firm i available to firm j is not affected by the existence of a cooperative agreement: the only effect of a research joint venture is the coordination of the level of R&D activity. We study the incentive to innovate and the welfare effects of

(i) non-cooperation,

and three types of cooperation between firms:

(ii) simple coordination of R&D investments (the firms decide jointly how much each invests, but then they exploit any discovery they make by themselves),
(iii) a joint venture where any patent obtained is licensed to the participants, and
(iv) a full cartel (or merger), where firms also cooperate in the product market.

We use the standard vertical differentiation model (Gabszewicz and Thisse, 1979; 1980; Shaked and Sutton, 1982) to capture the three main forces which affect the firms interaction: the degree of interdependence of the project (the rate of spillover), the extent of product market competition (the degree of differentiation between products) and the cost of R&D, relative to market size. Our conclusions on the R&D expenditures are contained in Section 3. We find that, when the spillover rate is low, the non-cooperative regime always yields a higher level of expenditure than the two partial cooperation regimes, (ii) and (iii) above. It also yields higher investment than the fully collusive regime unless the product market competition is very intense. This tallies with the view that firms use cooperative agreements to reduce the excessive—from their viewpoint—level of R&D expenditure that results in competition. But when competition is intense, the individual incentive to invest in R&D is reduced, as most of the benefit accrues to consumers: cooperation in the product market shifts the benefit of

† In the example of above, if I am pursuing a development using antibiotics, knowledge of your progress using genetic engineering may not be useful to me.

R&D from consumers to firms, and restores the incentive to undertake R&D. We also show that the fully collusive outcome determines a higher level of expenditure (and hence a higher probability of discovery) than both types of joint ventures. This is a natural result: when firms can cooperate in the product market, discoveries are most beneficial, which implies that they are willing to spend more to obtain them.

In Section 4, we compare the welfare level in the four regimes. The most striking conclusion that we reach is that any of the four regimes can be the best choice from a social welfare point of view: it is possible that, even in a static framework, a fully collusive market structure is the best possible option, even when more competitive arrangements could be imposed by the public authority. In this sense, this result would suggest that, at least in the case of technological spillovers considered here, one should not try to draw rigid rules for the treatment of any proposed research joint venture, and that a case by case approach is generally called for. Note that in our model, all the benefits of cooperation derive from the coordination of expenditure decisions, that is from the avoidance of wasteful duplications, rather than from automatic increase in the total knowledge available to the two firms as it is the case with information spillovers.

The model is presented in Section 2, the equilibrium levels of R&D are determined in Section 3, and the welfare analysis is in Section 4. Section 5 is a brief conclusion.

2. The model

2.1. THE CONSUMERS

We consider a simplified version of the standard vertical differentiation model originally proposed by Gabszewicz and Thisse (1979, 1980) and Shaked and Sutton (1982).

We consider a new good (e.g. a new drug). Before firms invest in R&D neither variety is available.

Consumers will derive utility from the consumption of the indivisible unit of the good considered, and from consumption of all the other goods, considered as one composite commodity, with price normalized to one. Consumers differ in income, being uniformly distributed between 0 and 1 with unit density. The product considered may, potentially, come in two varieties, and, of course, consumers are free not to purchase any of them. Their utility function (or the firm's best estimate of their utility function) is:

$$U = v_k y, \quad k = 0, l, h.$$

where y is the consumers' income, l denotes low quality, h high quality, and 0 no purchase of the good. Clearly, $v_0 < v_l < v_h$. We also assume that $v_0 = 0$.† The utility function can be written as:

$$U = v_0 y = 0, \quad \text{if no purchase is made;}$$
$$U = v_l(y - p_l), \quad \text{if the low quality is purchased;}$$
$$U = v_h(y - p_h), \quad \text{if the high quality is purchased;}$$

where p_k is the price of quality v_k, $k = l, h$. Straightforward algebraic manipulations yield the inverse demand functions:

$$p_k(q_k) = 1 - q_k, \quad k = l, h \tag{1}$$

if only quality k is available, $k = l, h$, and

$$p_h(q_h, q_l) = 1 - q_h - \frac{v_l}{v_h} q_l, \tag{2}$$

$$p_l(q_h, q_l) = 1 - q_h - q_l \tag{3}$$

when both qualities are supplied.

