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UNILATERAL COMMITMENTS TO DISCLOSE KNOW-HOW IN RESEARCH JOINT VENTURES

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In this paper, the use of unilateral commitments by the partners participating in a Research Joint Venture (RJV) is explained as part of the firms' attempt to select the efficient equilibrium in cases where multiple equilibria exist. In a framework including asymmetric information and uncertainty we show that unilateral commitment by a firm to disclose its own know-how to the venture can be effective in inducing cooperative behavior by the partners only if they have complementary technologies, their absorptive capacity is not very high and only for intermediate innovation values. Complementarity between the partners also increases stability in RJVs.

Keywords: Research joint ventures, unilateral commitments, moral hazard, know-how.

(*JEL* O31, O32)

1. Introduction

Despite the great popularity and the rapid proliferation of Research and Development (R&D) alliances during the last decade, they are highly unstable due, among other reasons, to opportunistic behavior by the partners. Gulati *et al.* (1994), argue that one of the reasons explaining failures in cooperative R&D projects could be the partners viewing the alliance as a prisoner's dilemma situation. Each firm fears that the partner could act opportunistically while it cooperates in good faith. Hence, even if both firms would be better off cooperating,

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they choose not to cooperate and end up worse off. The terms cooperation and non-cooperation can be interpreted in the following way: it is assumed that the alliance requires something from each partner, as some tangible investments (capital equipment) and some unobservable ones (for example disclosure of own know-how, or physical effort and degree of involvement into the project). Non-cooperation can arise if either partner fail to provide some of the agreed unobservable investments. But then, why should rational firms undertake a project if they anticipate non-cooperative behavior? The reason could be that the expected profits of participating in the project could be higher than the ones in the alternative option of no participation.

In this line, Bureth *et al.* (1997), report that the learning process that usually takes place in RJVs is a fundamental source of instability. It is usually the case that part of the knowledge learned is re-deployable outside the specific relationship. Under these circumstances, the partners could behave opportunistically, not providing their best know-how to the venture, especially if they are at the same time rivals in other markets. Finally, another reason for instability appears in Kogut (1991), and Vonortas (1997). They state that many firms first try out joint ventures to limit their exposure to potentially profitable activities which are still too uncertain to justify heavy investments, that is, they use joint ventures to buy options into new technological areas. If the new activity proves successful, a firm may decide to invest heavily in it and gain control of the joint venture.

Two important questions arising at this point are the following: first, if R&D alliances are so unstable, why then firms seem to have an insatiable appetite for them? And, second, how do they try to make them work? With respect to the first question, many papers exist that analyze the advantages of cooperation, such as the internalization of spillovers, capturing economies of scale, complementarities and synergies, favoring the dissemination of R&D output and inputs among the partners, or avoiding the duplication of efforts. Among others, we can mention Katz (1986), d'Aspremont and Jacquemin (1988), Beath *et al.* (1990), Suzumura (1992), De Bondt *et al.* (1992), Kamien *et al.* (1992), Combs (1993), Choi (1993) and Katsoulacos *et al.* (1998).

The present work focuses on the second question. In particular, this work analyzes one instrument that firms can use to increase stability in Research Joint Ventures (RJVs), namely, a unilateral commitment. This behavior is explained as a completely rational action, part of the firm's attempt to identify and select the efficient equilibrium in cases multiple equilibria exist.

As Gulati *et al.* (1994) report, an important and frequently observed characteristic in many alliances has to do with the partners acting unilaterally, trying to enhance the probability that all the partners fully cooperate. These unilateral actions are, however, difficult to rationalize in a prisoner's dilemma structure in which the best response of each firm is always not to cooperate regardless of what the rival does. Hence, we need to consider a different structure in which "not to cooperate" is no longer a dominant strategy. In particular, a structure in which firm i's cooperation is best responded by cooperation by firm j and firm i's failure to cooperate is best answered by a similar failure to cooperate. That structure of the game leads to the existence of two Nash equilibria, namely, both firms cooperating or no firm cooperating. It is in those cases that making unilateral commitments could be a way to select the efficient equilibrium. Gulati *et al.* (1994), report the existence of two types of unilateral commitments: the first one involves actions that a particular firm can take to alter only its own pay-offs under particular outcomes. In this way, the firm tries to change the pay-off structure of the game in order to cause the more desirable outcome; with the second type, rather than acting unilaterally to alter its own pay-offs, a firm irreversibly commits to one of the choices already available to it. Then, its partner takes this into account in making its decision. Gulati *et al.* (1994) report some interesting examples of the latter kind of behavior: a case in which one of the partners gave the other the resumes of all fifty of its development engineers and let the partner choose ten of them that it considered best suited to the alliance. By making this commitment the firm clearly demonstrated its clear intention of fully cooperate towards the success of the alliance, removing the partner's doubt about sharing its technology. Another case is that of a RJV between two automobile manufacturers in which one of the firms made its car designs available well in advance of the other firm's investments making clear the intention of transferring its best technology to the venture.

As Gulati *et al.* (1994) recognizes, "Managers must understand the economics of an alliance. Their recommendations for appropriate actions depend crucially on the nature of the alliance. An alliance in which the economics are better represented by one game versus another can lead to different avenues to ensure the participants' cooperation. For example, unilateral commitments play a much greater role in the (two equilibria game structure) and play no role in the prisoners dilemma formulation... Though the exact pay-offs are important, it is the structure of the pay-offs that determines whether the alliance is viable in the first instance and how it should be managed to get the most value of it".

In this work, we deal with unilateral commitments. In particular, with the second type described above. We analyze the circumstances under which any of the firms participating in an alliance has an incentive to unilaterally commit itself to disclose its best know-how to the venture in advance, trying to influence the outcome of the game. An important characteristic of this paper is that the pay-offs structure of the game is not exogenously fixed as in Gulati *et al.'s* paper. Each firm's expected pay-off as well as the pay-offs structure of the game is determined by the firms at the contracting stage, when they decide how to share the costs and the innovation value. Therefore, the partners will look for the contract that maximizes the joint expected profit of the venture taking into account the effect that their decision will have on the pay-offs structure of the game to be played.

