Research in Economics 59 (2005) 41–57

RESEARCH IN ECONOMICS

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Cooperation and competition in an R&D market with spillovers

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Received 8 June 2004; accepted 11 December 2004

Abstract

In a general setting with uncertainty and spillovers in R&D activity, we consider the incentive to cooperate among firms at any of the following three stages. Firms can jointly agree on the level of R&D expenditures (cost sharing), they can engage in an information sharing agreement, and they can setup joint research facilities (RJV). One of the major novelties of our research is that we introduce the concepts of offsetting and incremental spillovers. When the latter exist, there is a new incentive to cooperate in R&D due to the expansion of the market because of the increase in the number of producers. On the other hand, if spillovers reduce total profits, the innovating firm tends to retain the strategic gain from innovation. This enhances the possibility of a monopoly outcome, and makes competition desirable.

We show that when spillovers are offsetting competition tends to be preferred to cooperation, but with incremental spillovers cooperation tends to be the more desirable. This same tendency, however, does not exist when considering the level of investment in R&D, where the type of spillovers has little effect, but the extent of spillovers is often crucial. Cost sharing usually leads to increased investment and profits compared with a fully competitive R&D market. However, it is not the most profitable form of cooperation. In most cases firms prefer a RJV to cooperation with cost sharing, and, in fact, a RJV is always preferred to IS agreements.

Keywords: Cooperation in R&D; Spillovers; Information sharing; Cost sharing

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doi:10.1016/j.rie.2004.12.003

1. Introduction

It is well recognized that there is a market failure in the provision of innovations that is related to the nature of R&D activity. This failure is attributed to several factors. First, there is uncertainty about the outcome of R&D activity. Firms that devote resources to research into a new product or technique do not know whether they will succeed, or how long the research will take. Second, due to spillover effects, successful firms may not be able to appropriate all of the rents from the outcome of R&D activity. At the same time, the inability to appropriate all the gains of R&D successes may weaken the firms' incentive to invest in R&D.

One way to mitigate the detrimental effects of this market failure is to have firms cooperate in R&D activities. There are three primary benefits from cooperation in R&D. First, a fully inclusive cooperative agreement (including cooperation in the product market) eliminates all uncertainty with regards to which firm will win the R&D race, since the identity of the winner becomes unimportant. Even an agreement on only some aspects of the research programs will lower uncertainty. Second, cooperation may increase the efficiency of R&D investments through the elimination of duplication of efforts and the exploitation of synergies in R&D. Third, the externalities created by technological spillovers are internalized through cooperation. Each of these effects of cooperation results in an increased incentive on the firms' part to invest in R&D. Conversely, however, if the cooperative agreement does not encompass the product market, the expected competition in the final goods market can lead to a disincentive to invest. This is because with a cooperative agreement in the research stage only, the firms stand on even ground in the product market, so the benefits from discovery are divided. With no agreement, however, each firm stands to reap most of the benefits from its success, and so has a greater incentive to invest. We conclude, then, that the incentive to undertake a cooperative agreement and the effects of such an agreement on the intensity of R&D effort and on profitability depend on the degree and nature of uncertainty and spillovers, as well as on the specifics of the cooperative agreement.

Marjit (1991) and Combs (1992) examined the role of uncertainty on the incentive to cooperate, and showed that cooperation is worthwhile for the firms only if the probability of success is relatively high. Choi (1993) also considered the incentive to cooperate in a duopoly R&D market with uncertainty, but his main concern was with the effect of spillovers. He showed that the more acute the spillover problem, the more profitable is cooperation in R&D, and that the cooperative level of R&D expenditure is higher than the competitive level. He demonstrated that there is a critical level of spillovers such that if the spillover parameter is greater than this critical value cooperation is ex ante more profitable than competition, and if is not, competition is preferred. The existence of such a critical level of spillovers was found in similar contexts by d'Aspremont and Jacquemin (1988), Suzumura (1992), Motta (1992), Rosenkranz (1995), and Kamien et al. (1992). Kamien et al. also demonstrated that the type of cooperation most conducive to R&D is a Research Joint Venture (RJV), in which firms share all information, eliminate duplication of effort, and coordinate their R&D expenditures so as to maximize the sum of their profits.

One assumption present in all of these studies limits the generality of the existing results. The literature on the topic makes the assumption that spillovers of knowledge, although beneficial to the non-innovating firms and to welfare, leads to a reduction in industry profits due to intensified competition in the product market. There are many instances, however, when the opposite is likely to be true, even if spillovers are detrimental to the successful firm.

The empirical evidence supporting this possibility is compelling. Thus, for instance, Levin (1988), Levin et al. (1987), Bernstein and Nadiri (1988), and Jaffe (1988), show that in many cases spillovers increase industry profits and R&D expenditures. This is particularly true when the spillovers received from other firms complement the receiving firm's investment and raise its marginal return.

The main aim of this paper, then, is to generalize the existing theory to include incidents in which industry profitability increases with an increase in spillovers. To this end we introduce the concepts of offsetting (falling total industry profits) and incremental (increasing total industry profits) spillovers, and show how the nature of the spillovers affects firms' R&D behavior and the incentive to cooperate (which has previously been analyzed by Choi, 1993 only in a special case). Among other things, this generalization allows us to study the incentive to cooperate in many contexts, including cooperation in markets with complement as well as substitute products and cooperation among firms in the same and in different industries.