2.2. THE FIRMS

There are two firms, 1 and 2. They make decisions in two stages: they first select how much to invest in R&D, then, after the effects of their investment have been observed by both firms, they choose how much to produce for each product they have the ability to manufacture.

R&D investment determines the probability that a variety is discovered. Specifically, the probability that one firm makes a discovery is an increasing function of its own R&D expenditure, and because of spillovers, of its rival's R&D expenditure. R&D expenditure is subject to decreasing returns to scale. Discovery (of either variety) in the two firms are independent events. If a discovery is made, it is embodied in the high or in the low quality product with equal probability; moreover it is not possible for a firm to discover both qualities. It is however possible that both firms discover the same quality.

† This assumption has a number of consequences, which make it somewhat restrictive, such as the fact that, whenever only one quality is available, its demand function is the same whether it is the high or the low quality product. However, given our aim of analysing R&D competition, it is desirable to keep the demand side as simple as possible.

We assume Cournot competition in the product market: firms compete choosing their quantities.†

Formally, we assume the following.

ASSUMPTION 1: *Let x_i be the amount spent in R&D by firm i, $i = 1, 2$. Then,*

- *firm i discovers only the high quality with probability* $\min\{1, x_i + sx_j\}$, $i, j = 1, 2$, $i \neq j$;
- *firm i discovers only the low quality with probability* $\min\{1, x_i + sx_j\}$, $i, j = 1, 2$, $i \neq j$;
- *firm i does not discover anything with probability* $\max\{0, 1 - 2(x_i + sx_j)\}$, $i, j = 1, 2$, $i \neq j$;

where $0 \leq s \leq 1$ is the spillover parameter.

Note that the probability of discovery of one firm is not affected by whether there is a RJV or not or whether the other firm makes a discovery itself. This is how we capture the assumption that the spillover is of the technological type: sharing of information occurs whether the firms want or not, and the fact that firms agree to this sharing does not alter their amount of knowledge. This is clearly the extreme case, and is polar to that normally considered by the literature, where all spillovers are of the information type. In practice, in most cases, both types of spillovers will be important, and so our analysis applies to the case where technological spillovers are more important, in the same way that the standard analysis applies to the case where information spillovers are preponderant.

A further restriction imposed by Assumption 1 is that the probability of discovery of the two qualities is the same. It clearly could be relaxed, but the gain in generality would not compensate the additional algebraic brought by having an extra parameter. Moreover, a firm cannot discover both varieties. This assumption is again made for the sake of simplicity.

ASSUMPTION 2: *The cost of R&D is given by $c(x) = cx^2$, $c > 0$.*

The fact that with Assumptions 1 and 2 we posit specific functional forms does not, in the context of this paper, constitute an important restriction. This is so because the main result of our paper is that each of the four regimes described in the following assumptions can be the socially preferable regime, would clearly

† Cournot competition captures relaxed competitive conditions in the product market, and allows firms to earn positive profits even when they have discovered identical products.

hold with more general functional forms, of which those in Assumptions 1 and 2 are special cases.

We consider a two-stage game. In each stage the firms may choose their actions non-cooperatively or they may cooperate. The pattern of cooperation and competition in the two stages, which forms the main focus of the paper, is described in the four alternative formulations of Assumption 3. We start with the fully competitive regime.

ASSUMPTION 3N: Non-cooperative regime. *In stage* 1 *the two firms choose simultaneously and independently their level of R&D expenditure. In stage* 2, *having observed whether their competitor has made a discovery, they choose, again simultaneously and independently, the output level they supply of the quality they have discovered, if any.*

In the second stage of the game described in Assumption 3N, each firm can find itself in any of the following situations: (i) it can be a monopolist supplying the high quality, or (ii) the low quality, (iii) it can be a duopolist in a market where both firms supply the high quality, (iv) the low quality, (v) where it supplies the high quality competing with a low quality or (vi) vice versa, it can supply the low quality, facing a high quality rival. Finally (vii), it may have discovered nothing. The first stage (expected) payoff function, $E\Pi_1^N(x_1, x_2)$ and $E\Pi_2^N(x_1, x_2)$, are obtained by adding the payoff in each case, weighted by its probability.