In a simple model including uncertainty and asymmetric information we show first, that we can find unilateral commitments in equilibrium only when the partners have complementary technologies and for intermediate innovation values, which allows for the simultaneous existence of both a Nash equilibrium with both firms cooperating and a Nash equilibrium with no firm fully cooperating. Moreover, it is more likely to observe unilateral commitments when the absorptive capacity of the firms is not too high relative to the degree of complementarity between their technologies and when the firms are free to share R&D costs and the innovation value. Third, as it is also shown in Pérez-Castrillo and Sandonís (1996), there are situations in which profitable projects do not start due to the existing moral hazard problem regarding the provision of non-verifiable inputs to the venture. The project would be undertaken if the firms were able to commit themselves to fully cooperate but no contract can implement such behavior. In other cases, some projects are undertaken but, due to the moral hazard problem, they end up reaching an inefficient equilibrium.

The remainder of the paper is organized as follows. Section 2 presents the model. Section 3 analyzes competition in the final product market. Section 4 characterizes the incentive contracts and identifies the circumstances under which a unilateral commitment is an effective instrument to induce full disclosure of know-how by the partners. Section 5 enters into the participation decision. Finally, section 6 closes the paper. All formal proofs are relegated to an appendix.

2. The model

We consider two firms, denoted by $i = 1, 2$, that are competitors in a product market. They have the possibility to undertake an RJV project trying to obtain an innovation. In case both firms enter the project they face both uncertainty and asymmetric information. Uncertainty exists because the innovation value, denoted by v, is a random variable. We assume for simplicity that it is discrete and may take two values: either $v = 0$ or $v = V > 0$. Let us denote by p the probability that $v = V$ and $(1 - p)$ the probability that $v = 0$. In other words, p can be defined as the probability of project success, that is to say, the probability of achieving an innovation of known value V. This probability is assumed to depend positively on the amount of own know-how provided by each partner to the venture. If the project succeeds, the firms obtain an innovation that is useful in a market that is independent of the market in which the firms are rivals[1].

On the other hand, the firms face asymmetric information, as know-how is assumed to be a non-contractible variable. We consider the kind of know-how usually called "soft information", because it is very difficult to impose by contract the provision of a specific know-how. This induces a double moral hazard problem between the partners: each firm will provide its best know-how to the venture only if it has a private incentive to do it. The asymmetry of information matters because the know-how provided by a firm is (partially) absorbed by its partner, which uses it to increase its efficiency and become a stronger competitor in the market where they are rivals. Hence, even though the probability of project success increases with the amount of know-how provided by the partners, a firm may have incentives not to disclose its best know-how.

[1] Veugelers and Kesteloot (1994) report that 41 % of the ventures involving R&D activities are operating in different sectors than their parent companies. For the other cases the hypothesis we use can be taken as a simplification that helps to isolate and understand the effects at work.

We assume that, in order to start the project, the firms must jointly pay a known initial fee of F, which includes the transaction costs (usually high in a RJV), and the costs of establishing the laboratory and the facilities needed to undertake the project. After the fixed fee has been paid but before the stage of disclosure of know-how there is a commitment stage: both partners have the possibility to act unilaterally in order to precommit themselves to disclose its best know-how to the venture[2]. For simplicity, I will interpret this unilateral action as whether, in fact, the firms may disclose its best know-how in advance, and assume that behaving in that way is not costly[3]. In this case and, after observing that action, the other partner decides the amount of know-how to be provided, acting as a follower. In case no firm precommits, both firms choose the amount of know-how to be revealed simultaneously. After the disclosure stage and, in case of success ($v = V$), the firms share the innovation value as agreed in the contract. Finally, the firms compete in the market in which they are rivals.

More precisely, the timing of the game is the following: in the first stage the firms must reach an agreement on (F_1, F_2), (V_1, V_2) with $F_1 + F_2 = F$, $V_1 + V_2 = V$, that is, on how to share the innovation value and the fixed cost of the project. We consider this agreement to be binding, as F and V are verifiable variables.

In the second stage, each firm decides whether or not to participate in the project. If both firms enter the venture then, in the third stage and after each firm i has paid F_i, any of the firms has the option to act as a leader, disclosing its best know-how to its partner in advance[4]. In that case, the other firm will take its decision on disclosure after observ-

[2] For example, one firm could invite its partner to visit its laboratory or, as reported by Gulati *et al.* (1994), it could let the partner choose the best engineers to be sent to the joint laboratory, or it could make its product designs available to its partner.
[3] In this paper, only commitments by the partners to disclose their best know-how are considered. It is not easy to imagine how a firm could make a credible commitment not to disclose its best know-how. That announcement would not be credible because the firm could always disclose later on whenever it is interested in it. Anyway, allowing for credible non-disclosure commitments would lead to the existence of a "bad" equilibrium in which both firms simultaneously precommit not to disclose their know-how. However, we could avoid that equilibrium just by introducing a small cost of precommitment (for example, telephone calls, or mail, or the time devoted to show your technologies to your partner). Another way to avoid that equilibrium would be for the firms to make the commitment stage sequential.
[4] In fact, given the symmetry of the game, whenever an equilibrium based on a commitment by a firm (say firm 1) exists, there would always exist another equilibrium

ing that action. Otherwise, both firms decide on the know-how to be provided simultaneously. We simplify by assuming that the firms may disclose two different levels of know-how, either a low level, denoted by e_0 or a high one denoted by e_1, with $e_1 > e_0$. In the fourth stage, the firms observe the realization of v. If $v = V$, the firms share the innovation value as agreed in the contract. The probability that $v = V$ depends on the total amount of know-how disclosed by the firms. Let us denote by $p_{st} =$ Prob $(v = V/(e_s, e_t))$, where $s = 0, 1$ and $t = 0, 1$, with $p_{11} > p_{10} = p_{01} > p_{00} > 0$ (the first index refers to firm 1's decision)[5]. Finally, in the last stage of the game the firms produce for the market in which they are rivals. We look for the subgame perfect Nash equilibria of the game solving by backward induction.

