

# INFLUENCE ACTIVITY AND THE ORGANIZATION OF RESEARCH AND DEVELOPMENT<sup>1</sup>

by

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## Abstract

The organizational design of research and development conditions the incentives of the researchers of the research project. In particular, the organizational form determines the allocation of effort of the researcher between time spent on research and time spent lobbying management. Researchers prefer to spend their time on research. However, the researchers only get utility from performing research if the project is approved for its full duration. Spending time lobbying management for the continuation of the researcher's project increases the probability that the management observes a favorable signal about the project. Organizing a research joint venture increases the flexibility of the organizational form with respect to the continuation decision. For low correlation between the signals of the partners about the expected profitability of the project, we find that the organization of a research joint venture reduces influence activity by the researchers and increases expected profits of the partners. For high correlation between the signals, internal research projects lower influence activity by the researchers. We try to relate the correlation of the partners signals to the characteristics of basic research versus more applied research projects, and find that the model is consistent with the observation that research joint ventures seem involved in more basic research projects compared to internal R&D departments, which concentrate on more applied research.

*Keywords:* Research joint ventures; Influence activity; Signal jamming; Incomplete contracts

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## **Introduction**

In the literature the term research and development covers a wide range of activities from basic or fundamental research all the way to the actual development of a product or process to market strength (Nason (1981)). In economic modeling the type of research that is performed is never explicitly taken into account. However, the characteristics of the research project can be crucial in explaining the occurrence of different organizational forms with respect to research and development, in particular whether a firm decides to cooperate in research and development or prefers to develop a project as an internal R&D project. This paper analyzes the relation between the organizational structure of research and development, its effect on the researchers' incentives, and the characteristics of the research project that is performed.

The objective of the firm is to choose the organizational structure to maximize the expected profits of the research project. Typically, the research project involves several stages. After each stage, the results and progress of the research project are evaluated. At each of these stages, management has to decide whether the project still corresponds to the strategic objectives of the firm, and if so, the project is continued and new funds are allocated. The researchers usually care strongly about their research project and its continuation. This leads the researchers to try to influence this decision by the management in favor of continuing the project, regardless of the value of the project to the firm. These influence activities or organizational politics have been documented to be important activities within an organization (see Schilit and Locke (1982), Howell and Higgins (1990), Prasad and Rubenstein (1992), Gresov and Stephens (1993)). The time that researchers spend lobbying management, is time that the researchers do not devote to productive activities. Hence, the optimal organizational design needs to take into account its effect on the researchers' incentives to engage in influence activity, given that influence activity affects the expected profitability of the project (Milgrom (1988), Milgrom and Roberts (1991)).

In order to analyze this relation between organizational structure, researchers' incentives to engage in influence activity, and the project characteristics, we develop a stylized model of a research joint venture and an internal research project. In this model an individual firm is indifferent between organizing a research joint venture and setting up an internal research project when the researcher wastes no effort in lobbying management. We concentrate on one important reason for firms to set up research joint ventures: flexibility (Kogut (1991)), and abstract from the cost sharing aspect of joint ventures, because it clouds the other issues: obviously, all else equal (assuming that benefits stay the same) a joint venture where firms split costs is more attractive than an internal R&D project where one firm bears all the costs. The fact that joint ventures increase flexibility and the effect this increased flexibility has on the internal workings of the joint venture is less clear. We suggest that increased flexibility affects the allocation of the researcher's effort between productive and unproductive activities. In the literature the greater flexibility of joint ventures has often been mistaken for instability of joint ventures (Gomes-Casseres (1987)). Our joint venture model is more in line with Kogut (1991), where he describes the joint venture as a "real" option to expand. The timing of this expansion, which is associated with the acquisition of the joint venture by one of the partners, is related to a signal about the value of the venture. In our model, the firms receive a signal about the expected profitability of the project for their firm. The project can either be highly profitable for the firm (high signal) or worthless (low signal). These signals are assumed to be observable but not verifiable. The project is assumed to be profitable whenever at least one firm gets a high signal. The flexibility of the joint venture is related to the fact that the project can be profitable for one firm and not for the other. In this case, the project should be continued by the firm for which the project is expected to be profitable. This results in a higher flexibility of the joint venture with respect to the continuation decision compared to an internal R&D project.

The results of the model are driven by the following observation: the only option for the internal R&D project after a low signal is to liquidate the project, while in the research joint venture, there is the option to renegotiate control over the project. In the internal R&D project, there is no partner to observe a signal about the profitability of the project. Other firms are unable to value this project. This is consistent with the results of Gomeres-Casseres (1987) who finds that subsidiaries of multinational firms are more likely to liquidate compared to joint ventures. Joint ventures are more likely subject to renegotiation of control and ownership structures (Blodgett (1992)). The flexibility of the research joint venture and the allocation of control over the research project are thus interrelated. Renegotiation of control over the research project takes place in the research joint venture whenever the partner in control gets a low signal, while the other partner observes a high signal. Ownership and control are positively correlated but not necessarily perfectly (Geringer and Herbert (1989)). Ownership conveys the following residual rights (in the sense of Grossman and Hart (1986)) to the party not in control:

- veto right in important operating decisions,
- right of first refusal to buy out the other partner.<sup>2</sup>

Ownership thus creates an option on the future (Kogut (1983)), or, more appropriately in this model, an option on control over the research project. In an internal R&D project, on the other hand, ownership and control coincide and can not be separated. Ex post the research joint venture, thus, provides the instruments to separate ownership and control, a fact that we associate with the flexibility of the research joint venture. In that respect, this paper is related to Zender (1991) and Aghion and Bolton (1992). These authors view debt as an optimal mechanism for the contingent allocation of control. In our model, the research joint venture serves a similar purpose for the contingent allocation of control over a research project.

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<sup>2</sup> Usually, one partner will set the price of shares and the other has the option to buy that partner's shares or sell his own shares to the partner for that price.

As stated before, we have set up the model such that if there is no influence activity by the researchers, the firm is indifferent between organizing an internal R&D project or a research joint venture. This implies that any preference over whether to organize a research joint venture or an internal R&D project, is solely due to the existence of influence activity on the part of the researchers. Our main result in the paper states that whether or not the researcher spends more time influencing the continuation decision in the internal R&D project compared to the research joint venture, depends on the correlation between the signals of the potential partners. If the signals of potential partners are highly correlated, the researcher in the research joint venture spends more time influencing the continuation decision, because she can only guarantee continuation if both signals are high. This requires more lobbying effort. If the signals are not highly correlated, the researcher can assure continuation in the research joint venture whenever one of the signals is high. In the internal R&D project, the project is continued whenever the firm observes the high signal. Note that the firm in the internal R&D project cannot condition the continuation policy on the signal of the potential partner. That signal is not observable, given that the other firm did not commit to the partnership. The choice of the organizational design thus implies a choice over information structures. The information set in the internal R&D project is coarser than in the research joint venture. If the correlation is low, the finer information structure in the research joint venture lowers the influence activities of the researcher compared to the internal R&D project. If correlation is high, this result is reversed, where the coarser information structure of the internal R&D project reduces influence activity compared to the finer information structure of the research joint venture. Cremer (1995) finds a similar result, where the principal needs to decide on his monitoring technology. In his model a better monitoring technology can hurt the principal, because it increases the cost of commitment not to renegotiate with the agent. Note that in the absence of influence activities, the firm is indifferent about the information structure.

A natural second question is which organizational structure dominates in terms of expected profits: the research joint venture or the internal R&D project. Again, the answer depends on the correlation between the signals of the partners in the research joint venture. If the correlation between the signals is low, we find that the research joint venture always dominates the internal R&D project. However, when correlation is high, the results are ambiguous. We show that there exist cases where the internal R&D project dominates the research joint venture. This result is interesting, because in the research joint venture, the firms have better information to make a continuation decision. However, having better information can hurt the firm. In that case, the internal R&D project, where the firm limits its information set, dominates the research joint venture. In an example, we show that for high levels of correlation, it is possible that the research joint venture dominates the internal R&D project.

Next, we try to relate the model and its results to the statement that research joint ventures tend to perform more basic research projects compared to internal R&D projects. This statement is not uncommon in the popular literature on research and development. In their study of the VLSI project, Collins and Doorley (1990) find that “there was a clear split between fundamental research carried out within the joint laboratories and more applied work undertaken with the companies themselves.” One of the explanations for this observation is the fact that basic research is thought to be less appropriable than development. As a result, firms form research joint ventures in order to internalize this externality while concentrating internal R&D efforts on the more appropriable results of applied research. Although the appropriability argument seems to explain this observation, it does not account for the organizational design of the research joint venture. In order to solve this externality, firms need to be able to contract on the inputs and share in the costs of the project to realize it. The model in this paper does not rely on the sharing of costs.