$$\begin{aligned} E\Pi_1^N(x_1, x_2) = {} & (x_1 + sx_2)(x_2 + sx_1)r_{hh} + (x_1 + sx_2)(x_2 + sx_1)r_{hl} \\ & + (x_1 + sx_2)[1 - 2(x_2 + sx_1)]r_h + (x_1 + sx_2)(x_2 + sx_1)r_{lh} \\ & + (x_1 + sx_2)(x_2 + sx_1)r_{ll} \\ & + (x_1 + sx_2)[1 - 2(x_2 + sx_1)]r_l - cx_1^2 \end{aligned} \tag{4}$$

(4) holds for the case where neither $(x_1 + sx_2)$ nor $(x_2 + sx_1)$ exceed 1. The probabilities are derived in Assumption 1, and the terms r_{ij}, i, $j = h, l$ represent the revenues obtained by the firms in each of the possible market configurations:†

$$r_l = r_h = \frac{1}{4}, \quad r_{ll} = r_{hh} = \frac{1}{9}, \quad r_{hl} = \left[\frac{2v_h - v_l}{4v_h - v_l}\right]^2, \quad r_{lh} = \left[\frac{v_h}{4v_h - v_l}\right]^2.$$

† The derivation of the expressions for the product market revenue and the proof of the three propositions in Section 3 are very tedious algebraic calculations, and are omitted and available on request from the authors.

Thus, r_l and r_h are the revenues obtained by a monopolist, r_{ll} and r_{hh} the revenues obtained by each firm when they have discovered the same variety, and r_{hl} (r_{lh}) is the revenue of the high (low) quality firm, when each firm has discovered a different variety. Conversely for firm 2. If one of the expressions $(x_i + sx_j)$ exceeds 1, then it needs to be replaced by 1 in (4) (we have not written the complete expression to avoid burdening the notation with several repetitions of the min operator).

ASSUMPTION 3C: Coordination of research expenditure. *In stage 1, firms 1 and 2 choose their R&D expenditure in order to maximize their (stage 1) joint profit. In stage 2 they compete in the product market as in Assumption 3N.*

This is the weakest form of cooperation between firms, and it implies a stark contrast between the two stages, coordination in R&D and competition in the product market. In this case the expected net profit is:

$$\mathrm{E}\Pi_i^C(x_1, x_2) = \mathrm{E}\Pi_i^N(x_1, x_2), \quad i = 1, 2. \tag{5}$$

Clearly, given that, once the R&D stage is over, each firm goes alone, the expected payoff in this regime is the same as the expected payoff in (4).

The next possible regimes take cooperation a step further, by assuming that in addition to coordinating the R&D expenditure, firms will also share any findings obtained in their research.

ASSUMPTION 3J: Research Joint Venture. *In stage* 1 *the two firms choose jointly the level each spends on its own R&D project, and agree that any discovery made by one firm will be licensed, free of charge, to the other. However, the product market is competitive: as in Assumptions 3N and 3C, in stage* 2 *the firms choose their output level simultaneously and independently of each other*.

There is here a stronger form of competition in the product market than under the other two regimes. This competition has two facets: on the one hand, no collusion is allowed at the quantity setting level; this is a standard hypothesis. On the other hand, we assume that firms licence to each other any discovery they make.†

† Note that there is no need to specify the price at which the license is offered: *ex ante*, the probability of paying it or receiving it are the same. We would need to take it explicitly into account only if a firm believed that the price it would pay if a discovery were made by its rival were different from that it would receive from its rival in case it made a discovery. Symmetry of firms makes it plausible to rule out such possibility. Hence our assumption of free licensing of innovation.

Unlike under 3N and 3C, there are here therefore only four possible situations a firm may find itself in the product market: (i) it can be a duopolist in a market where both firms supply the high quality only, or (ii) the low quality only, or (iii) both qualities. Finally, (iv) it does not produce anything. Again, it is elementary to work out the two firms' expected payoff function:

$$\begin{aligned}\mathrm{E}\Pi_i^J(x_1, x_2) = \{&2(x_1 + sx_2)(x_2 + sx_1) + 2(x_1 + sx_2)[1 - 2(x_2 + sx_1)] \\ &+ 2(x_2 + sx_1)[1 - 2(x_1 + sx_2)]\}r_s^J \\ &+ 2(x_1 + sx_2)(x_2 + sx_1)r_d^J - cx_1^2. \end{aligned} \tag{6}$$

There are only two different levels of revenues in the product market, r_s^J and r_d^J, the revenues when only one variety is discovered, and when both are. Their algebraic expression is:

$$r_s^J = \frac{1}{9}, \quad r_d^J = \frac{v_h}{7v_h - 2v_l}.$$

Note, of course, $r_s^J < r_d^J$: it is better to discover both qualities than only one.