We are going to distinguish two cases regarding the relationship between the firms' technologies, namely, either they have complementary technologies or substitutive technologies. With complementary technologies, the contribution of both firms is crucial in order to attain the innovation. Therefore, the probability of achieving the innovation increases more when firm i provides a high level of know-how given that firm j also provides a high level than in case firm j provides a low one, that is, with complementary technologies we have $p_{11} - p_{01} > p_{10} - p_{00}$ and $p_{11} - p_{10} > p_{01} - p_{00}$. By contrast, if the firms have substitutive technologies, the probability of achieving the innovation increases more when firm i provides a high level of know-how given that firm j provides a low level than in case firm j provides a high one. Therefore, with substitutive technologies we have $p_{11} - p_{01} < p_{10} - p_{00}$ and $p_{11} - p_{10} < p_{01} - p_{00}$.

3. Competition in the product market

At the last stage of the game, firms' profits are contingent upon the amount of know-how disclosed in the previous stage. We have four possibilities. Let us denote by B^i_{00} firm i's profits in the product market when both firms disclose a low level of know-how, by B^i_{10} firm i's profits

in which it is the other firm (say firm 2) that uses a precommitment. We will not distinguish, however, between both equilibria as they are completely symmetric.

[5]Notice that we are assuming that both firms' know-how is equally valuable for the project and that even if both firms provide a low level of know-how to the venture the project may be successful with a positive probability. The low level of know-how can represent a minimum level required in order for the project to be feasible. On the other hand, the high level of know-how implies full disclosure, including some key know-how that the firm considers crucial for future developments.

when firm 1 discloses a high level and firm 2 a low level of know-how, and similarly for B^i_{01} and B^i_{11}. We consider the following assumptions regarding that market:

ASSUMPTION 1: each firm prefers not to disclose its know-how (to prevent the partner from absorbing it) but wishes to learn the rival's. Therefore, the next two conditions are satisfied:

$$B^1_{01} > \begin{matrix} B^1_{11} \\ B^1_{00} \end{matrix} > B^1_{10} \quad [1]$$

$$B^2_{10} > \begin{matrix} B^2_{11} \\ B^2_{00} \end{matrix} > B^2_{01} \quad [2]$$

ASSUMPTION 2: the more know-how disclosed by the firms the higher their joint profits in this market:

$$B^1_{11} + B^2_{11} > B^1_{01} + B^2_{01} = B^1_{10} + B^2_{10} > B^1_{00} + B^2_{00}, \quad [3]$$

It is easy to find examples of markets satisfying conditions [1]-[3][6].

4. Contracts inducing unilateral commitments

Let me now analyze the firms' decision on whether or not to fully disclose own know-how to the project in case both have entered the project and after they have paid F as agreed in the contract, assuming that no unilateral commitment has taken place before. The know-how provided by a firm is not verifiable and, therefore, it is not contractible. This implies the existence of a double moral hazard problem between the partners: each firm will privately decide on the disclosure of own know-how to the project. Providing a high level of know-how has two main consequences for firm i. First, it increases the probability of project success and hence, the expected joint profits from the venture. Second, it allows the partner (firm j) to (partially) absorb its key

[6]Let us propose the following example. Firms 1 and 2 are competing in quantities in a differentiated product market. The demand function faced by firm i is given by: $p_i = 1 - q_i - \beta\ q_j$. The parameter $\beta \in [0, 1]$ measures the degree of product differentiation. Before the RJV starts, firms' unit cost is c°. After the stage of disclosure, they become $c_1 = (1 - \gamma_2)\ c^\circ$ and $c_2 = (1 - \gamma_1)\ c^\circ$, where γ_i represents the amount of know-how disclosed by firm i and it can take two values, 1 denotes a high level of know-how and 0 denotes a low level. It is not difficult to verify that equations [1]-[3] hold for this market when $\beta > 0$.

know-how, becoming a stronger competitor in the market where they compete, which implies an increase in firm j's profits and a decrease in firm i's profits. Besides, the size of both effects depends on firm j's decision on know-how.

The optimal outcome from both a social and an industry point of view is that both firms fully disclose their know-how because, in that way, the firms increase both the expected profits from the venture and the joint profits in the product market (see eq. [3]). Besides, consumers benefit through lower prices in that market.

We concentrate now on the optimal contracts that implement full disclosure of know-how. In particular, we are interested in identifying among the optimal contracts those that induce unilateral commitments as an effective way to reach the efficient, full disclosure equilibrium.

Notice that whenever the firms can freely choose how to share the total profits from the venture, they will choose among the individually rational contracts one that maximizes the total expected profits from the venture. The particular pairs $(F_1, F_2), (V_1, V_2)$ set in the contract will determine each firm's expected pay-off[7]. The moral hazard problem concerning firms' decision on know-how disclosure not only imposes restrictions on the contract form but sometimes it prevents the partners from being able to reach efficient equilibria. Let us introduce three critical values of the innovation value that bound the different regions to be defined by the propositions below.

$$V^* = \frac{B^1_{00} - B^1_{10}}{p_{10} - p_{00}} + \frac{B^2_{00} - B^2_{01}}{p_{01} - p_{00}}, \quad [4]$$

$$V^{**} = \frac{B^1_{01} - B^1_{11}}{p_{11} - p_{01}} + \frac{B^2_{10} - B^2_{11}}{p_{11} - p_{10}}, \quad [5]$$

$$\widetilde{V} = \frac{B^1_{00} - B^1_{10}}{p_{10} - p_{00}} + \frac{B^2_{10} - B^2_{11}}{p_{11} - p_{10}}. \quad [6]$$

[7]In this paper, we do not analyze the bargaining process used by the partners to negotiate the sharing of the project value. We just investigate the existence of equilibrium contracts, that is, individually rational, incentive compatible contracts that maximize the partners' joint profits, implementing the efficient full disclosure equilibrium. Whenever those contracts exist, they are characterized. There will be, in general, many contracts such that the efficient full disclosure equilibrium is implemented. They will only differ in the exact pay-off they assign to each partner, which is not the focus of this paper.