We also extend the existing literature in other respects. First, we look at a broader range of definitions of 'cooperation' than did previous studies. Thus, for instance, Choi (1993) studied the incentive to cooperate in a duopoly R&D market with uncertainty and spillovers, in which (a) the parties agree on how much to spend on research, but each firm retains sole-proprietorship of the results from the research (aside from the amount that spillovers to the other firm). Following Choi, we denote this case cost sharing below. We investigate additional possibilities by analyzing the effects of cooperation between firms at two additional points in the R&D process. In addition to cost sharing, we allow for (b) firms setting up joint research facilities (denoted below joint ventures), which lend themselves to the exploitation of synergies by, for example, eliminating any duplication of costs and/or research efforts; and (c) firms entering into information sharing agreements (also known as sharing R&D output), whereby any firm that is successful in its research efforts is obligated to share the results with the other firm (an ex ante cross-licensing agreement). We do not allow for collusion in the product market in any of the cases since such cooperation tends to be forbidden by antitrust laws. In all cases we assume that any agreement is costlessly enforced.[1]

Finally, our analysis is more general than most of the existing studies because we adopt a more general functional form than did previous authors (see, e.g. d'Aspremont and Jacquemin, 1988; De Bondt and Veugelers, 1991; Suzumura, 1992; Motta, 1992; Kamien et al., 1992; Choi, 1993; Rosenkranz, 1995; Banerjee and Lin, 2001). Although our generalized functional specification precludes us from giving a complete ranking of all variables in all situations, we are able to derive several insights. The main findings are as follows.

[1] Choi (1993), conversely, considers the effects of monitoring costs.

First, it is the type of spillovers, and not merely their extent, that determine relative desirability. Specifically, when spillovers are offsetting competition in R&D tends to be more profitable than cooperation in R&D (through an information sharing agreement or a research joint venture), but with incremental spillovers cooperation is often more desirable. This is because some types of cooperation lead to maximal spillovers (since any findings by one firm are shared with the other), so if spillovers are incremental cooperation is to the benefit of the firms, and they have an incentive to cooperate, while if they are offsetting competition is more beneficial. The relative level of investment in R&D (cooperation vs. non-cooperation), however, depends mostly on the extent of spillovers and not on the type of spillovers. Second, cost sharing usually leads to increased investment and profits, and a joint venture categorically leads to more investment and profits than information sharing agreements.

This paper is organized as follows. Section 2 sets up the basic model. Section 3 presents the model and compares the three cases above. Section 4 summarizes and discusses the results.

2. The model—basic setup

Consider two firms undertaking R&D activity that must decide whether to cooperate and how much to spend on R&D activity. The purpose of the R&D efforts is to discover a new product or process, and if a firm's R&D efforts are successful, i.e. if it has discovered the product or process, it cannot reap any additional benefit by discovering the results of the other firm's R&D activities since these will be redundant.[2] Cooperation can be undertaken in the R&D market only, since local antitrust laws prohibit cooperation in the product market. In the absence of cooperation between the firms and in the absence of spillovers, success in R&D activities on the part of a single firm will result in a monopoly in the product market (the discovering firm gets a patent of infinite duration), while if both firms succeed, there will be competition between the firms. If, however, the patent system does not guarantee perfect appropriability, research results may spill over to the rival firm who will then be able to appropriate part of the benefits from the innovation even though its own research efforts were unproductive (it will be able to produce an imperfect substitute).[3]

The literature assumes that spillovers reduce the profit of the successful firm as well as industry profit. However, as mentioned in Section 1, there are many instances in which spillovers are likely to increase industry profit and welfare. Certainly, this is the case when the spillover is to an unrelated industry, since increased profitability in one industry does

[2] This is the same setup as in Choi (1993), but it differs from the setup in Kamien et al. (1992), where if both firms discover and spillovers are increased to their maximal level, each firm's costs are reduced by the sum of R&D efforts in the industry. Note that our assumption means that the R&D expenditures of the firms are substitutes not complements.

[3] There are various ways in which imitation of a novel idea can take place: property rights may be only broadly attributed; researchers may move between firms, transferring knowledge from successful to unsuccessful firms, and so on. Unsuccessful firms can therefore benefit from successful R&D without paying the full cost.

not come at the expense of the other. As Katsoulacos and Ulph (1998) point out, whether spillovers harm or help the successful firm depends on whether firms are in the same industry or in different but complementary industries. In the latter case, "a spillover from one firm to the other enables the receiving firm to improve its product or technology enabling it to attract more consumers and increase its profits. In this case, however this has a beneficial impact on the profits of the firm giving the spillover."[4] Similarly, an innovation by an upstream firm is likely to bestow a positive externality on the downstream firms, and the upstream firm may decide to internalize this externality by inviting the downstream firms to share the R&D costs.

In the cases just discussed not only does the recipient benefit from spillovers, the discovering firm also benefits, or at least does not lose, from the spillovers. Another circumstance exists, in which the discovering firm's profits fall as a result of the spillovers, but they fall less than the recipient's profits rise. This scenario is most likely when the spillovers are to producers of substitute products, or within an industry with a heterogeneous good. To this end, Choi (1993) suggests that a decrease in industry profits is most likely when the research yields a process innovation rather than a product innovation. As Choi states, "[f]or new product innovations it is plausible that market demand increases with the number of firms that market the innovation. This would be especially likely to occur in a model—such as the CES representative consumer model in the monopolistic competition literature—in which product variety is valued, or in a model in which network externalities are present." Since the main goal is to investigate the incentive to cooperate, we do not consider the case where all firms benefit from spillovers, because in that case cooperation is obviously beneficial as it increases spillovers to its maximal value (complete spillovers). Rather, the case of incremental spillovers we investigate is when the discovering firm loses from spillovers, but less than the non-discovering firm benefits.

Denoting the degree of spillovers in the project by α, $\alpha \in [0,1]$, define $R_1(\alpha)$ as the expected profit to the successful firm, $R_2(\alpha)$ the expected profit to the unsuccessful firm, and R_3 the expected profit to the duopolist in the case where both firms succeed, either independently or cooperatively. We proceed as in Choi (1993), and make the following natural assumptions.