In order to relate the organizational design of research and development to the nature of the research project, we pinpoint two characteristics of more basic research projects. First, the benefits of basic research projects are less likely to be correlated between the partners in the research project, because these projects are more likely to come up with unexpected results. Secondly, the results of more basic research projects still need to be incorporated into new products and processes. As a result, we expect that the eventual benefits from basic research projects are less likely to be competitive between partners. The results of the model indicate that if the correlation between the signals of the partners is low, and if future profits are not likely to be competitive, the organization of a research joint venture dominates organizing the project internally. Given the characteristics of more basic research projects, we thus find that these projects are more likely to be organized in a research joint venture. Organizing a more basic research project internally, creates more influence activity than when organized in a research joint venture.

The remainder of the paper is organized as follows: in the next section we develop the model. Section 3 derives the equilibrium of the model and analyzes the results of the model. We illustrate the results of the model by way of an example in Section 4. Finally, we conclude in Section 5 with a discussion and some possible extensions of the model.

### **Model**

Consider two firms, firm x and firm y, that each have a single line of business. For the time being we assume that firm x cannot or does not want to replicate firm y's line of business internally. Firm x is considering one R&D project and can decide to do this R&D project jointly with firm y by forming a research joint venture (RJV) or firm x can do the project internally (IRD). We concentrate on firm x's decision and assume that the control rights over the project are allocated to firm x at the start of the project, but can be renegotiated during the game in the research joint



venture.<sup>3</sup> The firm which has control rights over the project pays all the costs of the R&D project. This allows us to focus attention on other aspects of organizing a research joint venture than cost sharing and ownership.<sup>4</sup> We will discuss the implications of these assumptions and relax them later on. Each partner in the research project needs to sink an amount  $\varepsilon$  into setting up the project, where  $\varepsilon$  is “small”. This can be considered as an initial investment for starting up the project.

The project employs one researcher or one team of researchers. This researcher engages in preliminary research on the project. However, knowing that the project still needs to pass a final evaluation, the researcher devotes time both to preliminary research and lobbying activities. The lobbying activities are intended to influence management into continuing the research project. The researcher thus allocates her time,  $T$ , between influence activities,  $i$ , and research,  $t$ , on the project. The actual allocation of the researcher's time is not observed by the management, implying that the researcher cannot be rewarded for spending more time on research and less on lobbying management. This assumption seems reasonable, given that finding appropriate measures for evaluating research personnel in reality, is always problematic (Brown and Gobeli (1992)).

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<sup>3</sup> Having control rights over the project allows that party to intervene during the project and take actions that are not contractible, but increase the value of the project to that firm. The only rights that ownership conveys on the party that does not have control is a veto right to certain actions and certain rights when the partnership is dissolved. We will not explicitly model any decision over these non-contractible actions, but we assume that each firm weakly prefers to have control over the project. See Aghion and Bolton (1992) for an explicit model.

<sup>4</sup> We assume that firm  $x$  cannot sell the right to join the RJV to firm  $y$  to extract the value of the RJV to firm  $y$  and create any intrinsic value of the RJV over the IRD. Alternatively we could assume that the expected NPV of the project to firm  $y$  (and firm  $x$  under symmetry) is zero. Ownership in a research joint venture is often determined by the initial investment. In the model, we concentrate on the continuation decision of the project. The initial investment is sunk at that time.

The decision of the management whether or not to continue the research project, depends on the expected profitability of the project. The final evaluation of the project is based on a signal,  $s$ , that the management receives about the expected profitability of the project for that firm. If the project is set up as a RJV between firm  $x$  and firm  $y$ , we allow for renegotiation of the control (and ownership) of the project between the partners after the signal is observed. In equilibrium the signal is a perfect predictor of the researcher's allocation of time to research effort. To avoid a simplistic contract where the researcher is rewarded based on the signal, we assume that the signal is not verifiable by a third party. After the signals have been observed and renegotiation has taken place, the firm that has control over the project needs to decide whether or not to continue the project and sink another amount of capital,  $F$ , into the research project for its actual development. Finally, the payoffs are realized.

The timing of the game is summarized in Figure 1:

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|                                     |   |                             |                             |                               |                     |
|-------------------------------------|---|-----------------------------|-----------------------------|-------------------------------|---------------------|
| Organizational Design<br>IRD or RJV | Researcher<br>Allocates Time<br>$T = t + I$ | Firms receive<br>Signal $s$ | Renegotiation<br>of Control | Continuation<br>decision made | Payoffs<br>realized |
|-------------------------------------|---|-----------------------------|-----------------------------|-------------------------------|---------------------|

In order to describe the payoffs, we need to put some more structure on the model. The researcher has limited time to allocate over lobbying management for the continuation of the project and working on the research project. If the researcher spends  $i$  time on influence activity, then there is only  $T-i$  time left to do research. The researcher realizes private benefits from performing research if the project is continued past the evaluation stage.<sup>5</sup> The rationale for this assumption is that the researcher anticipates that once the funds are committed by the management, the researcher can enjoy performing the actual research after having made a

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<sup>5</sup> Because these benefits are not transferable, influence activity and the distribution of rents become an important issue (Milgrom and Roberts (1992)).

specific investment in this project. If the project is not continued, the researcher will need to find a new project and go through the whole evaluation stage again, i.e. making a new specific investment. We assume that the private benefits that accrue to the researcher from doing research, conditional on the continuation of the project, are increasing in the amount of time devoted to research,  $b(T-i)$ . To make the model tractable, we assume that the private benefits of the researcher are linear in the time devoted to preliminary research:  $b(T-i) = T-i$ . The researcher spends all her available time on research or lobbying, given that she is not averse to spending effort. However, lobbying is costly to the researcher because of the opportunity cost of lobbying time. We assume that the researcher is employed by the firm at a fixed wage (which we normalize to zero) and that she is not remunerated on a project by project basis. This could be due to the fact that some tasks that the researcher performs (such as doing “research”) are hard to measure. As a result, it is optimal to pay the researcher a flat wage (see Holmstrom and Milgrom (1991)). Alternatively we could assume that the researcher is infinitely risk averse and can not be motivated by a monetary transfer from the firm (Aghion and Tirole (1997)).<sup>6</sup>

The payoffs of the firms depend on their signal about the expected profitability of the project. Firm  $i$  can get one of two signals,  $s_i$ , about the expected profitability of the project: a high signal (1) or a low signal (0),  $s_i \in \{0,1\}$ . The prior marginal probability without influence activity is  $P(s_i = 1) = 1/2$ . Organizing a research joint venture implies bringing in another firm. The informational implication of this organization is that both firms get a signal about the profitability of the project to their firm. We define a state of nature,  $k$ , when organizing a IRD as  $k \in S^{IRD} = \{s_x \mid s_x \in \{0, 1\}\} = \{0, 1\}$ , while when organizing a RJV as  $k \in S^{RJV} = \{(s_x, s_y) \mid s_x,$

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<sup>6</sup> Given that the allocation of effort by the researcher is unobservable and given his specific investment into the project, the researcher always has an incentive to influence the signal if not fully compensated for the expected rents related to this investment. This compensation, however, might introduce other distortions in the effort choice of the researcher, especially if the researcher could also influence the signal in the negative direction.

$s_y \in \{0, 1\} = \{(1, 1), (1, 0), (0, 1), (0, 0)\}$ . The signals are usually not perfectly correlated. Note that these signals are not draws from the same distribution on the profitability of the project. Each firm has a specific line of business and the profitability of the project is related to their line of business. The joint distribution of the signals in the research joint venture is represented in the following table where  $w = \frac{I + r}{2}$  and  $\rho$  is the correlation between the signals of the firms.<sup>7,8</sup>

|        |           |                   |                   |
|--------|-----------|-------------------|-------------------|
|        |           | Firm y            |                   |
|        |           | $s_y = 0$         | $s_y = 1$         |
| Firm x | $s_x = 0$ | $\frac{w}{2}$     | $\frac{I - w}{2}$ |
|        | $s_x = 1$ | $\frac{I - w}{2}$ | $\frac{w}{2}$     |

The expected profits of firm x for the IRD, conditional on continuing the project,  $s_x p_x(t)$ , depend on the pure research effort of the researcher,  $t = T-i$ , and the signal the firm received. The signal measures the match of the project with the current or future business

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<sup>7</sup> Note that we could consider the choice of the IRD versus the RJV as a choice over information structures. In the IRD, the set of partitions of the information structure are  $P = \{\{(1, 1), (1, 0)\}, \{(0, 1), (0, 0)\}\}$ . Firm x only observes whether its signal is high or low. In the RJV the set of partitions of the information structure is  $P = \{\{(1, 1)\}, \{(1, 0)\}, \{(0, 1)\}, \{(0, 0)\}\}$ . The choice of the IRD over the RJV implies the commitment to a coarser evaluation structure.