Looking at the denominators, we can see that V^* tends to be higher (lower) than V^{**} as the firms have more complementary (substitutive) technologies. On the other hand, the numerators depend on the degree of competition between the firms in the market (the differences between the B's are higher the more firm i's profits decrease as firm j's learns firm i's know-how. In particular, those differences would be zero if the firms were not rivals in the market). Moreover, given the degree of competition, they also depend on the absorptive capacity of the firms (the higher their absorptive capacity the higher those differences)[8]. Although the numerators in V^* and V^{**} are in general different, we assume that they are close enough so that with complementary technologies $V^{**} < V^*$ holds (this is satisfied whenever the absorptive capacity of the firms is not too high relative to the degree of complementarity between their technologies). Finally, the critical value [6] will be useful to bound the region where precommitments arise in equilibrium[9]. Notice that under complementary technologies we have $V^{**} < \widetilde{V} < V^*$, whereas under substitutive technologies $V^* < \widetilde{V} < V^{**}$ holds. We are interested in identifying the conditions under which incentive compatible contracts exist such that (i) both (e_1, e_1) and (e_0, e_0) are simultaneously Nash equilibria in the stage of disclosure and (ii) there does not exist any contract leading to a unique (e_1, e_1) Nash equilibrium. The reason is that it is precisely in those cases when any firm would have an incentive to precommit itself by providing its best know-how in advance to its partner in order to avoid the inefficient (e_0, e_0) equilibrium. Next proposition describes that situation.

PROPOSITION 1. *Suppose that conditions [1]-[3] hold and that the partners have complementary technologies, so that* $V^{**} < \widetilde{V} < V^*$. *If*

$$V \in [V^{**}, \widetilde{V}), \qquad [7]$$

[8]For example, in a standard Cournot model with differentiated goods and linear demand $\partial^2\Pi_i/\partial c_i \partial c_j < 0$, where Π_i denotes firm i's market profits and c_i and c_j the firms' marginal costs. Applied to our model results in $B^1_{00} - B^1_{10} < B^1_{01} - B^1_{11}$ and $B^2_{00} - B^2_{01} < B^2_{10} - B^2_{11}$.

[9]It comes from the general expression $\widetilde{V} = \max\left\{ \frac{B^1_{00}-B^1_{10}}{\nu_{10}-\nu_{00}} + \frac{B^2_{10}-B^2_{11}}{\nu_{11}-\nu_{10}}, \frac{B^1_{01}-B^1_{11}}{\nu_{11}-\nu_{01}} + \frac{B^2_{00}-B^2_{01}}{\nu_{01}-\nu_{00}} \right\}$ by assuming symmetric absorptive capacity and equally valuable know-how for both firms, so that $\frac{B^1_{01}-B^1_{11}}{\nu_{11}-\nu_{01}} = \frac{B^2_{10}-B^2_{11}}{\nu_{11}-\nu_{10}}$ and $\frac{B^1_{00}-B^1_{10}}{\nu_{10}-\nu_{00}} = \frac{B^2_{00}-B^2_{01}}{\nu_{01}-\nu_{00}}$. That assumption just helps to simplify the model without affecting the main results of the paper.

then, incentive compatible contracts exist such that both (e_1, e_1) *and* (e_0, e_0) *are simultaneously Nash equilibria and there does not exist any contract such that* (e_1, e_1) *is the only Nash equilibrium. Such contracts satisfy the incentive constraint:*

$$V_1 \in \left[\begin{array}{c} \max\left\{V - \frac{B^2_{00}-B^2_{01}}{p_{01}-p_{00}}, \frac{B^1_{01}-B^1_{11}}{p_{11}-p_{01}}\right\}, \\ +\min\left\{\frac{B^1_{00}-B^1_{10}}{p_{10}-p_{00}}, V - \frac{B^2_{10}-B^2_{11}}{p_{11}-p_{10}}\right\} \end{array} \right]. \qquad [8]$$

Proposition 1 states that with complementary technologies, in order for contracts such that both (e_1, e_1) and (e_0, e_0) are simultaneously Nash equilibria to exist, the innovation value must be neither too high (to allow (e_0, e_0) to be an equilibrium) nor too low (to allow (e_1, e_1) to be also an equilibrium) with respect to the degree of rivalry between the partners in the product market. Note that the upper bound in condition [7] guarantees that there does not exist any contract such that (e_1, e_1) is the only Nash equilibrium. On the other hand, equation [8] characterizes such contracts. This condition states that V_1 has to be high enough to allow that firm 1's best response to cooperation is to cooperate but low enough as to allow that firm 2's best response to cooperation is also to cooperate. Moreover, V_1 has to be low enough as to guarantee that firm 1's best response to non cooperation is not to cooperate but high enough as to ensure that firm 2's best response to non cooperation is also not to cooperate. Expression [8] brings together all those conditions on V_1. Notice, first, that whenever condition [7] holds, there always exist contracts satisfying equation [8]. Second, the absolute levels of V_1 and V_2 do not matter as long as the contracts satisfy [8]. They are nevertheless important to determine firms' profits.

Next proposition characterizes the existence of contracts leading to the existence of a unique (e_1, e_1) full disclosure equilibrium for the case of complementary technologies.