Assumption 1. Part (i):

$$\frac{\partial R_1(\alpha)}{\partial \alpha} < 0; \quad \frac{\partial R_2(\alpha)}{\partial \alpha} > 0;$$

Part (ii):

$$R_2(0) = 0;$$

[4] This is part of a literature on endogenous spillovers (see De Fraja, 1993; Katz, 1986; Marjit, 1990; Katsoulacos and Ulph, 1998). These studies are based on the assumption that the Cournot–Nash industry profits rise after the transmission of knowledge and, in fact, that both firms benefit from the deal. Because of this, firms desire spillovers, so cooperation is always optimal.

and Part (iii):

$$R_1(1) = R_2(1) = R_3.$$

Part (i) of Assumption 1 states that spillovers are detrimental to the successful firm, but help the unsuccessful firm. As mentioned in Section 1, the first part of this does not necessarily hold if, for instance, the spillovers are to firms operating in different markets. Since our desire is to investigate the incentive to cooperate we do not consider this contingency. Part (ii) states that the expected profit of the unsuccessful firm is zero if there are no spillovers since it does not participate in the product market.[5] Part (iii) says that the profit with cooperation and discovery is equal to the profit of each duopolist in the case of non-cooperative discovery (by at least one duopolist) and complete spillovers.[6]

In contrast to Choi (1993), we introduce the possibility that spillovers can increase or reduce total industry profits. We thus define:

Definition 1. Spillovers are incremental if $(\partial[R_1(\alpha)+R_2(\alpha)]/\partial\alpha)>0$, and they are offsetting if $(\partial[R_1(\alpha)+R_2(\alpha)]/\partial\alpha)<0$.

The above definition states that an increase in the degree of spillovers can increase total industry profit, for instance, by enlarging the scope of use of a discovery (on this point see Marjit, 1990 and Levin and Reiss, 1988), or it may reduce total industry profit, for instance, due to intensified competition in the product market (Choi, 1993). When the former effect dominates the latter, we call the spillovers 'incremental', and we call them 'offsetting' if the reverse is true. In what follows, we implicitly assume that the relationship between α and industry profits is monotone.[7]

We assume that the results of R&D activity are uncertain. Denote by $P(x)$ the probability of success if the firm invests x in the project. Following Choi (1993), we make the following natural assumption.

Assumption 2. $P'(x)\geq 0$; $P''(x)\leq 0$; $P'(0)=\infty$; and $P'(\infty)=0$.[8]

Firms must decide whether or not to cooperate. Cooperation can occur at any or all of three stages. Firms can agree on the level of spending on research (as per Choi), they can

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[5] Alternatively, one can view this as 'normalizing' profits in this case to be zero.

[6] This assumption differs from that in Kamien et al. (1992) in that in their paper costs are decreased by the sum of research efforts, so that both firms succeeding differs from only one firm succeeding with complete spillovers. See Footnote 4.

[7] A simple example can demonstrate the existence of the two types of spillover in the case of a process innovation. Since, when there is a process innovation, demand is stationary, if competition in the product market is of the Bertrand type, spillovers will always be offsetting. However, with Cournot competition either type of spillover can prevail. Assume, for example, that demand is given by $q=1-p$, the unit cost for each firm is $\bar{c}=0.5$ before the innovation, and it is lowered to $\underline{c}=0.25$ for the discovering firm after the innovation. Assume also that the cost for the non-discovering firm after innovation is $c=\alpha\underline{c}+\bar{c}(1-\alpha)$, where α is the degree of spillovers. In this case, spillovers are offsetting if $\alpha<0.4$ and they are incremental if $\alpha>0.4$. We would like to thank Vincenzo Denicolò for this example.

[8] Choi makes the additional assumption that $P'(x)^2+P(x)P''(x)\geq 0$. This is an assumption about the degree of concavity of the cumulative probability function, and does not hold for every function. As will be discussed below, this assumption is a sufficient, but not necessary condition for signing a slope.

choose to conduct the R&D using joint research facilities, and they can choose to share the outcomes of their research efforts.[9] In addition, in this paper we do not develop the cases of research joint ventures or ex post information sharing without cost sharing. The interested reader can find these cases analyzed in the working paper version of this paper (Silipo and Weiss, 2002).

We proceed as follows. We first develop the case of competition without a cost sharing agreement, and address the issues of the level of R&D expenditures and the relative profitability from the firm's perspective.[10] We then allow for joint spending decisions, and analyze the cases of competition, information sharing and research joint ventures. While some of the results are already well known in the literature, in particular those about investment levels, we present them here anyway for completeness, and because they have previously not been shown to hold with incremental spillovers. To differentiate between the completely new results and those that have been at least partially demonstrated in prior studies (or are obvious from them), we denote the former 'Propositions' and the latter 'Lemmas.'

3. The model and results

3.1. Competition without cost sharing (C)

We consider first the case where there is no cooperation. If firms compete on all fronts, the expected net profit of firm i is[11]

$$E\Pi_i^c = P(x_i)(1-P(x_j))R_1(\alpha) + (1-P(x_i))P(x_j)R_2(\alpha) + P(x_i)P(x_j)R_3 - x_i. \quad (1)$$

The first term is the probability that the first firm alone is successful in its research efforts times the profit the firm gets if it alone discovers, and thus earns monopoly profits (given the level of spillovers). The second term is the probability that only the other firm discovers times the profit realized in this instance, and the third term shows the probability that both firms discover times the profit in that case. If neither firm discovers, profits are zero.[12] The cost of the research is incurred in all cases.

Firm i chooses the optimal level of expenditure on the project from maximization of (1) with respect to x_i for given x_j. The first-order condition for a maximum is

$$G_i = \frac{\partial E\Pi_i^c}{\partial x_i} = P'(\hat{x}_i^c)[R_1(\alpha) - P(x_j)(R_1(\alpha) + R_2(\alpha) - R_3)] - 1 = 0, \quad (2)$$

[9] Each of these will be described in more detail below.

[10] Also for a welfare analysis, see the working paper version of this paper (Silipo and Weiss, 2002).

[11] To simplify, we assume the firms are entrants into the new market, so that there are no profits from current production.