ASSUMPTION 3M: Monopoly, or merger, or fully fledged cartel. *In this regime, firms coordinate both their R&D expenditure in stage* 1, *and their output in the product market in stage* 2.

The expected net profit in this case:

$$\begin{aligned}\mathrm{E}\Pi_i^M(x_1, x_2) = \{&2(x_1 + sx_2)(x_2 + sx_1) + 2(x_1 + sx_2)[1 - 2(x_2 + sx_1)] \\ &+ 2(x_2 + sx_1)[1 - 2(x_1 + sx_2)]\}r_s^M \\ &+ 2(x_1 + sx_2)(x_2 + sx_1)r_d^M - cx_1^2 \end{aligned} \tag{7}$$

with expected revenues:

$$r_s^M = \frac{1}{8}, \quad r_d^M = \frac{v_h}{2(3v_h - v_l)}.$$

3. The equilibrium choice of R&D expenditure

In this section we address the question: which regime gives the highest equilibrium R&D investment? While in general this depends on the parameters, we give, in Proposition 1, a general characterisation of the equilibrium. We restrict our attention to equilibria which are symmetric in the R&D stage, in the sense that the two firms spend the same amount in R&D.† Of course, due to the uncertain nature of R&D, they may well end up in an asymmetric position in the product market, having made different discoveries.

In the rest of the paper, we use superscript to denote the equilibrium level of a certain magnitude in the regime considered: that is, we let x^N, x^C, x^J and x^M denote the level of R&D expenditure of each of the two firms, at the symmetric equilibrium of the four regimes.

PROPOSITION 1 *Let* $s = 0$. *Then*

$$\text{For } \frac{v_l}{v_h} < 0.8996443\ldots,\ x^N > \max\{x^C, x^J, x^M\},$$

$$\text{For } \frac{v_l}{v_h} > 0.8996443\ldots, x^M > \max\{x^C, x^J, x^N\}.$$

Thus a general result is that, in the absence of R&D spillovers, any cooperation between firms always reduces their investment in R&D, unless the market is extremely competitive, in the sense that the two varieties are very close to one another. On the other hand, when the market is very competitive, then the highest level of R&D is obtained when firms are allowed to cooperate in the product market: this is because intense competition dissipates the benefits of R&D, and therefore reduces the incentive to invest in this manner.

An immediate implication of Proposition 1 is that, with no spillovers, partial co-operation is always detrimental to the amount of R&D undertaken by firms. The result generalises to the case of positive spillovers.

PROPOSITION 2: *For every* $s \in [0, 1]$: $x^M > \max\{x^C, x^J\}$.

That is, imposing constraints on the nature of the cooperation between firms reduces the investment in R&D. In other words, if the cooperation is less than complete, then the incentive to undertake R&D is weakened. This is because some of the benefits of the discovery accrue to consumers in the form of lower prices.

The situation with positive spillovers is less clear-cut as far as the comparison between the fully competitive regime and the three co-operative regimes considered here. We have seen already how, even with no spillovers, the fully competitive regime may not yield the highest level of R&D expenditure. When the spillovers are positive,

† Note that the restriction to symmetric equilibria implies that it cannot happen that $x_i + sx_j = (1 + s)x_i$ exceeds 1. If it did, in equilibrium, then firms (individually or jointly) would have an incentive to reduce x_i until $x_i + sx_j$ is exactly 1: this would reduce the costs without any corresponding reduction in revenues.

some form of co-operation may give higher R&D investment than the competitive regime.