PROPOSITION 2. *Suppose that conditions [1]-[3] hold and that the partners have complementary technologies, so that* $V^{**} < \widetilde{V} < V^*$. *If*

$$V \geq \widetilde{V} \qquad [9]$$

then, incentive compatible contracts exist such that (e_1, e_1) *is the only Nash equilibrium. Such contracts are those satisfying at least one of these two conditions:*

$$V_1 \in \left[\frac{B^1_{01} - B^1_{11}}{p_{11} - p_{01}}, V - \frac{B^2_{00} - B^2_{01}}{p_{01} - p_{00}} \right], \qquad [10]$$

$$V_1 \in \left[\frac{B^1_{00} - B^1_{10}}{p_{10} - p_{00}}, V - \frac{B^2_{10} - B^2_{11}}{p_{11} - p_{10}} \right], \qquad [11]$$

Proposition 2 states that in order for contracts assuring that (e_1, e_1) is the only Nash equilibrium in the stage of disclosure to exist, the innovation value must be high enough with respect to the degree of rivalry between the partners in the product market. Moreover, such contracts are characterized. Conditions [10] and [11] guarantee that (e_1, e_1) is a Nash equilibrium and the upper bound in [10] and the lower bound in [11] assure, respectively, that firm 2's and firm 1's best response to non-disclosure is to disclose, thus preventing (e_0, e_0) from being an equilibrium. Finally, condition [9] guarantees that the intervals in [10] and [11] are not empty, so that there always exist contracts satisfying those conditions.

Let me remark that under the premises of Propositions 1 and 2 there would also exist contracts leading to asymmetric equilibria in which only one firm would disclose its best know-how. They would not be, however, equilibrium contracts as they would not maximize the firms' joint expected profits.

Finally, it is easy to check that if the innovation value is not high enough, there does not exist any contract giving both firms an incentive to fully disclose their know-how. In particular, if $V < V^{**}$, there only exist contracts leading to (e_0, e_0), (e_0, e_1) or (e_1, e_0) Nash equilibria[10]. In fact, for low enough values of V only (e_0, e_0) equilibria exist[11].

Let us analyze now the case of substitutive technologies. Next proposition enters into the existence of contracts leading to simultaneous (e_1, e_1) and (e_0, e_0) Nash equilibria for the case of substitutive technologies.

PROPOSITION 3. *Suppose that conditions [1]-[3] hold and that the partners have substitutive technologies, which implies* $V^* < \widetilde{V} < V^{**}$. *There does not exist any contract such that both* (e_1, e_1) *and* (e_0, e_0) *are*

[10] Such contracts satisfy respectively: $V_1 \in \left[V - \frac{B^2_{00}-B^2_{01}}{p_{01}-p_{00}}, \frac{B^1_{00}-B^1_{10}}{p_{10}-p_{00}} \right]$, $V_1 < \min \left[\frac{B^1_{00}-B^1_{10}}{p_{10}-p_{00}}, V - \frac{B^2_{00}-B^2_{01}}{p_{01}-p_{00}} \right]$ and $V_1 > \max \left[\frac{B^1_{00}-B^1_{10}}{p_{10}-p_{00}}, V - \frac{B^2_{00}-B^2_{01}}{p_{01}-p_{00}} \right]$.

[11] In particular, for $V < \min \left\{ \frac{B^1_{00}-B^1_{10}}{p_{10}-p_{00}}, \frac{B^2_{00}-B^2_{01}}{p_{01}-p_{00}} \right\} = \overline{V}$, only (e_0, e_0) equilibria exist.

simultaneously Nash equilibria, whatever the value of V*. On the other hand, for* $V \geq V^{**}$*, incentive compatible contracts exist such that* (e_1, e_1) *is the only Nash equilibrium. Those contracts satisfy:*

$$V_1 \in \left[\frac{B_{01}^1 - B_{11}^1}{p_{11} - p_{01}}, V - \frac{B_{10}^2 - B_{11}^2}{p_{11} - p_{10}} \right]. \qquad [12]$$

Proposition 3 shows that, with substitutive technologies, we can not find a situation in which two simultaneous Nash equilibria in the disclosure stage exist. The intuition behind the result is straightforward: if each firm has an incentive to fully disclose its know-how even when it believes that the partner is going to do the same, it will certainly disclose when it believes that the partner will not. The reason is that it is precisely in the latter case when its know-how is more valuable and contributes more to the project success, given the similarity between their technologies. In other words, with substitutive technologies, (e_1, e_1) being an equilibrium prevents (e_0, e_0) from being simultaneously an equilibrium and, similarly, (e_0, e_0) being an equilibrium prevents (e_1, e_1) from being simultaneously an equilibrium.

Proposition 3 also shows that for high enough innovation values ($V \geq V^{**}$), we can always find contracts leading to a unique (e_1, e_1) equilibrium and characterizes such contracts. Notice that the interval in equation [12] is never empty given $V \geq V^{**}$. Finally, it is easy to check that for $V^* \leq V < V^{**}$ only contracts leading to asymmetric equilibria exist and that for low enough values of V (in particular for $V < \overline{V}$), only (e_0, e_0) equilibria can be implemented by the firms.

In short, a unilateral precommitment by a firm can be an effective way to induce full disclosure of know-how by the partner only under the conditions established in Proposition 1, that is, if the firms have complementary technologies, their absorptive capacity is not too high relative to the degree of complementarity between their technologies and for intermediate innovation values. Under these conditions, unilateral commitments can be explained as a completely rational action, part of the firms' attempt to identify and select the efficient equilibrium in cases where multiple equilibria exist. The intuition of the result is clear. It is in alliances in which every partner's contribution is crucial to achieve the innovation (i.e. they have complementary technologies) where the willingness of any firm to fully cooperate in the project may completely depend on its beliefs about the partners behaving in the same way. Therefore, it is in this kind of projects where a unilateral action taken by any of the firms that precommits that firm to fully cooperate can be an effective way to induce a cooperative behavior by the partner. Proposition 1 is a formalization of Gulati *et al.'s* (1994) statement: "Contemporary alliances tend to be more interdependent, requiring crucial inputs from all partners involved to be successful.... it is precisely in alliances where each partner is crucial to its success that it is advisable for each firm to make unilateral commitments to ensure the venture's success". Moreover, we have to take into account that one of the main motivations for the formation of R&D cooperative ventures reported by firms is precisely the possibility of capturing complementary know-how and technologies from their partners, and it is usually the case that many of the RJVs formed are carried out by firms with complementary technologies (Mariti and Smiley, 1985; Hagendoor and Schakenraad, 1991).