[12] This assumption is a continuation of the assumption that $R_2(0)=0$—profits exist only with discovery. It is, of course, possible that $R_2(0)=0$ but profits without discovery are positive. For example, consider Bertrand competition. Without spillovers only the discovering firm sells, but if no one discovers, both sell (and profit if marginal costs are increasing) at the same price. Normalization is still possible, but we would have to change Assumption 1 to state that $R_2(0)\leq 0$ in order to avoid normalizing twice.

where $\hat{x}_i^c \equiv \hat{x}_i^c(x_j, R_1(\alpha), R_2(\alpha), R_3)$ is the solution to (2).[13] An analogous condition holds for firm j.

Totally differentiating (2) with respect to x_i and x_j, we have

$$\frac{d\hat{x}_i^c}{dx_j} = \frac{P'(\hat{x}_i^c)P'(x_j)(R_1(\alpha) + R_2(\alpha) - R_3)}{P''(\hat{x}_i^c)(R_1(\alpha) - P(x_j)(R_1(\alpha) + R_2(\alpha) - R_3))} < 0$$

by the second-order conditions. Moreover, $(\partial(d\hat{x}_i^c/dx_j)/\partial x_j) < 0$ if $[P'(x_j)^2 - P''(x_j)P(x_j)](R_1(\alpha) + R_2(\alpha) - R_3) > -P''(x_j)R_1(\alpha)$, which will occur except in extreme instances.[14] If this condition holds, there is guaranteed to be a unique and symmetric Nash equilibrium in the R&D competitive game. If this condition does not hold there may also be non-symmetric equilibria. We focus on the symmetric equilibrium.

Given the Nash equilibrium, we now confirm the following proposition.

Lemma 1. *An increase in the degree of spillovers reduces the level of R&D expenditure in a competitive R&D market irrespective of the nature of the spillovers.*

The proof of this lemma is given in Appendix A.

This well-known result continues to hold even with incremental spillovers because, in deciding the level of R&D expenditure, each firm takes into account only its own gain. Since $\partial R_1(\alpha)/\partial\alpha < 0$ independent of the type of spillovers that exists, each firm reduces the level of R&D expenditure as the degree of spillovers increases.[15]

We now add the possibility of cost sharing agreements to our previous analysis. Under a cost sharing agreement, firms agree upon a total research budget, and then split this cost equally. It would stand to reason that firms agreeing to share costs would also share the outcome of the research efforts. Nevertheless, we present both the case in which the R&D results are shared and the case in which they are not. We assume that expenditures can be costlessly monitored.[16] As is intuitively clear, cost sharing makes the firms more profitable, and so will be desired by firms. Such setups, however, may be untenable because of monitoring difficulties and/or because of legal (antitrust) prohibitions as discussed in the conclusions. In all that follows, we denote cost sharing by a second superscript c.

[13] Assumption 2 ensures that a solution to Eq. (2) always exists. In addition, the second-order conditions for a maximum are satisfied:

$$\partial G_i/\partial x_i^* = P''(x_i^*)[R_1(\alpha) - P(x_j)(R_1(\alpha) + R_2(\alpha) - R_3)] < 0,$$

since $P''(x_i^*) < 0$, and the expression in square brackets is positive, by the first-order condition.

[14] Note that this condition is not related to Choi's (1993) condition (see Footnote 8), because here both terms in the first brackets are positive, while in Choi's condition one is positive and the other is negative.

[15] Notice that Lemma 1 is an extension of Choi's (1993) result to the case of incremental spillovers as well as offsetting spillovers. For the latter case, Choi (1993) proved that an increase in the degree of spillovers reduces the level of R&D expenditure.

[16] This assumption becomes more problematic in the presence of a larger number of firms.

3.2. Competition with cost sharing

With cost sharing, but competition in all other stages, expected profits are given by:[17]

$$E\Pi^{cc} = P(x)(1-P(x))R_1(\alpha) + (1-P(x))P(x)R_2(\alpha) + P(x)P(x)R_3 - x. \tag{3}$$

The optimal level of R&D expenditures is then found through the first-order condition:

$$\frac{\partial E\Pi^{cc}}{\partial x} = P'(\hat{x}^{cc})[R_1(\alpha) + R_2(\alpha) - 2P(\hat{x}^{cc})(R_1(\alpha) + R_2(\alpha) - R_3)] - 1 = 0. \tag{4}$$

Comparing investment levels with those in competition without cost sharing, we arrive at the following (d'Aspremont and Jacquemin, 1988).

Lemma 2. *There exists a value of* α, *denoted* $\tilde{\alpha}$, $0 < \tilde{\alpha} < 1$, *such that if* $\alpha < \tilde{\alpha}$ *then* $\hat{x}^c > \hat{x}^{cc}$, *if* $\alpha = \tilde{\alpha}$, *then* $\hat{x}^c = \hat{x}^{cc}$, *and if* $\alpha > \tilde{\alpha}$, *then* $\hat{x}^c < \hat{x}^{cc}$.

(Proof in Appendix A.) Comparing profit levels, we find that:

Lemma 3. $E\Pi^{cc} \geq E\Pi^c$, *with equality when* $\alpha = \tilde{\alpha}$.

(Proof in Appendix A.) The logic behind this result is immediate. Since the firms with cost sharing can always choose the level of investment chosen without cost sharing, their profits cannot fall below those without cost sharing. Lemmas 2 and 3 are the same as the results in Choi (1993).

3.3. Information sharing agreements with cost sharing

In this case firms decide independently on the amount of resources to invest in R&D and on the type of research to carry out, but they write a costless[18] enforceable contract to share research results with the other firm ex post.[19,20] Hence, both firms succeed if at least one firm succeeds. This stylized depiction of R&D cooperation allows us to analyze the relationship between the incentive to cooperate and the imperfect appropriability of R&D results separately from the elimination of effort duplication (analyzed in the next Section).