<sup>8</sup> The model could be extended to a continuum of signals for an individual firm. The intuition derived from this discrete model would not be changed. However, a model with a continuum of signals does not allow us to separate the issues of cost sharing and flexibility as transparently as in the discrete model. Also, the modeling of the effects of influence activity by the researcher would be more involved.

prospects for the firm, while  $p_x(t)$  measures the potential of this research idea as a function of research effort. The profits of firm  $x$  organizing a RJV are  $r(s_x, s_y) s_x p_x(t)$ , where  $r(1, 1) = \gamma$  and  $r(1, 0) = r(0, 1) = r(0, 0) = 1$ . One of the costs of engaging in cooperative R&D is the possibility that proprietary know-how is leaked to the partner and that through the cooperative venture a new future competitor is created (Contractor and Lorange (1988)). In this case  $\gamma$  is less than one, implying that firm  $x$  loses some of its expected future profits through the cooperative venture. On the other hand, partners in a cooperative agreement can bring in complementary resources and create synergies, which increase the expected future profits for any partner. In this case  $\gamma$  is larger than one. However, we will restrict attention to the case where  $\gamma \leq 1$ , given that it is obvious that the RJV becomes more attractive when the firms create some form of synergies in the RJV, which cannot be achieved by the IRD. We make the following assumptions on the payoffs:

Assumption 1:

$$1.1 \quad \forall 0 \leq t \leq T: \frac{g p_x(t)}{2} > F + e$$

$$1.2 \quad \pi_x(t) \text{ is increasing and continuous in } t.$$

Assumption 1.1 guarantees that it is individually rational to consider the project ex ante for any amount of influence activity by the researcher. Implicitly this puts a lower bound on  $\gamma$  and eliminates cases where the IRD is ex ante profitable, while the RJV is not. This assumption also implies that some time must be spent on research, so  $T$  does not include all the available time to the researcher, some of the researcher's time will be spent on research without question. Given Assumption 1.1, we can restrict attention to the effect of influence activity on the continuation policy. Assumption 1.2 indicates that the expected profits of the project are non-decreasing in the time spent by the researcher on preliminary research. The profits of firm  $y$  are symmetric. In the remainder of the paper we focus on the decision of firm  $x$  and drop the firm subscripts when no confusion is possible.

We assume that the profits are not contractible ex ante. Contractibility in this simple setting would imply that the firm can infer the amount of influence activity from the realization of the payoffs and force the optimal amount of influence activity (zero). This assumption could be avoided by constructing a more involved model, without adding any insights to the results of the paper. We think that it is reasonable to assume that for R&D projects, future profits are not likely to be contractible (Aghion and Tirole (1994)).

A first result provides a useful benchmark for the rest of the analysis. This proposition also enlightens the set up of the model, where we want to focus attention on the relation between organizational design and influence activity by the researcher while eliminating other possible effects in the model.

Proposition 1: If there is no influence by the researcher,  $i = 0$ , and if individual firm profits are the same under both organizational forms,  $\gamma = 1$ , firm  $x$  is indifferent between organizing the project as an internal R&D project or as a research joint venture.

proof: Given the low signal, firm  $x$  gets zero profits. In that case firm  $x$  does not care whether the project is discontinued or if control is given to firm  $y$ , since the firm in control pays full continuation costs and the organization, by assumption, does not influence the researcher's effort allocation.

Next we need to describe how time spent influencing the continuation decision of management, impacts the problem. The researcher wants to avoid the discontinuation of the project. The project is discontinued for sure if the party in control gets the low signal. Influence activity reduces the probability that the low signal is actually observed. Hence, influence activity increases the probability that the management observes the high signal while the true signal is low. Assume that the probability that the firm observes a high signal, while the true state is low, is a function of the time that the researcher spends influencing the decision,  $q(i)$ .

Formally:  $P(\hat{s}_i = 1 | s_i = 0) = q(i)$  where  $\hat{s}$  denotes the signal that management observes and  $s$  denotes the true signal.

To simplify the analysis, we assume that  $P(\hat{s}_i = 1 | s_i = 1) = 1$ . If the true signal is high, management will always observe this. Influence activity only tries to avoid a bad evaluation of the project. This assumption does not affect the main insights of the model. The results continue to hold provided that influence activity increases the probability of observing the high signal relative to when no influence is exerted.

We make the following assumptions about the influence function:

Assumption 2:

- 2.1  $q(i)$  is increasing, concave and twice continuously differentiable in  $i$ ,
- 2.2  $q(0) = 0$ ,  $q(T) = 1$  and  $q'(0) = \infty$ ,
- 2.3  $\forall 0 \leq i \leq T: \frac{1 - q(i)}{q(i)} \leq (T - i)q'(i)$

If there is no influence activity by the researcher, then the probability that management observes the high signal while the true signal is low, is zero. By engaging in influence activity, the researcher can increase the probability that management observes the high signal while the true signal is low. As noted above, we assume that if the true signal is high, it will always be revealed as high. Assumption 2.3 is a condition on the likelihood ratio of observing high versus low when the true signal is low. Influence activity needs to be sufficiently successful in changing the observed signal from the true signal when the true signal is low. In the example section, we identify a class of functions that satisfy this assumption.

In the research joint venture we assume that influence activity works independently on both the signals of firm  $x$  and firm  $y$ . It is then straightforward to extend the effect of influence activity to the case of the research joint venture. The researcher concentrates on avoiding a low signal.

If both true signals are low, the signal observed by management has the following properties:

$$P(\hat{s}_x = 1, \hat{s}_y = 1 | s_x = 0, s_y = 0; i, w) = q(i)^2$$

$$P(\hat{s}_x = 1, \hat{s}_y = 0 | s_x = 0, s_y = 0; i, w) = P(\hat{s}_x = 1, \hat{s}_y = 0 | s_x = 0, s_y = 0; i, w) = q(i)(1 - q(i))$$

$$P(\hat{s}_x = 0, \hat{s}_y = 0 | s_x = 0, s_y = 0; i, w) = (1 - q(i))^2$$

If one of the true signals is high while the other is low, the signal observed has the following properties:

$$P(\hat{s}_x = 1, \hat{s}_y = 1 | s_x = 1, s_y = 0; i, w) = P(\hat{s}_x = 1, \hat{s}_y = 1 | s_x = 0, s_y = 1; i, w) = q(i)$$

$$P(\hat{s}_x = 0, \hat{s}_y = 1 | s_x = 0, s_y = 1; i, w) = P(\hat{s}_x = 1, \hat{s}_y = 0 | s_x = 1, s_y = 0; i, w) = 1 - q(i)$$

If both true signals are high, this is always observed by management:

$$P(\hat{s}_x = 1, \hat{s}_y = 1 | s_x = 1, s_y = 1; i, w) = 1$$

Given a level of influence  $i$  and correlation  $w$ , this leads to the following joint distribution of the observed signals:

|        |                 | Firm y   |   |
|--------|-----------------|--|---|
|        |                 | $\hat{s}_y = 0$  | $\hat{s}_y = 1$   |
| Firm x | $\hat{s}_x = 0$ | $\frac{w}{2} - q(i)^2 \frac{w}{2} - 2q(i) \left(1 - q(i) \frac{w}{2}\right)$ | $\frac{1 - w}{2} + q(i)(1 - q(i)) \frac{w}{2} - q(i) \frac{1 - w}{2}$ |
|        | $\hat{s}_x = 1$ | $\frac{1 - w}{2} + q(i)(1 - q(i)) \frac{w}{2} - q(i) \frac{1 - w}{2}$        | $\frac{w}{2} + q(i)^2 \frac{w}{2} + 2q(i) \frac{1 - w}{2}$            |

Influence activity affects the marginal distribution of the observed signal in the following way:

$$P(\hat{s}_i = 0) = \frac{1}{2} - \frac{q(i)}{2} \quad \text{and} \quad P(\hat{s}_i = 1) = \frac{1}{2} + \frac{q(i)}{2}.$$

We assume that the researcher has no private information about the true signal. This



simplifies the analysis considerably and classifies this model as a signal jamming model (Fudenberg and Tirole (1986)). Given that the signal reveals something about the business opportunities of the project, it seems reasonable to assume that the researcher has no hidden information. The only private information in the model is a hidden action by the researcher namely the allocation of the researcher's time between influence and research activity (see also Milgrom (1988)).

To describe the expected profits of the firms, we need to introduce some more notation.

Definition 1: Define  $\mu(k | \hat{s}; i)$  as the beliefs of the firm that the true state of nature is  $k$  after observing  $\hat{s}$  when the researcher spends  $i$  time on influence activity where  $k$ ,  $\hat{s} \in S^{\text{IRD}}$  when organizing the project internally or  $k$ ,  $\hat{s} \in S^{\text{RJV}}$  when organizing a joint venture.

Definition 2: Define  $\lambda(\hat{s}; i)$  as the probability that state  $\hat{s}$  is observed when the influence level is  $i$ , where  $\hat{s} \in S^{\text{IRD}}$  when organizing the project internally or  $\hat{s} \in S^{\text{RJV}}$  when organizing a joint venture.

Note that  $\lambda(\hat{s}_x = 1; 0) = \lambda(\hat{s}_x = 0; 0) = 1/2$  and  $\lambda(\hat{s}_x = 1, \hat{s}_y = 1; 0) = \lambda(\hat{s}_x = 0, \hat{s}_y = 0; 0) = w/2$ .

Definition 3: A *Continuation Policy* is a function

$$d^j : S^j \rightarrow \{0, 1\}$$

where  $d^j(s) = 1$ , implies that the project is continued after signal  $s$  is observed and where  $d^j(s) = 0$ , implies that the project is discontinued after signal  $s$  is observed and  $j \in \{\text{IRD}, \text{RJV}\}$ .