The next step in the analysis has to do with the participation stage. The question is whether individually rational contracts exist leading to the different situations described in the above propositions.

5. Deciding whether to participate

Once F_1, F_2, V_1, V_2 have been negotiated, each firm decides whether or not to enter the RJV. This decision depends on the firms' expectations about the partner's decision on disclosure. We are going to analyze the characteristics of the contracts that guarantee that the firms are willing to participate in the venture, and the restrictions that must hold for those contracts to exist. In order to carry out the analysis, it is useful to look first at the conditions ensuring that the project is profitable from an overall point of view.

LEMMA 1: *The necessary and sufficient condition for the RJV to be profitable from an overall point of view is, for A=11, 10, 01, 00:*

$$F \leq p_A V + \Delta B_A, \quad [13]$$

where we have denoted by $\Delta B_A = (B_A^1 + B_A^2) - (B^1 + B^2)$ *and* $(B^1 + B^2)$ *denotes the sum of the firms' market profits in case they do not enter the venture.*

FIGURE 1
Profitability of the RJV

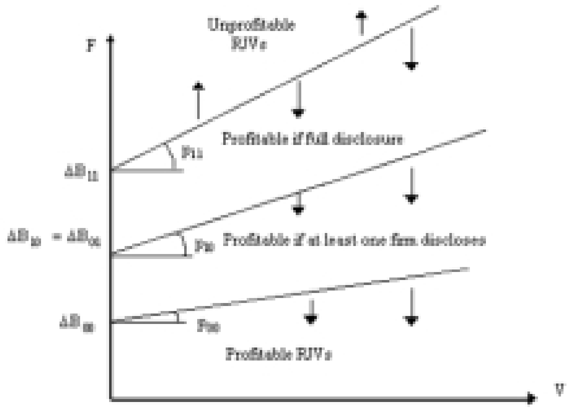

Figure 1 displays in the (F, V) space the different regions in which the RJV is profitable from an overall point of view.

We are now interested in the conditions assuring the existence of individually rational contracts that implement the different equilibria described in the above propositions. In order for both firms to be willing to enter the venture, the contract has to guarantee each of them its reservation expected profits. Next proposition shows that if the project is profitable in the sense that it satisfies expression [13], there always exist ways to share profits so that each firm is willing to participate. It also characterizes those contracts.

PROPOSITION 4. *Suppose conditions [1]-[3] hold, that the firms have complementary technologies, so that* $V^{**} < V^*$ *and that the project is profitable if both firms fully disclose their know-how (equation [13] holds for A=11). Then, if*

$$V \geq V^{**}, \tag{14}$$

there always exist individually rational, incentive compatible contracts that the partners will use, implementing a $(e1, e1)$ *full disclosure equilibrium. Such contracts satisfy:*

$$F_1 \in [F - p_{11}V + p_{11}V_1 - (B^2_{11} - B^2), p_{11}V_1 + (B^1_{11} - B^1)] \qquad [15]$$

and the incentive constraint [8] if $V \in [V^{**}, \widetilde{V})$*, involving precommitment and either [10] or [11] if* $V \geqslant \widetilde{V}$*, involving no precommitment.*

Proposition 4 states that, under the conditions established in Propositions 1 and 2 and if the project is profitable when both firms fully disclose their know-how, they will find a way to share the fixed cost F so that both firms are willing to participate, implementing an efficient (e_1, e_1) full disclosure equilibrium. Equation [15] bounds the share of the fixed costs to be paid by firm 1: it needs to be neither too high so that firm 1 agrees to participate, nor too low so that the other firm has non-negative profits. The premise of Proposition 4 guarantees that the intervals [10], [11] and [15] are not empty. Finally, notice that Proposition 4 includes two different ways of reaching the efficient equilibrium. For very profitable projects, precommitments are not necessary to implement the efficient equilibrium. However, for intermediate values of V, the firms reach the efficient equilibrium through precommitment, that is, a firm will choose to fully disclose its know-how in advance in order to induce the same behavior by its partner, avoiding in that way the inefficient (e_0, e_0) equilibrium[12].

Under the premise of the above proposition we could also characterize the existence of individually rational contracts leading to asymmetric outcomes in which only one firm discloses its know-how and where no firm discloses its know-how to the venture. All we need is the project to be profitable from an overall point of view in each of those situations. However, those would not be equilibrium contracts, as they would not maximize the firms' joint expected profits.

Next proposition enters into the participation decision for the case of substitutive technologies.

PROPOSITION 5. *Suppose conditions [1]-[3] holds, that the firms have substitutive technologies, so that* $V^* < V^{**}$ *and that the project is pro-*

[12] In fact, another equilibrium in the stage of precommitments exists in which both firms precommit to disclose their best know-how (for example, the firms could cross e-mails, or letters inviting each other to visit the partner's laboratory). This equilibrium would lead, obviously, to the efficient full disclosure outcome. Observe that two-sided precommitment would not be an equilibrium if we assumed there is a small cost of precommitment.

fitable if both firms fully disclose their know-how (equation [13] holds for $A = 11$*). Then, if*

$$V > V^{**}, \tag{16}$$

there always exist individually rational, incentive compatible contracts that the partners will use, implementing a (e_1, e_1) *full disclosure equilibrium. Such contracts satisfy:*

$$F_1 \in [F - p_{11}V + p_{11}V_1 - (B_{11}^2 - B^2), p_{11}V_1 + (B_{11}^1 - B^1)], \tag{17}$$

$$V_1 \in \left[\frac{B_{01}^1 - B_{11}^1}{p_{11} - p_{01}}, V - \frac{B_{10}^2 - B_{11}^2}{p_{11} - p_{10}}\right]. \tag{18}$$

and involve no precommitment.