PROPOSITION 3:

3.1 *There exists a function* $c^*(s, v_l/v_h)$ *such that* $x^C > x^N$ *if and only if* $c > c^*(s, v_l/v_h)$. *Moreover,* $(\partial c^*(s, v_l/v_h))/\partial s < 0$, $c^*(1, v_l/v_h) = 0$ *and* $\lim_{s \to 0} c^*(s, v_l/v_h) = +\infty$.

3.2 *There exists a function* $s^{**}(v_l/v_h)$ *such that*

(i) $s \leq s^{**}(v_l/v_h)$ *implies* $x^J < x^N$.

(ii) *If* $s > s^{**}(v_l/v_h)$ *then there exists a function* $c^{**}(s, v_l/v_h)$ *such that* $x^J > x^N$ *if and only if* $c > c^{**}(s, v_l/v_h)$. *Moreover,* $(\partial c^{**}(s, v_l/v_h))/\partial s > 0$.

In other words, according to 3.1, when the spillover is positive, the “coordination of research expenditure” regime gives a higher expenditure on R&D than the competitive regime, provided the cost of R&D investment is sufficiently high. The same is true for an RJV, but in this case the spillover itself must be sufficiently high, as detailed in 3.2: if both spillover and cost are sufficiently high, then a RJV yields a higher investment in R&D than the non-cooperative regime. It is therefore easier for “coordination of research expenditure” than for an RJV to increase the level of R&D expenditure above the non-cooperative level. This is because, the RJV, where any discovery is licensed to the competitor, makes it impossible for a firm to be a monopolist in any market, and, as implied by Proposition 3, it is the hope of reaping monopoly profits that gives the highest incentive for R&D investment.

With regard to profit, it is clearly the case that $E\Pi^M \geq E\Pi^C \geq \max\{E\Pi^N, E\Pi^J\}$ (because of the enlargement of the choice set, as we move from Assumptions 3N or 3J through to 3M). Left alone, firms would clearly want to form a cartel agreement, cooperating both in R&D and the product market. Coordination of research expenditure is always preferred to the non-cooperative regime: firms can always agree to do what they would do in the absence of any agreement, but they can do something different, thus improving their payoff. The only profit ranking that may change is that between the non-cooperative regime and the joint venture with licensing. This may be intriguing. Numerical comparisons, moreover, show that firms prefer the latter regime for low spillover and low R&D cost, and for high spillover and high R&D cost. The intuition of this result is the following. The distinctive advantage of the N regime compared to the J regime is that in the former it is possible for a firm to be a monopolist in the product market. Low spillover and low cost implies that firms are doing too much R&D in the non-cooperative regime, implying that the likelihood of being a monopolist in the product market is low, and the distinctive advantage of the N regime becomes of little relevance. Conversely, when both the spillover and the cost of R&D are high, then the N regime has too little R&D, and again coordination of expenditure, even at the price of having to licence any discovery made, is the preferred regime between N and J. Moreover, numerical simulations show that as the degree of product differentiation increases, the set shrinks of the values of s and c for which firms prefer to undertake a research joint venture. So, again, our analysis highlights the counterintuitive results that firms may prefer full competition to the possibility of establishing a research joint venture.

4. Welfare analysis

We take welfare as the sum of consumers utility and firms profit; in the present model consumers' utility coincides with the standard measure of consumers surplus. Although elementary, the model can be used to address some of the issues which arise naturally in the debate about the most appropriate policy to follow in the legal treatment of research joint ventures and research cooperation between firms.

(i) Given that the public authority can impose the nature of the coordination agreement, is it always preferable to allow such coordination to go ahead?

Grossman and Shapiro (1986) implicitly assume that antitrust policy can affect the possibility to cooperate as well as the form of cooperation. They provide some guidelines for the antitrust treatment of research joint ventures. Case (i) would arise, for example, when the public authority is able to (and is known in advance to) compel the firm who makes a discovery to license it to its competitor, even in the absence of any agreement to do so.

(ii) Given that it is impossible to impose the socially preferred form of RJV, that is given that, if firms are allowed to talk about R&D then they will also talk about product markets, and will collude effectively, can it be socially beneficial to allow RJV anyway?