Let  $\Pi_x^{\text{IRD}}(t, i, \hat{s})$  be the expected profits of firm  $x$  in the IRD, given research effort  $t$ , influence level  $i$ , and when signal  $\hat{s}$  is observed, conditional on continuation of the project:

$$\Pi_x^{\text{IRD}}(t, i, \hat{s}) = \mu(s_x = 1 \mid \hat{s}; i) \pi(t) - F.$$

Similarly,  $\Pi_x^{\text{RJV}}(t, i, \hat{s})$  defines the expected profits of firm x in the RJV, given research effort t, influence level i, and observing signal  $\hat{s}$ , conditional on continuation:

$$\Pi_x^{\text{RJV}}(t, i, \hat{s}) = \mu(s_x = 1, s_y = 1 \mid \hat{s}; i) \gamma \pi(t) + \mu(s_x = 1, s_y = 0 \mid \hat{s}; i) \pi(t) - F.$$

Let  $V_x^{\text{IRD}}(d^{\text{IRD}}, i)$ , be the expected profits of firm x in the IRD with continuation policy  $d^{\text{IRD}}$  and influence level i:

$$V_x^{\text{IRD}}(d^{\text{IRD}}, i) = d^{\text{IRD}}(\hat{s}_x = 1) \Pi_x^{\text{IRD}}(t, i, \hat{s}_x = 1) + d^{\text{IRD}}(\hat{s}_x = 0) \Pi_x^{\text{IRD}}(t, i, \hat{s}_x = 0).$$

Let  $V_x^{\text{RJV}}(d^{\text{RJV}}, i)$ , be the expected profits of firm x in the RJV with continuation policy d and influence level i:

$$\begin{aligned} V_x^{\text{RJV}}(d^{\text{RJV}}, i) &= d^{\text{RJV}}(\hat{s}_x = 1, \hat{s}_y = 1) \Pi_x^{\text{RJV}}(t, i, \hat{s}_x = 1, \hat{s}_y = 1) \\ &\quad + d^{\text{RJV}}(\hat{s}_x = 1, \hat{s}_y = 0) \Pi_x^{\text{RJV}}(t, i, \hat{s}_x = 1, \hat{s}_y = 0). \end{aligned}$$

The expected profits of firm y are similarly defined.

We can state a second intuitive result. The proof of this proposition points to the sources of inefficiency of influence activity:

**Proposition 2:** Any positive amount of influence activity,  $i > 0$ , reduces the firm's expected profits.

**Proof:** If there is no influence activity ( $i=0$ ), the expected profits of firm x are:

$$\lambda(\hat{s}_x = 1; 0) [\pi(T) - F].$$

If  $\gamma = 1$ , the firm is indifferent whether an IRD or a RJV is organized (Proposition 1).

**1. Compare to IRD with influence activity.**

The expected profits in the IRD are:  $\lambda(\hat{s}_x = 1; i) [\mu(s_x = 1 \mid \hat{s}_x = 1; i) \pi(t) - F]$ , where  $i > 0$ .

From Bayes rule we know that:  $\mu(s_x = 1 \mid \hat{s}_x = 1; i) = \frac{l(\hat{s}_x = 1; 0)}{l(\hat{s}_x = 1; i)}$

The difference between the profits of the IRD with and without influence activity is:

$$\Delta = l(\hat{s}_x = 1; 0)[p(T) - p(t)] + [l(\hat{s}_x = 1; i) - l(\hat{s}_x = 1; 0)]F$$

Given that  $i > 0$ ,  $T > t$  and  $\lambda(\hat{s}_x = 1; i) \geq \lambda(\hat{s}_x = 1; 0)$ . Profits are strictly increasing in  $t$ . This implies that this difference is strictly positive. The inefficiency of influence activity in the IRD derives from two sources. First, spending time lobbying, is time not spent doing research which increases the expected profitability of the project. Secondly, influence activity leads to continuing the project, when in fact the project is valueless to the firm. The firm loses its investment,  $F$ , in that case.

## 2. Compare to RJV with influence activity.

We need to discuss two cases, depending on the continuation policy in the RJV. In a later Proposition we will show that these are the only relevant cases.

$$\begin{aligned} \text{Case a: } d^{\text{RJV}}(\hat{s}_x = 1, \hat{s}_y = 1) &= d^{\text{RJV}}(\hat{s}_x = 0, \hat{s}_y = 1) \\ &= d^{\text{RJV}}(\hat{s}_x = 1, \hat{s}_y = 0) = 1; d^{\text{RJV}}(\hat{s}_x = 0, \hat{s}_y = 0) = 0. \end{aligned}$$

After some manipulation (using Bayes rule), we find that the difference in profits because of influence activity is:

$$\begin{aligned} \Delta &\geq l(\hat{s}_x = 1, \hat{s}_y = 1; 0)g[p(T) - p(t)] + l(\hat{s}_x = 1, \hat{s}_y = 0; 0)[p(T) - p(t)] \\ &+ [l(\hat{s}_x = 1, \hat{s}_y = 1; i) + l(\hat{s}_x = 1, \hat{s}_y = 0; i) - l(\hat{s}_x = 1, \hat{s}_y = 1; 0) - l(\hat{s}_x = 1, \hat{s}_y = 0; 0)]F \end{aligned}$$

Note that the last term is nonnegative. This term indicates the cost of influence activity, because it specifies the expected cost of continuing the project, while in reality the firm has no profit to gain from the continuation. The first two terms are losses due to time spent influencing the decision, instead of doing research. This is very similar to the case of the IRD.

$$\begin{aligned} \text{Case b: } d^{\text{RJV}}(\hat{s}_x = 1, \hat{s}_y = 1) &= 1; d^{\text{RJV}}(\hat{s}_x = 0, \hat{s}_y = 1) \\ &= d^{\text{RJV}}(\hat{s}_x = 1, \hat{s}_y = 0) = d^{\text{RJV}}(\hat{s}_x = 0, \hat{s}_y = 0) = 0. \end{aligned}$$

The difference in profits due to influence activity is:

$$\begin{aligned} \Delta &= l(\hat{s}_x = 1, \hat{s}_y = 1; 0)g[p(T) - p(t)] + l(\hat{s}_x = 1, \hat{s}_y = 0; 0)[p(T) - p(t)] \\ &+ [l(\hat{s}_x = 1, \hat{s}_y = 1; i) + l(\hat{s}_x = 1, \hat{s}_y = 0; i) - l(\hat{s}_x = 1, \hat{s}_y = 1; 0) - l(\hat{s}_x = 1, \hat{s}_y = 0; 0)]F \\ &+ \pi(s_x = 1, s_y = 0 / \hat{s}_x = 1, \hat{s}_y = 0; i) | (\hat{s}_x = 1, \hat{s}_y = 0; i) p(t) \end{aligned}$$

Note that this difference is non-negative. In this case there are three sources of inefficiencies of influence activity. First, there is less time to do research. Second, there is a cost of continuing the project while it is not worthwhile for the firm to do so, given the true signal. These inefficiencies are similar to the previous cases. A third inefficiency comes from the fact that the decision rule is not optimal. The third term shows the loss due to a non optimal continuation rule. It would be profitable to the firm to continue the project when  $(\hat{s}_x = 1, \hat{s}_y = 0)$  is observed and the true signal is  $(s_x = 1, s_y = 0)$ .

For all cases we have shown that influence activity is costly to the firms.

One corollary of Proposition 2 is that, everything else equal, the firms prefer less influence activity to more within the same organizational form. We are now ready to analyze the equilibrium of this model of imperfect information.

## Equilibrium

The equilibrium concept used is Perfect Bayesian Equilibrium. In the first two subsections we solve for the equilibrium in the subgames where the firm organizes an IRD project or a RJV. We compare the equilibrium outcomes for these subgames in subsection 3.

### 1. The Internal R&D Project

A Perfect Bayesian Equilibrium of this subgame is a triplet  $(i^*, d^*(\cdot), \mu^*(\cdot))$  where the following three conditions are satisfied:

1.  $i^*$  maximizes  $(T - i) [d^*(\hat{s}_x = 1) | (\hat{s}_x = 1; i) + d^*(\hat{s}_x = 0) | (\hat{s}_x = 0; i)]$
2.  $d^*$  satisfies  $V_x^{\text{IRD}}(d^*, i^*) \geq V_x^{\text{IRD}}(d, i^*)$ ,  $\forall d$ :  $d$  is a *Continuation Policy* for the IRD.
3.  $\mu^*(k | s; i^*)$  satisfies  $\mu(k | s; i^*) \geq 0 \forall k \in \{0, 1\}$  and  $\mu(s_x = 1 | s; i^*) + \mu(s_x = 0 | s; i^*) = 1$ . These beliefs of the firms are derived from Bayes Rule where possible.