Proposition 5 reproduces the result of Proposition 4 for the case of substitutive technologies. The important difference with that case is that now, the firms do not need to use

unilateral commitments to reach the efficient equilibrium. Equations [17] and [18] characterize the optimal contracts and their interpretation is similar to the corresponding conditions in Proposition 4. Notice that the premise of Proposition 5 guarantees that those intervals are never empty. Figures 2 and 3 display the main conclusions on the (F, V) axes for the cases of complementary and substitutive technologies respectively.

FIGURE 2
Complementary Technologies

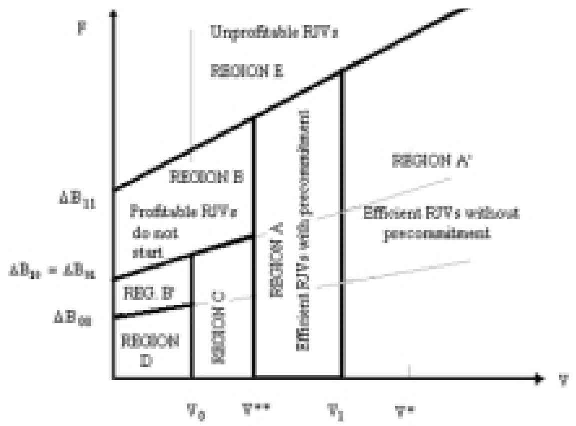

FIGURE 3
Sustitutive Technologies

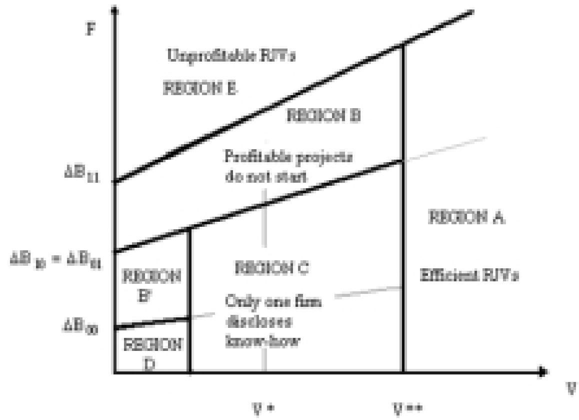

Figure 2 displays the case of complementary technologies. The (F, V) space has been divided into seven regions. In regions A or A', V is high enough and F low enough for individually rational, incentive compatible contracts to exist. The RJV starts and both firms provide their best know-how to the venture. However, in region A two simultaneous equilibria exist and any firm will have an incentive to disclose its best know-how in advance in order to select the efficient equilibrium. Therefore, it is for parameters in region A that we can expect to observe unilateral precommitments. In regions B and B', profitable projects do not start due to the double moral hazard problem regarding the disclosure decision. In particular, in region B the project is profitable only if both firms fully disclose their know-how, but there does not exist any incentive compatible contract. For the parameters in this region the joint venture would start if the firms could credibly commit to disclosure, but no contract can implement such behavior. In region B', the project would be profitable if at least one of the firms disclosed, but there does not exist any contract leading to such situation. In regions C and D the best equilibria the firms can reach are, respectively, an asymmetric equilibrium with only one firm fully disclosing and one with no firm disclosing (notice that the lower bound in region C represents the condition displayed in footnote [10]). Finally, region E contains the (F, V) pairs for which the project is not profitable. Therefore, projects in this region are not undertaken.

On the other hand, Figure 3 displays the main results for the case of substitutive technologies. The (F, V) space has been divided into six regions. Region A contains the (F, V) pairs for which the firms reach an efficient full disclosure equilibrium. Notice that with substitutive technologies no region of precommitments exist. Regions B, B', C, D and E have a similar interpretation than in Figure 2. With substitutive technologies, the region of efficient RJVs is reduced with respect to the case of complementary technologies. The reason is that in the former case, the incentives of a firm to free ride on the partner are high. Given the similarity between their technologies, the probability of project success is high whenever one of the partners provide its best know-how to the venture and each firm prefers the partner to do that. Therefore, if a firm believes that its partner is going to fully disclose its know-how, it has fewer incentives to also disclose than in the case of complementary technologies, where both firms' know-how is crucial to achieve the innovation. Only for very profitable projects we find efficient RJVs (i.e. V^{**}shifts to the right from Figure 2 to Figure 3).

Finally, notice that we have assumed that the partners can freely share the patent value and the fixed cost of the project. Otherwise, the number of situations in which the efficient equilibrium is reached would be reduced. In particular, if the shares of the innovation value are fixed (because, for example, the firms sell the innovation in geographically separated markets), it could be the case that individually rational contracts exist leading to an efficient equilibrium, as described in Proposition 4, but the fixed shares of the innovation value do not provide them with an incentive to fully disclose their know-how. On the other hand, if the firms can not freely share the fixed cost of the project, it could be the case that incentive compatible contracts exist leading to an efficient equilibrium, but any of the partners is not willing to enter the project because it has negative expected profits.

6. Conclusion

As reported by Gulati *et al.* (1994), very often firms participating in RJVs act unilaterally trying to influence the outcome of the game. In this work, we explain precommitments as a completely rational action the firms can use to increase stability in RJVs, by eliminating the risk of opportunistic behavior by the partners. In a model including uncertainty and asymmetric information we show, first, that a precommitment by a firm can be effective to induce cooperative behavior by the partners only when they have complementary technologies, the firms' absorptive capacity is not very high relative to the degree of complementarity between their technologies and for intermediate innovation values. Second, complementarity between firms is shown to be an important characteristic that helps to increase stability in RJVs. Third, there are situations in which profitable projects do not start due to the moral hazard problem regarding the disclosure of firms' know-how. The project would be undertaken if the firms were able to commit themselves to disclose. However, no contract can implement such behavior. In other cases, some projects are undertaken but due to the moral hazard problem they end up reaching an inefficient equilibrium.

