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To reveal or not to reveal – The case of research joint ventures with two-sided incomplete information

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To reveal or not to reveal - The case of research joint ventures with two-sided incomplete information

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Abstract

Firms' incentives to form RJVs are analyzed in an incomplete information framework when technological know-how is private information. Firms first decide on cooperation and then compete for a patent in a second price auction. Provided that firms have to indicate their willingness to cooperate by revealing a fraction of their know-how it can be shown that non-cooperation is always an equilibrium. If this fraction is sufficiently low cooperation can also occur in equilibrium. For intermediate levels of know-how revelation there exists an equilibrium in which only firms with low know-how cooperate.

Keywords: Research joint ventures, incomplete information, spillovers, second-price auction.

JEL-classification: O31, L13, D82

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1 Introduction

Imagine the case of an economist who one morning awakes with a brilliant idea about an important problem he wants to write a paper on. But instead of writing this paper alone the economist prefers to co-author this paper with a mathematician because this would go faster, thus diminish the chance that someone else publishes the same idea earlier and would also be more fun. The economist knows only one mathematician he could ask on this matter but, unfortunately, does not know too much about the mathematician's economic abilities or about his trustworthiness. If the economist tells this person his idea, he not only risks a rejection of the co-authorship but also a publication on this problem by the mathematician alone. What could we suggest to the economist? The same problem the economist is confronted with may also be faced by an R&D manager who meets a competitor's representative to negotiate a possible research joint venture. The dilemma is that while (some) know-how has to be revealed in order to determine possible benefits of cooperation, revelation also bears the risk to be exploited.

Although there is a broad literature on research joint ventures and on the effects of involuntary knowledge spillovers, the problem of incomplete information about the other firm's know-how, technological competencies or ideas has been largely neglected in the industrial organization analysis.[1] There are a few papers approaching this issue from an optimal contract perspective: Gandal & Scotchmer [1993] extend the analysis of research joint ventures by assuming that research abilities are private information. In their model firms can signal their research abilities without revealing know-how such that the above described dilemma does not exist. Bhattacharya, Glazer & Sappington [1990, 1992] focus on optimal mechanisms for the sharing of know-how. In both models it is assumed that there exists a disinterested planner who knows invention technologies and designs the appropriate payoff structure for full disclosure, such that the above described dilemma is ruled out. D'Aspremont, Bhattacharya & Gérard-Varet [1995] consider a problem of bargaining over the disclosure of interim research knowledge between two parties in a contest for a patentable innovation. They analyze optimal licensing fee schedules only for one-sided revelation while in this paper the focus is on the bilateral situation. All these papers restrict their analysis to the case

[1] See for example the fundamental work by D'Aspremont & Jacquemin [1988] which led to about 40 extensions in the following years, or see De Bondt [1996] for a survey on that topic.

in which …rms' knowledge can be ordered in a Blackwell sense, and thus is substitutable, whereas the focus in the present paper is on complementary know-how. Here even a …rm with low know-how may have an incentive to reveal. This alternative characterization of knowledge seems to be a natural extension.[2]

In an incomplete contract framework, Anton & Yao [1994] analyze the problem faced by a single independent inventor when selling a valuable, but easily imitated, invention for which no property rights exist. They …nd that an inventor with little wealth prefers to reveal the invention prior to negotiating with the buyer. While in their paper the threat of selling the invention to a competitor is the driving force behind know-how revelation, here …rms may have an incentive to reveal even without being able to threat. Pérez-Castrillo & Sandonís [1996] analyze possible incentive contracts between two asymmetric …rms inducing know-how disclosure in a scenario of uncertainty and asymmetric information. While in their model negative e¤ects of know-how revelation stem from future product market competition, in this paper it is assumed that possible negative e¤ects are exhibited by the R&D race itself. [3]

The present paper concentrates on the characterized dilemma in a pre-contractual situation, under the assumption that the …rms' know-how levels are private information and that they have to reveal some of their know-how in order to indicate their willingness to cooperate. An alternative interpretation is that a player who wants to cooperate has to reveal all his know-how but only a fraction spills over to the other …rm. Given this framework we try to analyze whether and how …rms' know-how levels determine their incentive to cooperate.

We …nd that if the revelation (and thus transfer) of a large proportion of know-how is required in order to indicate a …rm's willingness to cooperate, the risk to be exploited dominates possible gains from cooperation and non-

[2] See also D'Aspremont, Bhattacharya & Gérard-Varet [1998].