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[17] Note that we have each firm choosing its own level of investment instead of the two firms together choosing the optimal investment level. The result is identical.

[18] An interesting extension would be to consider costly information, with the price depending on the level of spillovers.

[19] Our definition of information sharing is similar to the definition in Kamien et al. (1992), except that in our paper firms do not avoid duplication of R&D activities; rather, each firm decides on its own activities independently.

[20] IS as defined here could be implemented by exchange of researchers between the two firms, in order to avoid the problem of incomplete communication of R&D results.

In this case the firm's expected profits are

$$E\Pi^{sc} = [2P(x) - P(x)^2]R_3 - x, \tag{5}$$

and in equilibrium:

$$2P'(\hat{x}^{sc})(1 - P(\hat{x}^{sc}))R_3 = 1. \tag{6}$$

Comparing competition with cost sharing, with IS with cost sharing, we find that:

Proposition 1. *When* $\alpha = 1$, $\hat{x}^{sc} = \hat{x}^{cc}$. *When* $\alpha < 1$, *if spillovers are incremental and the probability of success is lower than* 1/2, *or spillovers are offsetting and the probability of success is greater than* 1/2, *then* $\hat{x}^{sc} > \hat{x}^{cc}$. *In all other cases the sign is not clear.*

(Proof in Appendix A.) This result differs sharply from what a comparison of competition and information sharing without cost sharing would yield, where there is always more research with competition than with cooperation (Silipo and Weiss, 2002). The reason for the difference is that under the current regime the competitor is matching each dollar of research expenditures with a dollar of his own, so spillovers become less problematic. Nevertheless, it is clear from the proof that it is still likely that there will always be more investment in competition than with an IS. Such a determination, however, cannot be made in such a generalized setting.

Turning to a comparison of profits, we have:

Proposition 2. *With cost sharing, competition and an IS are identical when* $\alpha = 1$. *When* $\alpha < 1$, *an IS is preferred if spillovers are incremental, and competition is preferred if spillovers are offsetting.*

(Proof in Appendix A.) This result is logical. Recall that costs are shared in either case, and that each firm has an ex ante equivalent probability of discovering. Therefore, when spillovers are offsetting the firms, ex ante, prefer as little spillovers as possible, and so prefer competition. Conversely, when spillovers are incremental, they are better off, ex ante, with full spillovers, so cooperation is the preferred venue.

3.4. Research joint ventures with cost sharing

As an alternative to information sharing agreements, firms can conduct cooperative R&D by undertaking research joint ventures, that is, by conducting R&D in only one research lab or coordinate their research strategies as well as sharing the results of R&D activity.[21] In this instance, the probability of one firm succeeding is not independent of the actions of the other. This form of cooperation allows the two firms to save costs due to the presence of complementary assets (since they build a common research lab) and the elimination of any duplication of effort.[22]

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[21] Our definition of a RJV is equivalent to the Research Joint Venture Competition case in Kamien et al. (1992).

[22] We include the elimination of duplication of efforts as a possible justification for Assumption 3 even though Combs (1992) suggests that when there is uncertainty, conducting experiments in several research labs instead of one single lab can increase the probability of discovery with a given amount of R&D expenditure. In addition, there may be intangibles that each firm brings to the table when they cooperate which are not there if they do not cooperate.

We do not model the cost savings from the RJV explicitly. Rather, we make the following assumption, which captures the 'spirit' of these cost savings.

Assumption 3. $P(2x) > 1-(1-P(x))^2\ \forall\, x$.[23]

This assumptions states that for the same level of expenditures on research in each regime, the probability of success under a RJV is greater than the probability of success by at least one firm when research is carried out independently. This means that by avoiding duplication of efforts and by taking advantage of synergies from joint operations, the RJV increases the probability of success for any given size investment. We assume that this relationship holds for changes also, so that:

Assumption 3a. $P'(2x) > P'(x)(1-P(x))\ \forall\, x$.

This assumption means that at each level of investment, an additional dollar spent in a joint venture is more productive than an additional dollar in separate research facilities. This assumption continues to capture the essence of avoiding the duplication of efforts. Note that Assumptions 3 and 3a will be used only when comparing a RJV to other forms of organization.

Expected profits with a RJV and cost sharing are:

$$E\Pi_i^{\mathrm{vc}} = P(2x)R_3 - x. \tag{7}$$

The first-order condition for a maximum is given by:

$$2P'(2\hat{x}^{\mathrm{vc}})R_3 = 1. \tag{8}$$

Comparing a RJV with cost sharing with an IS with cost sharing, we see that:

Lemma 4. *$\hat{x}^{\mathrm{vc}} > \hat{x}^{\mathrm{sc}}$, and $E\Pi^{\mathrm{vc}} > E\Pi^{\mathrm{sc}}$.*

(Proof in Appendix A.) The logic behind this result is that a joint venture has an advantage over an IS since it has all the benefits of an IS, plus the added benefit of cost-savings.

Our final comparison is between a RJV with cost sharing and competition with cost sharing.

Proposition 3. *If (a) spillovers are incremental and the probability of success is lower than* 1/2; *(b) spillovers are offsetting and the probability of success is greater than* 1/2; *or (c)* $\alpha = 1$, *then* $\hat{x}^{\mathrm{vc}} > \hat{x}^{\mathrm{cc}}$.

(Proof in Appendix A.) Note that there is no instance in which we can conclusively state that there is more research in competition than in a RJV, and, in fact, this may never occur. However, without specifying the functions, a more precise statement is not available.

[23] A more general way of stating this is $P(x_i, x_j) > 1-(1-P(x_i))(1-P(x_j))$. This allows for the possibility that it is not only the aggregate level of investment that matters in a joint venture, but also the division between the firms. Thus, a situation where $x_i = 2x$ and $x_j = 0$ may be vastly different from a situation in which $x_i = x_j = x$. This generalization would not affect our results because, in equilibrium, the firms act symmetrically.