Ordover and Willig (1985) and Choi (1993) argue that research joint ventures should go unchallenged by antitrust authorities even when they lead to perfect collusion in the ex post market, but only if no-innovation could take place without monopoly position in the product market. This argument is supported also by Grossman and

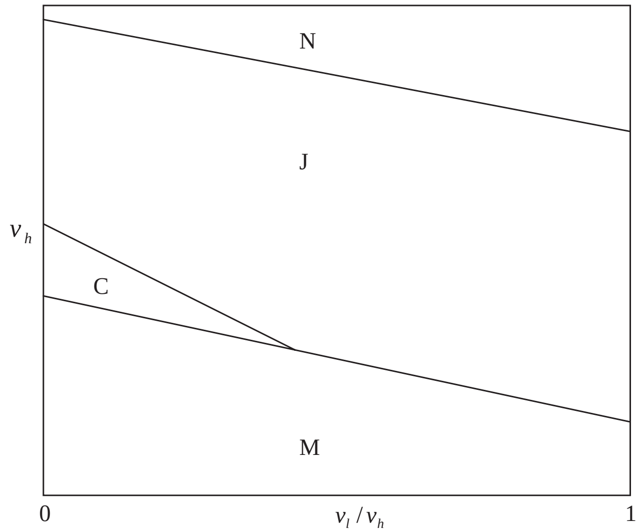

FIGURE 1. The partition of the parameter space according to the welfare maximising regime of R&D cooperation.

Shapiro (l986). Conversely, d'Aspremont and Jacquemin (1988), Kamien *et al*. (1992), Suzumura (1992) among others find that collusion reduces welfare if it occurs both in the product market and in the R&D market. On the other hand, a number of other authors, including De Bondt and Veugelers (1991) and Ziss (1994) find ambiguous results, and note the trade-off between static and dynamic efficiency of innovative activity. Thus, several authors (e.g., Ordover and Willig, 1985; Grossman and Shapiro, 1986; Katz and Ordover, 1990; de Bondt and Veugelers, 1991; Choi, 1993) stress that antitrust consideration of cooperative agreements should be drawn from a case by case analysis. All these models consider information spillovers. Our model allows us to draw some rather strong conclusions with respect to welfare which support the last view, in the case of technological spillover.

We examine the welfare ranking with the aid of numerical simulations. Our results are illustrated in Figure 1.† It depicts the partition of a subset of the parameter space according to which regime yields the highest value of welfare. This is drawn for $c = 0.3$, and $s = 0.1$, with the ratio v_l/v_h on the horizontal axis, and the value v_h on the vertical one (with different choice for c and s we obtain similar pictures). The immediate surprising conclusion which

† Figure 1 has been obtained via lengthy algebraic calculations, which we have performed using MAPLE. The programme and the derivation of the figure are available from the authors upon request.

emerges from the figure is that each of the regimes is the one that yields the highest level of welfare for some parameter combination. For example, suppose that the ratio v_l/v_h is kept fixed at a low level, say 1/4; then according to Figure 1, as v_h increases, we note that the best regime is first M, then C, then J, and finally N (the values of the welfare are illustrated in detail in Table 1, as v_h varies, when the other parameters are fixed at: $c = 0.3$, $s = 0.1$, and $v_l/v_h = \frac{1}{4}$; the numbers in bold are the highest in each row, and identify the preferred regime). The value of R&D investment and expected profit are constant along this vertical line (given by $x^M = 0.383$, $x^C = 0.351$, $x^J = 0.372$, $x^N = 0.487$, and $E\Pi^M = 0.125$, $E\Pi^C = 0.114$, $E\Pi^J = 0.108$, $E\Pi^N = 0.968$), thus the only reason why the social welfare varies is the increased utility value of the goods.

Thus even in such a simple model as the one we are considering here, each of the four possible regimes can be the one that the public authority ought to select to maximise industry welfare; there can be no general rule, but a case by case study would therefore be required in order to evaluate the relative benefit of any proposed arrangement. In particular, both regimes M and N, that is both a fully monopolistic and a fully competitive market, could be that yielding the highest welfare. Since this result is likely to occur in richer models as well, it suggests that it is wrong to give ready and fast rules such as “always allow joint ventures as long as there is no market collusion”.