Following Bayes rule, the firms beliefs are:

$$\pi_{s_x = 1 | \hat{s}_x = 1; i} = \frac{I}{I + q(i)}, \quad \pi_{s_x = 0 | \hat{s}_x = 1; i} = \frac{q(i)}{I + q(i)}.$$

If the firm observes the high signal, the firm continues the project whenever:  $\Pi_x^{\text{IRD}}(t, i, s_x = 1) \geq 0$ .

If Assumption 1 holds, the firm decides to always continue when the observed signal is high.

Assumption 1 guarantees a dominant strategy for the firm in the internal R&D project.

Obviously, if the signal is low, the firm knows the project is junk and will discontinue it. The optimal continuation strategy of the firm in an IRD is:<sup>9</sup>

$$d^*(\hat{s}_x = 1) = 1, d^*(\hat{s}_x = 0) = 0$$

The optimal influence effort by the researcher, taking into account the dominant strategy of the firm, maximizes:

$$(T-i) | (\hat{s}_x = 1; i) = (T-i) \frac{1 + q(i)}{2}$$

$$\text{foc: } (T-i)q'(i) - (1 + q(i)) = 0$$

Note that Assumption 2 guarantees a unique interior solution to the researcher's problem.

## 2. The Research Joint Venture

A Perfect Bayesian Equilibrium of this subgame is a triplet  $(i^*, d^*(\cdot), \mu^*(\cdot))$  where

1.  $i^*$  maximizes

$$(T-i) \left[ d^*(\hat{s}_x = 1, \hat{s}_y = 1) | (\hat{s}_x = 1, \hat{s}_y = 1; i) + d^*(\hat{s}_x = 1, \hat{s}_y = 0) | (\hat{s}_x = 1, \hat{s}_y = 0; i) \right. \\ \left. + d^*(\hat{s}_x = 0, \hat{s}_y = 1) | (\hat{s}_x = 0, \hat{s}_y = 1; i) + d^*(\hat{s}_x = 0, \hat{s}_y = 0) | (\hat{s}_x = 0, \hat{s}_y = 0; i) \right]$$

2.  $d^*$  satisfies  $V_x^{\text{RJV}}(d^*, i^*) + V_y^{\text{RJV}}(d^*, i^*) \geq V_x^{\text{RJV}}(d, i^*) + V_y^{\text{RJV}}(d, i^*)$ ,

$\forall d$ :  $d$  is a *Continuation Policy* for the RJV.

3.  $\mu^*(k | s; i^*)$  satisfies  $\mu(k | s; i^*) \geq 0 \forall k \in \{(0, 0), (0, 1), (1, 0), (1, 1)\}$  and

$$\mu(s_x = 1, s_y = 1 | s; i^*) + \mu(s_x = 1, s_y = 0 | s; i^*) + \mu(s_x = 0, s_y = 1 | s; i^*) + \mu(s_x = 0, s_y = 0 | s; i^*) = 1$$

1. These beliefs of the firms are derived from Bayes Rule where possible.

Before the continuation policy is implemented, we allow for renegotiation of the ownership and control. As such, the continuation policy maximizes the joint profits of the RJV. If

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<sup>9</sup> We need to check that the firm does not want to commit to continue the project when the signal is low. The firm could just disregard the signal and always continue the project. We assume that it is never profitable for the firm to do so. In the extensions we will come back to this assumption.

there is a positive level of influence activity, all information sets are reached in equilibrium and beliefs are formed according to Bayes rule:

- If  $(\hat{s}_x = 1, \hat{s}_y = 1)$  is observed, beliefs are:

$$\mathfrak{m}(s_x = 1, s_y = 1 / \hat{s}_x = 1, \hat{s}_y = 1; i, w) = \frac{w}{2q(i) + w(I - q(i))^2}$$

$$\mathfrak{m}(s_x = 0, s_y = 1 / \hat{s}_x = 1, \hat{s}_y = 1; i, w) = \frac{I - w}{2q(i) + w(I - q(i))^2} = \mathfrak{m}(s_x = 1, s_y = 0 / \hat{s}_x = 1, \hat{s}_y = 1; i, w)$$

$$\mathfrak{m}(s_x = 0, s_y = 0 / \hat{s}_x = 1, \hat{s}_y = 1; i, w) = \frac{wq(i)^2}{2q(i) + w(I - q(i))^2}$$

- If  $(\hat{s}_x = 1, \hat{s}_y = 0)$  or  $(\hat{s}_x = 0, \hat{s}_y = 1)$  is observed, beliefs are:

$$\mathfrak{m}(s_x = 0, s_y = 1 / \hat{s}_x = 0, \hat{s}_y = 1; i, w) = \frac{I - w}{I - w(I - q(i))} = \mathfrak{m}(s_x = 1, s_y = 0 / \hat{s}_x = 1, \hat{s}_y = 0; i, w)$$

$$\mathfrak{m}(s_x = 0, s_y = 0 / \hat{s}_x = 0, \hat{s}_y = 1; i, w) = \frac{q(i)w}{I - w(I - q(i))} = \mathfrak{m}(s_x = 0, s_y = 0 / \hat{s}_x = 1, \hat{s}_y = 0; i, w)$$

- If  $(\hat{s}_x = 0, \hat{s}_y = 0)$  is observed, the firms believe with probability 1, that the true state is  $(s_x = 0, s_y = 0)$ .

Given the firms' beliefs about the true state after observing the signal about their expected profitability, we can derive the optimal continuation policy of the research joint venture:

- If  $(\hat{s}_x = 1, \hat{s}_y = 1)$  is observed, firm x decides to continue the project iff:

$$d^*(\hat{s}_x = 1, \hat{s}_y = 1) = 1 \Leftrightarrow \Pi_x^{\text{RJV}}(t, i, \hat{s}_x = 1, \hat{s}_y = 1) \geq 0.$$

Given Assumption 1, it is easy to check that the optimal continuation policy requires:

$$d^*(\hat{s}_x = 1, \hat{s}_y = 1) = 1 \text{ and } d^*(\hat{s}_x = 0, \hat{s}_y = 0) = 0.$$

- If  $(\hat{s}_x = 1, \hat{s}_y = 0)$  is observed, firm x decides on continuing the project iff:

$$d^*(\hat{s}_x = 1, \hat{s}_y = 0) = 1 \Leftrightarrow \Pi_x^{\text{RJV}}(t, i, \hat{s}_x = 1, \hat{s}_y = 0) \geq 0. \quad (1)$$

Condition (1) holds whenever the firm attributes enough probability to the event that in the true state one firm has a high signal. This condition turns out to be pivotal in the remainder of the analysis.

- If  $(\hat{s}_x = 0, \hat{s}_y = 1)$  is observed, firm x would scrap the project. However, firm y will veto this decision and obtain the control rights in the RJV through renegotiation whenever the symmetric condition to Condition (1) holds for firm y.

Suppose that Condition (1) holds. In this case the optimal continuation policy has:

$$d^*(\hat{s}_x = 1, \hat{s}_y = 1) = d^*(\hat{s}_x = 0, \hat{s}_y = 1) = d^*(\hat{s}_x = 1, \hat{s}_y = 0) = 1; d^*(\hat{s}_x = 0, \hat{s}_y = 0) = 0 \quad (2)$$

The researcher's problem then becomes to maximize:

$$(T - i) \left[ I - (I - q(i))^2 \frac{w}{2} \right]$$

$$\text{foc: } (T - i)(I - q(i))q'(i)w - \left[ I - (I - q(i))^2 \frac{w}{2} \right] = 0$$

Again, Assumption 2 guarantees an interior solution to the researcher's maximization problem.

**Lemma 1:**  $\forall F > 0: \exists w^*: 0 < w^* < 1$  and Condition (1) is violated  $\forall w > w^*$ .

proof:  $w^*$  is defined as  $G(w^*) = \frac{I - w^*}{I - w^*(I - q(i(w^*)))} p(T - i(w^*)) = F$

$G(w)$  is continuous in  $w$ .  $i(w)$  is the optimal influence level of the researcher.

Note that  $G(1) = 0$  and  $G(0) = \pi(T) > F$ .

It is easy to show that  $\frac{dG(w)}{dw} < 0$

This implies that  $\exists w^*: 0 < w^* < 1$ .

Lemma 1 implies that the continuation policy defined in (2) cannot be an equilibrium for all  $w$ . For high levels of correlation between the firms' signals, continuation after observing one high and one low signal is not optimal. For a high level of correlation, the firm attributes a high

conditional probability on both firms having a low signal. As a consequence of influence activity, the firms change their continuation policy. This introduces an inefficiency, created because of influence activity.

We can derive the following comparative static result on  $w^*$ :

**Proposition 3:**  $\frac{dw^*}{dF} < 0$

proof:  $(i^*, w^*)$  solve the following system of equations:

$$(T - i)(1 - q(i))q'(i)w - (1 - (1 - q(i))^2) \frac{w}{2} = 0$$

$$\frac{1 - w}{1 - (1 - q(i))w} p(T - i) = F$$

It is easy to show that if the second order conditions for the researcher's problem hold, that the sign of the determinant of this system is positive. Total differentiation of this system of equations gives that  $\text{sign} \frac{dw^*}{dF} = \text{sign}(soc) < 0$ , where soc is the second order condition for the researcher's optimization problem.