Finally, comparing profits under a RJV with cost sharing and competition with cost sharing we get:

Proposition 4. *If spillovers are incremental, firms prefer a RJV with cost sharing to competition with cost sharing. A RJV is also preferred with offsetting spillovers if α is large*.

(Proof in Appendix A.) Note that the situation with offsetting spillovers is not, in general, clear. Since costs are shared, there are two issues affecting the choice between the regimes. With a RJV there are cost savings, and, in addition, there are maximum spillovers. When spillovers are incremental both of these effects favor a RJV over competition, so the result is clear. With offsetting spillovers, however, there is a tradeoff between the two effects, and the relative desirability cannot, in general, be discerned. If, however, spillovers are large, the benefit from competition is mitigated, and cooperation becomes more profitable.

4. Summary of results and discussion

In this paper we considered cooperation among firms involved in R&D activities with spillovers and uncertainty. We used more generalized functional forms than usual in the literature, and considered the increasing degree of cooperation at any of the following three stages. Firms can jointly agree on the level of R&D expenditures, they can engage in an information sharing agreement, and they can setup joint research facilities. One of the major novelties of our research is that we introduce the concepts of offsetting and incremental spillovers.

A clear pattern emerges. First, when spillovers are offsetting competition tends to be preferred to cooperation, but with incremental spillovers cooperation tends to be more desirable. In the latter case, there is a new incentive to cooperate in R&D due to the expansion of the market because of the increase in the number of producers. On the other hand, if spillovers reduce total profits, the innovating firm tends to retain the strategic gain from innovation.

This same tendency, however, does not exist when considering the level of investment in R&D, where the type of spillovers has little effect, but the extent of spillovers is often crucial.

Other patterns also emerge. Cost sharing usually leads to increased investment and profits compared with a fully competitive R&D market. However, cost sharing is not the most profitable form of cooperation. In most cases firms prefer a RJV to cooperation with cost sharing, and, in fact, a RJV is always preferred to IS agreements.

In principle, all of these implications are empirically testable. Thus, for instance, we are more likely to see cooperation in research efforts when spillovers are incremental (such as when there are multiple uses for the discovery or the good produced is heterogeneous) than when they are offsetting (such as when the research is geared at lowering the costs of an existing technology).

Care must be taken, however, in taking these conclusions to the extreme. For instance, the model suggests that we should never see an IS agreement since a RJV is superior, and there should almost always be cost sharing. And yet there are many instances in which firms cooperate without using joint research facilities, and without sharing costs. Thus, it would seem that we could conclude that the model is wrong. To understand why such a conclusion would be erroneous, we must look beyond the model presented, and consider other issues.

Firms tend not to trust one another. Thus, firms may feel that in a joint venture they will be giving away too many of their secrets, and prefer to stay at arms length. Similarly, cost sharing without a joint venture may require that each firm monitor the accounting books of the other firm—a clear intrusion into their private matters. Even if firms are willing to bear this intrusion, the monitoring process itself may be problematic. Issues of questionable cost allocations, fabrication of expenditures, and overstatement of efforts could plague the relationship. Each firm has a clear incentive to agree on a high level of investment, and then spend less.[24] And, from an antitrust perspective, such monitoring may be an instrument that can pave the way to collusion. Finally, information sharing agreements may be difficult or costly to enforce. Although ex ante firms desire such cooperation, ex post the discovering firm has a clear incentive to attempt to renege on the agreement, and enforcement through the court system is likely to be costly and lengthy.

Governments also tend not to trust cooperation between firms. The fear is that while cooperation in R&D may increase the probability of discovery, cooperation at the research stage of the process could well turn into collusion at the production stage. Thus, any type of cooperation is viewed skeptically, and is often not permitted. But even assuming cooperation is permitted, some types may seem more conducive to collusion than others. Thus, for instance, when engaged in a joint venture, members of the different firms spend much time and effort working in tandem, and this type of contact may create particularly fertile ground for discussions and decision-making in other realms (such as price setting). Information sharing, on the other hand, requires a less intimate setting, and thus may be preferred by authorities. Thus, we may see IS agreements flourish despite their inferiority.

If any of these concerns are present, the scope of possibilities available to the firms may be limited, and firms will have to choose from among the remaining options. For this reason we expect to see no cooperation at all or different types of agreements in use.

The bottom line of this research, we believe, lies in its implications for antitrust legislation and litigation. It is important to recognize the circumstances that lead to one type of setup being superior to another (especially from a welfare perspective). Antitrust officials should be aware that there are often real benefits to be had from allowing certain types of cooperation, with the exact type of cooperation depending mainly on the degree and nature of spillovers. The challenge they face is to find ways to allow for such cooperation when it is beneficial, while at the same time buckling down on antitrust infringements at the product level.

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[24] Silipo (2004) provides a survey of the moral hazard problems and the organizational issues arising in the formation of the cooperative R&D agreements.

Acknowledgements

We thank Huw Dixon, John Hey and especially Vincenzo Denicolò, Gianni De Fraja and two anonymous referees for their useful comments on a previous version of this paper. The usual disclaimer applies. Financial support from the Italian MURST, from the Samuel Neaman Institute for Advanced Studies in Science and Technology, and from the Bar-Ilan University Research Center is gratefully acknowledged.