TABLE 1 *Welfare in the four possible regimes of R&D cooperation*

v_h	SWN	SWJ	SWC	SWM
0.11	2.1324	2.3282	2.4263	**2.5811**
0.21	2.3105	2.4893	2.5585	**2.6616**
0.31	2.4886	2.6504	2.6908	**2.7421**
0.41	2.6666	2.8116	**2.8230**	2.8225
0.51	2.8447	**2.9727**	2.9553	2.9030
0.61	3.0228	**3.1338**	3.0876	2.9835
0.71	3.2009	**3.2950**	3.2198	3.0639
0.81	3.3790	**3.4561**	3.3521	3.1444
0.91	3.5571	**3.6172**	3.4843	3.2249
1.01	3.7352	**3.7783**	3.6166	3.3054
1.11	3.9133	**3.9395**	3.7489	3.3858
1.21	4.0914	**4.1006**	3.8811	3.4663
1.31	**4.2695**	4.2617	4.0134	3.5468
1.41	**4.4476**	4.4228	4.1456	3.6272
1.51	**4.6257**	4.5840	4.2779	3.7077
R&D exp. per firm: x	0.48722	0.37227	0.35088	0.38348
Profit per firm:	0.09682	0.10754	0.11403	0.12463

While our result is obtained in an admittedly simple model, the main economic factors are likely to remain valid in more general set-ups. The M regime has one drawback and one advantage over the other two "cooperative" regimes. The drawback is that, in the absence of product market competition, prices are kept well above marginal costs, which increases the deadweight loss; the advantage is that more R&D is undertaken. When quality is low valued ($v_h < 0.409$) the product market deadweight loss is not very costly, and the increased probability of having the market at all which this regime determines outweighs the lower allocative efficiency of the market. Notice that, for v_h low, the C regime is better than the J regime. In the C regime there is the lowest level of R&D expenditure, but it is the only regime such that monopoly never occurs in the product market. For low value of quality, it is better to have a more competitive market with low probability. Thus, for $v_h \in (0.409, 0.45)$, regime C is preferred. As the value of the market increases, the trade-off changes and the cost of not having the market is greater than that of having a monopoly, and for v_h up to 1.264, J is the regime yielding the highest welfare. When quality is highly valued, competition in R&D ensures a higher probability that the market exists at all, because at least one variety is discovered.

With regard to the role of market competition, we note first that as it increases, with the goods becoming better substitutes, that is with the ratio v_l/v_h sufficiently close to 1, it is no longer possible for regime C to be the preferred one: this is natural, when one remembers that the distinctive advantage of regime C was precisely the impossibility of monopoly in such regime. But when the two products become similar the situation of differentiated duopoly, with each firm supplying a separate product, tends to be similar to the situation of undifferentiated duopoly, which happens in regime C. Thus the product market competition typical of regime C becomes less distinguishable from the situation which arises in the other regimes, and the drawback of regime C, its lowest level of R&D investment, outweighs the benefit of stronger product market competition. Conversely, as the degree of differentiation decreases, regime M is less likely and regime N is more likely to be the best. This is quite natural too: if product market competition is fierce, then firms will use the opportunity to cooperate to increase their probability to be monopolists, and they can do so by reducing the extent of R&D investment.

5. Concluding remarks

Using a cost-reducing R&D model, d'Aspremont and Jacquemin (1988) find that, for high values of the spillovers parameter, cooperation on R&D leads to greater technological advance than competitive R&D. Kamien *et al*. (1992) confirm this result and show that the effective R&D expenditure is at its maximum when firms coordinate their R&D activity and share the results. These authors conclude that collusion in the product market should be banned. This seems to be confirmed also in the welfare analysis performed by De Bondt and Veugelers (1991), where total welfare is always lower when firms collude also in the product market.

In this respect, our analysis suggests some puzzling policy conclusions with respect to the attitude towards collusion among firms. When R&D activity is involved, monopoly can be better than competition, or either of the two forms of research joint venture we have considered here.

Like all specific models, ours can be accused of being too rudimentary. We would however claim that its basic message is realistic: the outcome of the interaction between competing firms depends on the costs and benefits of R&D: whereas individual and social costs move in the same direction, society and firms perceive differently the main outcome of the innovative activity a higher likelihood of intense product market competition: good for society bad for firms. Moreover, the main conclusions of the paper can be interpreted as stressing that, when R&D is involved, all is possible, and no fast and ready rules should be applied: to reach this conclusion, an example is obviously all one needs.

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