As the cost of continuing the project,  $F$ , increases, Condition (1) will be violated for lower levels of correlation between the signals of the partners. As a result of influence activity, the level of the continuation costs matter.

Whenever  $w > w^*$ , the RJV only continues the R&D project when both signals are observed to be high. In that case the researcher determines her influence effort by maximizing:

$$(T - i) \left[ q(i) + (1 - q(i))^2 \frac{w}{2} \right]$$

$$\text{foc: } (T - i) [q'(i) - (1 - q(i))q'(i)w] - \left[ q(i) + (1 - q(i))^2 \frac{w}{2} \right] = 0$$

Note that at  $w^*$ , the level of influence activity when  $d^{\text{RJV}}(\hat{s}_x = 1, \hat{s}_y = 1) = d^{\text{RJV}}(\hat{s}_x = 0, \hat{s}_y = 1) = d^{\text{RJV}}(\hat{s}_x = 1, \hat{s}_y = 0) = 1$ , is lower than when only  $d^{\text{RJV}}(\hat{s}_x = 1, \hat{s}_y = 1) = 1$ .



This implies that at  $w^*$ , due to Proposition 2, the firms' policy is to continue the project for all signals except when both firms observe a low signal.<sup>10</sup>

As noted in Proposition 2, influence activity can cause several inefficiencies. First, influence activity is costly to the firm because it reduces the research effort by the researcher. Secondly, it worsens decision making because the project is continued when sometimes it is unprofitable to do so. A third inefficiency is created when the correlation of the signals is high. In that case, the firms observing one high and one low signal will be very suspicious about the observation and prefer to discontinue the project, believing that in the true state both signals are low. Influence activity thus forces the firm to change the efficient continuation decision in that case. This is exactly when Condition (1) is violated.

The following comparative statics can be derived on the influence activity of the researcher in the RJV:

Proposition 4:    *if*  $w < w^*$  :  $\frac{\partial i^{RJV}}{\partial w} > 0$   
                           *if*  $w > w^*$  :  $\frac{\partial i^{RJV}}{\partial w} < 0$

proof:    Obvious comparative statics result from the first order conditions of the problem.

The intuition for this result is as follows: If  $w < w^*$ , the researcher should only be concerned if the true signal is low for both firms. The likelihood of this being the case increases

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<sup>10</sup> There does not exist a mixed strategy equilibrium of the game. Note that given the concavity of the researcher's problem, the researcher has a unique pure strategy influence level, regardless of the continuation decision by the firms. At  $w = w^*$ , the firm making the continuation decision is indifferent between continuation or not. Any mixed strategy on the part of the decision maker would increase the amount of influence activity by the researcher because  $i^{RJV2} > i^{RJV1}$ ,  $\forall w$ . This implies that if  $w > w^*$ , we know that Condition (1) is violated for the RJV. Any mixed strategy increases influence activity and thus it must be the case that Condition (1) is also violated for any mixed strategy so that the firm cannot be indifferent.

with the correlation and as a result, influence activity increases with correlation.<sup>11</sup> If  $w > w^*$ , the researcher can only obtain continuation if both firms observe high signals. As correlation increases, the likelihood of the true signal being high for both firms increases. Increased correlation thus reduces the optimal level of influence activity by the researcher.

### 3. Relating the IRD and the RJV

In this subsection we attempt to compare the outcome when the firm organizes the project as an IRD with the case where the firm decides to perform the project with a partner in a RJV. We state our main finding in Proposition 5:

**Proposition 5:** Suppose that Assumption 2 holds,

$$\begin{aligned} \forall w \leq w^*: & \quad i^{IRD} > i^{RJV} \\ \forall w > w^*: & \quad i^{IRD} < i^{RJV} \end{aligned}$$

proof: Case  $w \leq w^*$

When substituting  $i^{IRD}$  into the first order condition for the RJV, we find after some manipulation:

$$\frac{w}{2} [3 - 2q(i^{IRD}) - q(i^{IRD})^2] - 1 \quad (P1)$$

Note that  $i^{IRD}$  does not depend on  $w$  and  $0 < w < w^* < 1$ .

If  $1 - 2q(i^{IRD}) - q(i^{IRD})^2 < 0$ , we can show that this expression is negative.

This obviously hold for  $w$  small.

Using the first order condition for the IRD:

$$1 - 2q(i^{IRD}) - q(i^{IRD})^2 = 1 - q(i^{IRD}) - (1 - i)q'(i^{IRD})q(i^{IRD})$$

We know from Assumption 2 that this expression is negative for all  $i$ .

Now given that the second order conditions on the problem hold and (P1) is negative, we conclude that  $i^{RJV} < i^{IRD}$ .

Case  $w > w^*$

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<sup>11</sup> This result seems to suggest that firm  $x$  should look for a partner with a signal that is perfectly negatively correlated ( $w=0$ ). Low correlation of the signals does not imply that the firms are necessarily distant in terms of their technology employed. We will argue that this correlation is related to the nature of research performed, i.e basic versus applied (see below). In order to relax this result somewhat we could introduce a probability of success for projects. Projects with lower correlation of the signals would imply lower expected success rates.

After substitution of  $i^{IRD}$  into the appropriate first order condition for the RJV and after similar manipulations as in the previous case, we get:

$$1 + \frac{w}{2}[3q(i^{IRD}) - 2q(i^{IRD}) - 1] = 1 + \frac{w}{2}(q - 1)\left(q + \frac{1}{3}\right) \quad (P2)$$

The quadratic reaches its minimum at  $1/3$  at a value of  $-10/9$ .

Since  $0 < w^* < w < 1$ , (P2) is always positive.

This, together with the second order conditions, imply that  $i^{IRD} < i^{RJV}$ .

The proposition states that whether or not the researcher spends more time influencing the continuation decision in the IRD compared to the RJV, depends on the correlation between the signals of the potential partners. If the signals of potential partners are highly correlated, the researcher in the RJV spends more time influencing the continuation decision of the RJV, because she can only guarantee continuation if both signals are high. This requires more lobbying effort. If the signals are not highly correlated, the researcher can assure continuation in the RJV whenever one of the signals is high. In the IRD, the project is continued whenever the firm observes the high signal. Note that the firm in the IRD cannot condition the continuation policy on the signal of the potential partner. That signal is not observable, given that the other firm did not commit to the partnership by investing the initial set up cost  $\epsilon$ . The choice of the organizational design thus implies a choice over information structures (see footnote 7). The information set in the IRD is coarser than in the RJV. If the correlation is low, the finer information structure in the RJV lowers the influence activities of the researcher compared to the IRD. If correlation is high, this result is reversed where the coarser information structure of the IRD reduces influence activity compared to the finer information structure of the RJV. Note that in the absence of influence activities, the firm is indifferent about the information structure.

One interesting note is that these results are independent of the actual level of the profits in the RJV versus the IRD. This follows from the fact that Condition (1) is determined by the expected profits of firm x when observing a high signal while firm y observes a low signal. The

project is worthless to firm y in this case and as a result firm x does not expect firm y to continue developing competitive products with the final results of the project.

In order to analyze the choice of the organizational design by firm x, we do need to compare expected profit levels under both organizational designs. Let's define  $\gamma^*(w, F)$  such that the expected profits of firm x in the IRD are equated to the expected profits of firm x in the RJV. At  $\gamma^*$ , the firm is indifferent between organizing the project as an IRD or as a RJV where  $\gamma^*$  indicates the percentage reduction in profits that the firm is willing to sustain in the RJV as to be indifferent between the IRD and the RJV. Obviously, if there is no influence activity,  $\gamma^* = 1$ . This is just a restatement of Proposition 1.

**Proposition 6:** Suppose  $0 < w < w^*$ , then  $\gamma^*(w, F) < 1$ .

proof: The expected profits of firm x in the IRD are:  $\frac{p_{IRD}(t^{IRD})}{2} - \frac{I + q(i^{IRD})}{2} F$

The expected profits of firm x in the RJV are:

$$\frac{I - (I - g)w}{2} p(t^{RJV}) - \frac{I + q(i^{RJV})}{2} F$$

The profits of the RJV are strictly increasing in  $\gamma$ .

Given that  $i^{IRD} > i^{RJV}$  from Proposition 5, the result follows immediately.

The intuition for this result is straightforward. For low levels of correlation, the researcher spends more time on influence activities in an internal R&D project than in the RJV. Given equal levels of influence activities, firm x is indifferent between the IRD and the RJV. The corollary to Proposition 2 stated that, given the same continuation policy, the firm prefers less influence activity. Because of the lower influence levels in the RJV, the RJV can trade off some future expected profits in case both firms get the high signal, in return for lower levels of influence activities. This is exactly what  $\gamma^*(w, F) < 1$  means. It is also easy to show that  $\gamma^*(w, F)$  is increasing in  $w$ , when  $w < w^*$ . Meaning that the acceptable level of ex post competition between partners is decreasing in the correlation of the signals.