Appendix A. Proofs of Propositions

Proof of Lemma 1. Totally differentiating (2) we have,

$$\frac{\mathrm{d}\hat{x}_i^{\mathrm{c}}(\alpha)}{\mathrm{d}\alpha} = -\frac{\frac{\partial G_j}{\partial x_j}\frac{\partial G_i}{\partial \alpha} - \frac{\partial G_i}{\partial x_j}\frac{\partial G_j}{\partial \alpha}}{\frac{\partial G_i}{\partial x_i}\frac{\partial G_j}{\partial x_j} - \frac{\partial G_j}{\partial x_i}\frac{\partial G_i}{\partial x_j}}.$$

At a symmetric equilibrium $\partial G_i/\partial\alpha = \partial G_j/\partial\alpha$, $\partial G_i/\partial x_i = \partial G_j/\partial x_j$, and $\partial G_i/\partial x_j = \partial G_j/\partial x_i$, i, $j = 1,2$, so

$$\frac{\mathrm{d}\hat{x}_i^{\mathrm{c}}(\alpha)}{\mathrm{d}\alpha} = -\frac{\frac{\partial G_i}{\partial \alpha}}{\frac{\partial G_i}{\partial x_i} + \frac{\partial G_i}{\partial x_j}} < 0,$$

since $\partial G_i/\partial x_i < 0$ by the second-order conditions,

$$\frac{\partial G_i}{\partial \alpha} = P'(\hat{x}_i^c)\left[(1 - P(x_j))\frac{\partial R_1(\alpha)}{\partial \alpha} - P(x_j)\frac{\partial R_2(\alpha)}{\partial \alpha}\right] < 0$$

from Assumption 1, and

$$\frac{\partial G_i}{\partial x_j} = -P'(\hat{x}_i^{\mathrm{c}})P'(x_j)[R_1(\alpha) + R_2(\alpha) - R_3] < 0. \qquad \square$$

Proof of Lemma 2. In a symmetric Nash equilibrium, conditions (2) and (4) become, respectively,

$$G' = P'(\hat{x}^{\mathrm{c}})[(1 - P(\hat{x}^{\mathrm{c}}))R_1(\alpha) + P(\hat{x}^{\mathrm{c}})(R_3 - R_2(\alpha))] - 1 = 0. \tag{A1}$$

Comparing (A1) and (A4), we get:

$$P'(\hat{x}^{\mathrm{c}})[R_1(\alpha) - P(\hat{x}^{\mathrm{c}})(R_1(\alpha) + R_2(\alpha) - R_3)]$$
$$= P'(\hat{x}^{\mathrm{cc}})[R_1(\alpha) + R_2(\alpha) - 2P(\hat{x}^{\mathrm{cc}})(R_1(\alpha) + R_2(\alpha) - R_3)]. \tag{A2}$$

If $\alpha = 1$ this reduces to

$$P'(\hat{x}^{\mathrm{c}})(1 - P(\hat{x}^{\mathrm{c}})) = 2P'(\hat{x}^{\mathrm{cc}})(1 - P(\hat{x}^{\mathrm{cc}})),$$

which can only hold if $\hat{x}^{\mathrm{c}} < \hat{x}^{\mathrm{cc}}$. If, alternatively, $\alpha = 0$, (A2) becomes:

$$P'(\hat{x}^{\mathrm{c}})[R_1(0) - P(\hat{x}^{\mathrm{c}})(R_1(0) - R_3)] = P'(\hat{x}^{\mathrm{cc}})[R_1(0) - 2P(\hat{x}^{\mathrm{cc}})(R_1(0) - R_3)].$$

If $\hat{x}^c = \hat{x}^{cc}$ then this amounts to requiring that $P(R_1(0) - R_3) = 0$, which can only occur when $P = 0$. If $\hat{x}^c < \hat{x}^{cc}$ the RHS is clearly less than the LHS. Thus, equality can be attained only if $\hat{x}^c > \hat{x}^{cc}$.

Since the functions are all continuous in α it follows that there exists a value of α for which $\hat{x}^c = \hat{x}^{cc}$. □

Proof of Lemma 3. When $\hat{x}^c = \hat{x}^{cc}$ (3) and (1) are identical, so profits under the two regimes are equal. If $\hat{x}^c \neq \hat{x}^{cc}$, it is clear that $E\Pi^{cc} > E\Pi^{c}$, since the investment level is chosen so that, at $\hat{x}^{cc}$, $\partial E\Pi^{cc}/\partial x = 0$. □

Proof of Proposition 1. Comparing competition and information sharing under cost sharing, we get the following:

$$2P'(\hat{x}^{sc})(1 - P(\hat{x}^{sc}))R_3 = P'(\hat{x}^{cc})[R_1(\alpha) + R_2(\alpha) - 2P(\hat{x}^{cc})(R_1(\alpha) + R_2(\alpha) - R_3)]. \quad \text{(A3)}$$

When $\alpha = 1$, (A3) reduces to

$$2P'(\hat{x}^{sc})(1 - P(\hat{x}^{sc}))R_3 = 2P'(\hat{x}^{cc})(1 - P(\hat{x}^{cc}))R_3,$$

so clearly $\hat{x}^{sc} = \hat{x}^{cc}$.

To evaluate what occurs when $\alpha < 1$, note that the LHS of (A3) does not change when α changes, but the RHS does. Thus, we investigate the sign of the derivative of the RHS with respect to α. The derivative is given by:

$$P'(\hat{x}^{cc})\left(\frac{\partial(R_1 + R_2)}{\partial\alpha}\right)(1 - 2P(\hat{x}^{cc})) + P''[R_1 + R_2 - 2P(\hat{x}^{cc})(R_1 + R_2 - R_3)] \times \frac{\partial\hat{x}^{cc}}{\partial\alpha} - 2P'(\hat{x}^{cc})^2(R_1 + R_2 - R_3)\frac{\partial\hat{x}^{cc}}{\partial\alpha}. \quad \text{(A4)}$$

The second and third terms are clearly positive since, by Lemma 1, investment in R&D falls when spillovers increase. The first term can be positive or negative. It will clearly be positive (or zero) if either of the condition in the proposition hold. Thus, in those instances, lowering α below 1 will cause the RHS of (A3) to fall, so that investments will have to fall to bring equality in (A3). Thus, $\hat{x}^{sc} > \hat{x}^{cc}$. If the conditions stated in the proposition do not hold the first term in (A4) will be positive, and the derivative cannot be signed. □

Proof of Proposition 2. An information sharing agreement with cost sharing will be preferred to competition with cost sharing if:

$$P(\hat{x}^{sc})(2 - P(\hat{x}^{sc}))R_3 - \hat{x}^{sc} > P(\hat{x}^{cc})[R_1(\alpha) + R_2(\alpha) - P(\hat{x}^{cc}) \times (R_1(\alpha) + R_2(\alpha) - R_3)] - \hat{x}^{cc}. \quad \text{(A5)}$$

Competition will be preferred if the inequality is reversed.