Appendix A1

Proof of Proposition 1. We look for the conditions ensuring that (e_1, e_1) is a Nash equilibrium in the disclosure stage. Assume firm 1 believes that firm 2 is going to fully disclose its know-how. Then, it has an incentive to fully disclose if and only if

$$p_{11}.V_1 + B^1_{11} \geq p_{01}V_1 + B^1_{01}. \qquad [A1]$$

Similarly, assume firm 2 believes that firm 1 is going to fully disclose its know-how. Then, it has incentives to fully disclose if and only if

$$p_{11}.V_2 + B^2_{11} \geq p_{10}V_2 + B^2_{10}. \qquad [A2]$$

Taking into account that $V_2 = V - V_1$ and after some calculations we obtain that (e_1, e_1) is a Nash equilibrium if and only if

$$V_1 \in \left[\frac{B^1_{01} - B^1_{11}}{p_{11} - p_{01}}, V - \frac{B^2_{10} - B^2_{11}}{p_{11} - p_{10}}\right]. \qquad [A3]$$

Note that this interval is not empty whenever $V \geq V^{**}$.

In the same way, (e_0, e_0) is a Nash equilibrium if and only if

$$V_1 \in \left[V - \frac{B^2_{00} - B^2_{01}}{p_{01} - p_{00}}, V - \frac{B^1_{00} - B^1_{10}}{p_{10} - p_{00}}\right]. \qquad [A4]$$

and this interval is not empty whenever $V \geq V^*$. Then, for $V \in [V^{**}, V^*]$, contracts exist such that both (e_0, e_0) and (e_1, e_1) are simultaneously Nash equilibria. Moreover, [A3] and [A4] jointly imply that those contracts must satisfy equation [8] in Proposition 1. Finally, we have to look for the conditions assuring that there does not exist a contract such that $(e1, e1)$ is the only Nash equilibrium. Notice that it is not possible that $(e0, e1)$ or $(e1, e0)$ are equilibria simultaneously with $(e1, e1)$. Therefore, we have to look for a sufficient condition assuring that we cannot find a contract such that, at least for one of the firms, the best response to non-disclosure is to fully disclose know-how. That condition is given by:

$$V < \min\left\{\frac{B^1_{00} - B^1_{10}}{p10 - p00} + \frac{B^2_{10} - B^2_{11}}{p11 - p10}, \frac{B^1_{01} - B^1_{11}}{p11 - p01} + \frac{B^2_{00} - B^2_{01}}{p01 - p00}\right\}. \quad [A5]$$

However, under the assumptions of symmetric absorptive capacity and equally valuable know-how (A5) just becomes $V < \widetilde{V}$. Finally, condition $V \in [V^{**}, V^*]$ and [A5] jointly imply:

$$V \in [V^{**}, \widetilde{V}). \quad [A6]$$

Proof of Proposition 2. We have already proved in Proposition 1 that $(e1, e1)$ is a Nash equilibrium if and only if condition [8] in Proposition 1 holds and for the interval in that expression to be non- empty we need that $V \geq V^{**}$, which is satisfied whenever condition [7] holds. On the other hand, a sufficient condition ensuring that a contract exists such that $(e1, e1)$ is the only Nash equilibrium is given by:

$$V \geq \min\left\{\frac{B^1_{00} - B^1_{10}}{p10 - p00} + \frac{B^2_{10} - B^2_{11}}{p11 - p10}, \frac{B^1_{01} - B^1_{11}}{p11 - p01} + \frac{B^2_{00} - B^2_{01}}{p01 - p00}\right\}. \quad [A7]$$

Again, under the assumptions of symmetric absorptive capacity and equally valuable know-how [A7] just becomes $V \geq \widetilde{V}$. Finally, with respect to the contract, it has to guarantee that the best response of at least one of the firms to non-disclosure is to fully disclose its know-how, in order to prevent $(e0, e0)$ from being an equilibrium, which is satisfied whenever either [10] or [11] hold.

Proof of Proposition 3. From the proof of Proposition 1 we know that for a contract such that both (e_0, e_0) and (e_1, e_1) are simultaneously Nash equilibria to exist we need that $V \in [V^{**}, V^{*}]$. However, when the firms have substitutive technologies, we have that $V^{*} < V^{**}$ and, therefore, that interval is empty. On the other hand, condition [12] is obtained following the first part of the proof of Proposition 1.

Proof of Lemma 1. The total expected revenues and costs of the project depend on the decision on disclosure that each firm anticipates. The project is profitable in case A, where A= 11, 10, 01, 00, if and only if the expected revenues are not lower than the expected costs. Comparing them directly results in equation [13].

Proof of Proposition 4. Consider a contract that satisfies equation [13] and that V is such that condition [14] holds. In this situation, we know that if both firms decide to enter, they can always sign a contract such that the efficient equilibrium is reached. Therefore, the firms are willing to enter the project if and only if

$$p_{11}V_1 + (B^1_{11} - B^1) \geq F_1, \qquad \text{[A8]}$$

$$p_{11}V_2 + (B^2_{11} - B^2) \geq F_2. \qquad \text{[A9]}$$

Simple computation of these inequalities yields equation [16]. The necessary and sufficient condition for such a contract to exist is that the interval is non-empty, that is:

$$F \leq p_{11}V + (B^1_{11} - B^1) + (B^2_{11} - B^2). \qquad \text{[A10]}$$

This equation is similar to equation [13] for A=11, which it is satisfied by hypothesis.

Proof of Proposition 5. The proof is similar to that of Proposition 4.

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Resumen

En este trabajo se explica el uso de compromisos unilaterales por parte de las empresas participantes en un Proyecto de Investigación Conjunta (PIC) como un intento de seleccionar el equilibrio eficiente cuando existan múltiples equilibrios. En un modelo con información asimétrica e incertidumbre, se muestra que el uso del compromiso unilateral por parte de una empresa a revelar know-how a sus socios puede ser efectivo para inducir un comportamiento cooperativo sólo si sus tecnologías son complementarias, su capacidad de absorción no es muy elevada y para valores intermedios de la innovación. La complementariedad de los socios también facilita la estabilidad en los PIC.

Palabras clave: Proyectos de investigación conjunta, compromisos unilaterales, riesgo moral, Know-How.

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