When correlation is high, it is not clear whether the IRD or the RJV dominates. In the example section, we will give an example of both cases. To see the intuition for the case where  $w > w^*$ , let's look at the difference in profits between the IRD and the RJV. After some manipulation, using the counterfactual that we can observe the signal of the potential partner in the IRD, we get that the profits in the IRD are larger than the profits in the RJV iff

$$\begin{aligned} \Delta = & \mid (\hat{s}_x = 1, \hat{s}_y = 1; i) \mid \mathbb{1}(s_x = 1, s_y = 1 / \hat{s}_x = 1, \hat{s}_y = 1; i) [p(t^{IRD}) - gp(t^{RJV})] \\ & + \mid (\hat{s}_x = 1, \hat{s}_y = 1; i) \mid \mathbb{1}(s_x = 1, s_y = 0 / \hat{s}_x = 1, \hat{s}_y = 1; i) [p(t^{IRD}) - p(t^{RJV})] \\ & + \mid (\hat{s}_x = 1, \hat{s}_y = 0; i) \mid \mathbb{1}(s_x = 1, s_y = 0 / \hat{s}_x = 1, \hat{s}_y = 0; i) [p(t^{IRD}) - F] \geq 0 \end{aligned} \quad (3)$$

Given that there is more influence activity in the RJV than in the IRD and given that there are no synergies between the firms ( $\gamma \leq 1$ ), the first two elements of this difference are positive.<sup>12</sup> The last part of the expression is negative by the fact that  $w > w^*$ . This part becomes more negative as  $w$  increases. The overall sign of this expression is ambiguous. The trade off between the IRD and the RJV is as follows: in the IRD the firm experiences a lower lobbying effort by the researcher and at the same time there is no competitive effect as in the RJV. However, in the IRD the firm when observing a high signal can not discriminate between the case where the potential partner would observe a high signal or a low signal given its coarser information structure. If the firm would have the ability to observe that the signal of the other firm is low, it would discontinue the project, given that it actually has a negative expected value. This follows from the fact that Condition (1) is violated. The RJV allows the firm to screen for this case and thus avoid this negative expected profit outcome. There thus exists a trade off between the IRD and the RJV where influence activity is traded off for a coarser information structure. The net effect depends on the exact specification of the model. The result that a finer

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<sup>12</sup> We could extend the model to allow the level of future competition,  $\gamma$ , to depend on the correlation. We would expect that competition becomes more intense as the correlation between the partners' signals increases:  $\gamma(w)$  is increasing in  $w$ . This leads to a result that favors the formation of more IRDs relative to RJVs since it increases the first term in the expression.

information structure for evaluating the project could hurt the firm, is interesting in its own respect. Cremer (1995) finds a similar result, where the principal needs to decide on his monitoring technology. In his model a better monitoring technology can hurt the principal, because it increases the cost of commitment not to renegotiate with the agent.

Although our model is stylized, its predictions are consistent with some of the casual observations, related to the nature of research and development, and its organization. The model is consistent with the stylized fact that RJVs tend to be employed for projects that are more “basic” than applied. The reason is as follows. It seems plausible that more applied projects involve more correlated information among the partners. This is because “basic research is more likely to lead to “unexpected” results” (Nason (1981)). A second related fact is that “the output of basic research is never some final product to which the market place can attach a price tag.” (Rosenberg (1990)). As a result we would expect that future expected profits of a research project are not so closely related for more basic research projects. In terms of the model,  $\gamma$  is close to 1 for basic research projects. When the correlation between the signals is low and future profits are not too competitive, the model predicts that research projects will be organized in a RJV. This is consistent with the observation that RJVs perform research projects that are of a more basic nature.

### **Example**

To illustrate the model and its results we develop the following example:

The firm profits, conditional on the signal are defined as:  $\pi(t) = 1 + t$ . The continuation costs for the project are  $F = .50$ . Assumption 1 is satisfied for this profit function if  $\varepsilon = 0$  and  $\gamma = 1$ . As a reference point note that without any influence activity, the expected profit of the firm is .75. This is the best the firm could ever hope to do.

The researcher's private benefit is:  $b(T-i) = T-i$ , and  $T = 1$ . To characterize the effect of influence activity, we consider the following class of functions:  $q(i) = i^\alpha$ . Assumption 2 is satisfied for this class of functions, where  $0 < \alpha < .32$ .

Case 1:  $\alpha = .1$

In the IRD project the researcher invests  $i = .04035$  in influence activity. The expected profits of the firm from organizing the project internally are:  $V^{IRD}(i^*, d^*) = .5485$ .

In the RJV the results depend on the correlation of the signals,  $w$ , between the partners. The critical correlation is  $w^* = .8154$ . Figure 1 illustrates how this critical correlation is found through its dependence on  $F$ . Increasing  $F$ , decreases  $w^*$ . Figures 2 and 3 illustrate the amount of influence activity by the researcher and the expected profits of firm  $x$  for both organizational structures. For example, if correlation is  $w = .5$ , the researcher spends  $i = .0117$  time in influence activities and the expected profits of organizing the research project in a joint venture is  $V^{RJV}(i^*, d^*) = .5838$ . The level of influence activity is increasing in the correlation level for  $w < w^*$ . Clearly the firm prefers the RJV to the IRD project when correlation between signals is low. If correlation is high, the result depends on the correlation level. For example, if  $w = .85$ , the researcher invests  $i = .0724$  of her time in influencing the continuation decision. As a result expected profits are  $V^{RJV}(i^*, d^*) = .5345$ . In this case, the firm would prefer to perform the project internally. For the correlation close to one, the firm will again prefer to organize the project as a RJV. For example, if  $w = .95$ , the firm invests  $i = .07$  time in influence activity. The resulting profits of the firm are  $V^{RJV}(i^*, d^*) = .5575$ .<sup>13</sup> Note that influence activity is decreasing in the correlation level for  $w > w^*$ .

Case 2:  $\alpha = .25$

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<sup>13</sup> It can be shown that for this example, the RJV always dominates the IRD for correlation levels in a neighborhood of 1, except if  $\alpha = 0$ . In that case the IRD and RJV are equivalent for  $w = 1$  and the RJV is strictly worse for any  $w < 1$ .

In the IRD project the researcher invests  $i = .0798$  in influence activity. The expected profits of the firm from organizing the project internally are:  $V^{\text{IRD}}(i^*, d^*) = .57719$ . The results are shown in Figures 4 through 6.

In the RJV, the results again depend on the correlation of the signals,  $w$ , between the partners. The critical correlation is  $w^* = .85536$ . For example, if correlation is  $w = .5$ , the researcher now spends  $i = .0322$  time in influence activities and the expected profits of organizing the research project in a joint venture is  $V^{\text{RJV}}(i^*, d^*) = .628$ . The level of influence activity is increasing in the correlation level for  $w < w^*$ . Clearly the firm prefers the RJV to the IRD project when correlation between signals is low. If correlation is high, the result depends on the correlation level. For example, if  $w = .9$ , the researcher invests  $i = .1232$  of her time in influencing the continuation decision. As a result expected profits are  $V^{\text{RJV}}(i^*, d^*) = .567$ . In this case the firm would prefer to perform the project internally. However, if  $w = .95$ , expected profits are  $V^{\text{RJV}}(i^*, d^*) = .588$ , and the firm prefers to organize a RJV for high correlation levels. Again, note that influence activity is decreasing in the correlation level for  $w > w^*$ .

### **Conclusions and Extensions**

In the model we purposefully abstracted away from any cost sharing in the RJV. Note that the assumption that profits in the low state are zero only allows for actual cost sharing when both firms observe the high signal. In all other cases, the firm with the low signal will refuse to continue the project. As such, the main result of the paper remains valid under cost sharing. In particular, the critical correlation level remains unchanged, given that one firm will have to bear all the costs after observing the high signal while the partner observes a low signal. This result can be generalized, given that the researcher only cares about the continuation of the project and not which firm is in control. As long as  $s_x \pi(t) + s_y \pi(t) > F$ , renegotiation between the partners will insure continuation of the project when correlation is low and there will exist a critical  $w^*$  such that expected profits are zero when one firm observes a high signal and the other a low



signal. Cost sharing will improve the expected profitability of the RJV compared to the IRD. This does not affect the results of Proposition 6, that the RJV is preferred to the IRD when  $w < w^*$ . If  $w > w^*$ , the effects of cost sharing counterbalance the negative effect of competitive future profits and the expected profits of the RJV increase compared to the IRD. Another effect of cost sharing is that Proposition 1 does not hold when firms share costs after both observing a high signal, so allowing cost sharing breaks the indifference of firms between a RJV and an IRD when there is no influence activity by the researcher. We could think of the firms setting up a 50-50 RJV. This might be the outcome of a bilateral bargaining game. After the signals are revealed, the ownership shares are renegotiated whenever both firms do not observe a high signal. Extending the model to endogenously account for cost sharing, might generate some insights into ownership structures of research joint ventures.