When $\alpha=1$ it is clear from Proposition 1 that there is equality. Differentiating the RHS of (A5) with respect to α and using the Envelope Theorem:

$$\frac{\partial E\Pi^{\mathrm{cc}}}{\partial\alpha}=\frac{\partial(R_1+R_2)}{\partial\alpha}P(\hat{x}^{\mathrm{cc}})(1-P(\hat{x}^{\mathrm{cc}})).$$

Since this is, by definition, positive with incremental spillovers and negative with offsetting spillovers, the result follows. □

Proof of Lemma 4. Comparing (8) and (6), we need:

$$2P'(2\hat{x}^{\mathrm{vc}})R_3=2P'(\hat{x}^{\mathrm{sc}})(1-P(\hat{x}^{\mathrm{sc}}))R_3,$$

and from Assumption 3a it is clear that this can only occur if $\hat{x}^{\mathrm{vc}}>\hat{x}^{\mathrm{sc}}$.

Since there is cost sharing, it is clear that $E\Pi^{\mathrm{vc}}(x=\hat{x}^{\mathrm{vc}})>E\Pi^{\mathrm{vc}}(x=\hat{x}^{\mathrm{sc}})$. Consequently, it is sufficient to show that $E\Pi^{\mathrm{vc}}(x=\hat{x}^{\mathrm{sc}})>E\Pi^{\mathrm{sc}}(x=\hat{x}^{\mathrm{sc}})$. This amounts to showing that:

$$P(2\hat{x}^{\mathrm{sc}})R_3-\hat{x}^{\mathrm{sc}}>[2P(\hat{x}^{\mathrm{sc}})-P(\hat{x}^{\mathrm{sc}})^2]R_3-\hat{x}^{\mathrm{sc}},$$

which holds by Assumption 3. □

Proof of Proposition 3. From (8) and (4) we require that:

$$2P'(2\hat{x}^{\mathrm{vc}})R_3=P'(\hat{x}^{\mathrm{cc}})[R_1(\alpha)+R_2(\alpha)-2P(\hat{x}^{\mathrm{cc}})(R_1(\alpha)+R_2(\alpha)-R_3)]. \tag{A6}$$

If $\alpha=1$, then (A6) becomes:

$$2P'(2\hat{x}^{\mathrm{vc}})R_3=2P'(\hat{x}^{\mathrm{cc}})[1-P(\hat{x}^{\mathrm{cc}})]R_3,$$

so $\hat{x}^{\mathrm{vc}}>\hat{x}^{\mathrm{cc}}$ by Lemma 2.

Differentiating the RHS of (A6) by α, we find that

$$\frac{\partial\mathrm{RHS}}{\partial\alpha}=P'(\hat{x}^{\mathrm{cc}})\frac{\partial(R_1+R_2)}{\partial\alpha}(1-2P(\hat{x}^{\mathrm{cc}})).$$

Since a lowering in α that leads to a lowering of the RHS of (A6) will cause $\hat{x}^{\mathrm{cc}}$ to fall further below $\hat{x}^{\mathrm{vc}}$, we can conclude that if $P(\hat{x}^{\mathrm{cc}})<1/2$ and spillovers are incremental, or $P(\hat{x}^{\mathrm{cc}})>1/2$ and spillovers are offsetting, then $\hat{x}^{\mathrm{vc}}>\hat{x}^{\mathrm{cc}}$. □

Proof of Proposition 4. For a RJV with cost sharing to be preferred to competition with cost sharing we require, from (7) and (3)

$$P(2\hat{x}^{\mathrm{vc}})R_3-\hat{x}^{\mathrm{vc}}>P(\hat{x}^{\mathrm{cc}})[R_1(\alpha)+R_2(\alpha)-P(\hat{x}^{\mathrm{cc}})(R_1(\alpha)+R_2(\alpha)-R_3)]-\hat{x}^{\mathrm{cc}}. \tag{A7}$$

When $\alpha=1$ this reduces to:

$$P(2\hat{x}^{\mathrm{vc}})R_3-\hat{x}^{\mathrm{vc}}>[2P(\hat{x}^{\mathrm{cc}})-P(\hat{x}^{\mathrm{cc}})^2]R_3-\hat{x}^{\mathrm{cc}}.$$

We extend this equation to:

$$P(2\hat{x}^{\mathrm{vc}})R_3-\hat{x}^{\mathrm{vc}}>P(2\hat{x}^{\mathrm{cc}})R_3-\hat{x}^{\mathrm{cc}}>[2P(\hat{x}^{\mathrm{cc}})-P(\hat{x}^{\mathrm{cc}})^2]R_3-\hat{x}^{\mathrm{cc}}.$$

The first inequality holds since $\hat{x}^{vc}$ maximizes $E\Pi^{vc}$, and the second holds by Assumption 3. Thus, when $\alpha=1$ a RJV with cost sharing is preferred to competition with cost sharing.

Differentiating the RHS of (A7) with respect to α, and using the envelope theorem, we find that $\partial E\Pi^{cc}/\partial\alpha = P(\hat{x}^{cc})(1-P(\hat{x}^{cc}))\partial(R_1+R_2)/\partial\alpha$. The sign of this derivative depends on the nature of the spillovers. If the spillovers are incremental this is positive, so by lowering α the profits under competition fall, so a RJV continues to be more profitable. If, however, spillovers are offsetting, it is possible that at some level of α the two are equal, so that when α is small competition is preferred, while when α is large a RJV is preferred. □

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