Another important assumption about the firms in the model is that they operate in a single business. As a result they are unable to create the same organizational flexibility internally and thus an internal R&D project can not mimic the research joint venture. This begs the question whether diversified firms could create the same environment as in the joint venture. Indeed, suppose the firm has two divisions in different lines of business. An internal R&D project as a joint venture across divisions could create the same incentives for researchers as a joint venture would. The signals that the different divisions observed, would not be perfectly correlated and create a similar flexibility as in the research joint venture. Unrelated diversified firms would reduce the correlation within the signal structure of the firm even more than related diversification. In that respect, the observation that central R&D labs of diversified firms perform more basic research projects is also consistent with the model. Diversified firms would thus realize economies of scope as a result of less influence activity and more research effort by the

researchers without the divisions necessarily sharing the costs of a research project.<sup>14</sup> An empirical prediction resulting from this argument is that we should observe more joint ventures between non-diversified firms than between diversified firms, because diversified firms can create a similar flexibility by engaging in internal R&D projects across divisions. The central R&D lab of a firm that is divisionalized according to geographic markets, however, will not outperform R&D projects organized within each division, because we expect the signals in this firm to be highly correlated. Scott (1988) suggests that there is actually some substitution between R&D in diversified firms and cooperative joint ventures. He claims that the introduction of the NCRA in 1984, which made the formation of cooperative ventures less costly for firms, might have resulted in a substitution of diversified R&D for cooperative ventures. As a result welfare might not have increased by as much as people like to claim, especially if you believe that joint ventures behave more collusive on the market than two separate but diversified firms would.

An alternative view of the RJV presented in the paper, would be one where the researcher needs to lobby to two decision makers in the RJV compared to only one in the IRD.<sup>15</sup> In this case, the researcher needs to convince the two parties in order to continue the project. The marginal cost of influence activity increases in the RJV and as a result the researcher spends less effort in influence activity in the RJV compared to in the IRD. In this model organizational design impacts the cost of engaging in influence activity, while in our model we attribute private benefits from continuing the project and as a result from influence activity.

Another possibly interesting extension of the model is to increase the number of firms that participate in the RJV. Technically, it is not immediately obvious how to extend the signal structure to more than two firms. The intuition, however, would be similar. Increasing the

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<sup>14</sup> Union Miniere has the policy that a research project at the central R&D lab can have several business units as a partner, but only one of the business units will actually fund the project.

<sup>15</sup> I would like to thank Scott Schaefer for suggesting this alternative approach.

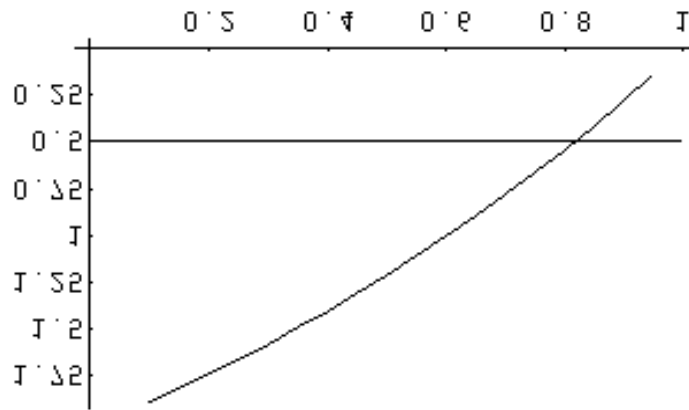
number of participants increases the likelihood that at least one firm gets a high signal and is willing to continue the project. In the limit, the project is continued for sure and there is no influence activity by the researcher. All her effort goes into research, which increases the expected future profits of the research project. However, we would expect that increasing the number of firms, increases the likelihood that future profits are competitive. In the notation of the model, this means that  $\gamma(n)$  is decreasing in the number of firms. It is reasonable to conjecture that the marginal benefits of increasing the number of member firms through reduced influence activity, decreases fast, while its marginal cost, the reduction in benefits, increases fast. This would lead to an optimal number of member firms. A plausible extension of Proposition 6, would be that the optimal number of member firms in the RJV is decreasing in the correlation between signals (however defined). We expect only one member firm (IRD) for a high level of correlation, while we expect many member firms for low levels of correlation. The parallel between more basic research projects versus more applied projects is readily extended: we expect more member firms to join a more basic research project. MCC, which is considered to engage in more basic research has 22 member firms. However, more applied research projects, typically have only a few member firms. An alternative mechanism that would eliminate influence activity by the researchers, is to organize a research institute. The research institute would commit to continue any project that has been commissioned. At some point it might be more efficient to organize a research institute with several firms and limit the number of members and as such the competitive effect of research joint ventures.

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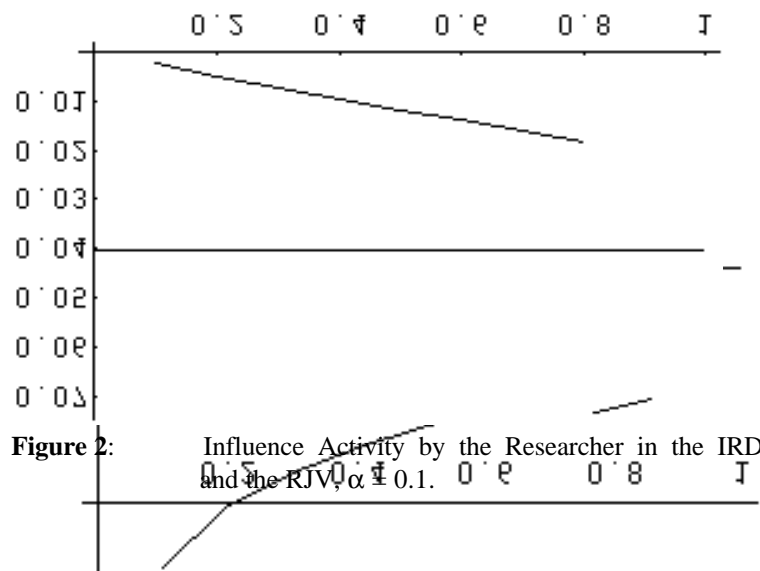
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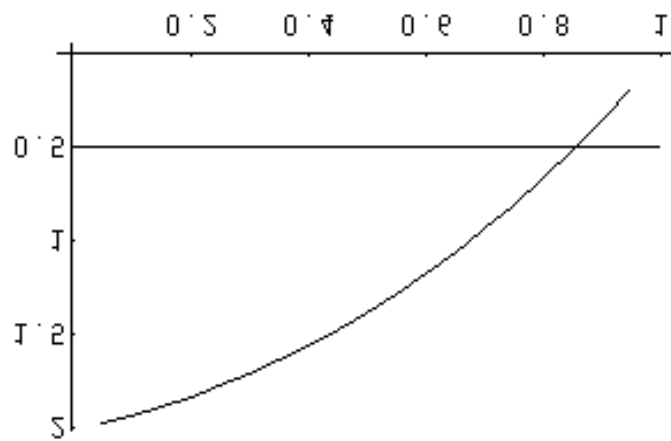
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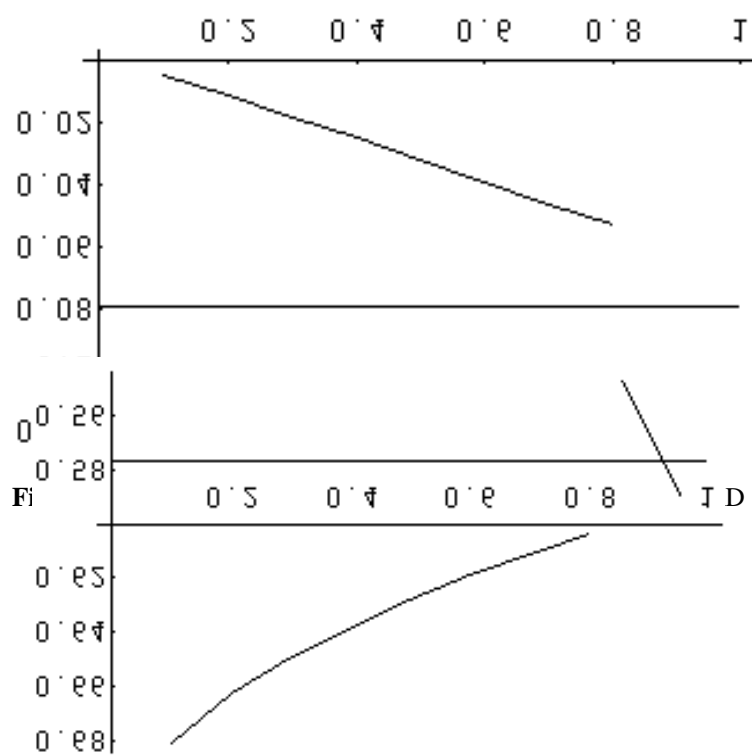
**Figure 1:** Critical Correlation Level,  $\alpha = 0.1$ .



**Figure 2:** Influence Activity by the Researcher in the IRD and the RJV,  $\alpha = 0.1$ .



**Figure 4:** Critical Correlation Level,  $\alpha = 0.25$ .



**Figure 6:** Profits of the Firm for the RJV and the IRD,