[3] Another branch of literature concentrates on the problem of information sharing and strategic information revelation. The distinctive assumption in this literature is that …rms decide on information sharing before they actually know the realization of their own type, while this paper focuses on the case in which players are aware of their own know-how when they decide to cooperate. Okuno-Fujiwara, Postlewaite & Suzumura [1990] model strategic revelation of private information via public disclosure by adding a …rst stage announcement game to a given game with asymmetric and incomplete information. Agents are allowed to certi…ably announce some or all of their private information by announcing a set of types. For an excellent overview see Raith (1997).

cooperation is the unique equilibrium. On the other hand, provided that only little know-how is transferred if a firm indicates its willingness to cooperate, cooperation can also be an equilibrium strategy. Furthermore, we characterize conditions under which only players with low know-how cooperate: This is the case for intermediate levels of know-how revelation, large enough for the high know-how type to benefit from cheating, and low enough for the low know-how type to prefer cooperation.

Thus, the model allows the explicit integration of those features that are idiosyncratic to R&D, i.e. the public good aspect of know-how and type dependent strategies. Both of these features seem to be most relevant when analyzing research joint ventures: In the complete information framework it has been outlined that the internalization of spillovers is a driving force behind cooperation in research activities, and that the degree of spillovers directly determines possible welfare implications.[4] And more recently it has been shown empirically that especially heterogeneous firms participate in research joint ventures.[5] In the following sections we present a very simple model in which both these aspects are analyzed in the framework of incomplete information.

2 The model

Formally, a non-cooperative two-stage game with (observed actions and) incomplete information is analyzed. Assume there are two players $i = 1; 2$ with types v_i: Both players believe that the v_i are independent and have only two possible values v_l and v_h; with $v_l < v_h$. Furthermore, they believe that p is the probability that v_i equals v_h and that $(1 - p)$ is the probability that v_i equals v_l. Each player's type v_i is private information only to that player. Assume that players' types are given by their technological know-how. They play the following two-stage game:

On the first stage they both have two possible actions, 'cooperate' or 'do not cooperate', denoted by $A_i \in \{C; D\}$ on which they decide simultaneously. If a player chooses action C (cooperate) he has to indicate his willingness to cooperate by revealing (truthfully) some fraction $\alpha \in [0; 1]$ of his technological know-how (or a player who wants to cooperate has to reveal all his know-how but only a fraction α spills over to the other firm), if he chooses

[4] See for example D'Aspremont & Jacquemin [1988] or Katz & Ordover [1990].

[5] See Veugelers & Kesteloot [1995] or Roeller, Tomback & Siebert [1997].

D he does not reveal any know-how. Once know-how is revealed it de…nitely is not lost for the one who revealed it, but it may also not be possible to be taken back.[6] Whenever one player j unilaterally reveals his know-how, the other player i's know-how is increased by ®v_j.[7] If both players choose C then they will form a joint venture, for which we assume that technological know-how is always perfectly transferred at no cost such that the know-how of the joint venture corresponds to the sum of individual know-how.

At the beginning of the second stage players can …nd themselves in four di¤erent situations depending on the choice of both their actions at the …rst stage: Either both players chose not to cooperate, only one indicated his willingness to cooperate or both indicated their willingness to cooperate and a joint venture is formed.

On the second stage the players compete against each other with their know-how for a given patent. Let us assume that they participate in a second-price auction for the patent. For the auction we assume the following: A player's technological know-how v_i (or his basic technological idea) is given to him ex ante and does not require any further investment. It may be a (by-)product of former research activities or just the result of intuition. This know-how (which may be increased by a fraction ® of the other player's know-how) determines the player's valuation for a given patent. The higher is the know-how, or the better the idea, the more he can earn on the market with a future innovation based on that idea. Hence, the more he is willing to spend on the development of that innovation. The bid in the auction can be interpreted as a construction plan determining the costs of development as well as the quality of the innovation. Once the patent is granted (for the plan with highest quality innovation), real resources have to be spend to realize the innovation. The minimum costs of development which are required for a patentable innovation are …xed and given by v_s 2 $[0; v_l]$ and are common knowledge.

At this stage, players' actions are their bids b_i; unless players form a

[6] We abstract from any (additional) spillovers due to backward engineering or espionage. Therefore there is no leakage of know-how if players choose not to reveal.

[7] In a patent race with technological spillovers a …rm's know-how may have two e¤ects on a rival's probability of success: The more know-how a …rm i has, the more likely it is to pre-empt its rival and therefore the success probability of its rivals may be lowered. Second, a rival's probability of success, conditional on not being pre-empted by …rm i, rises due to spillovers if …rm i unilaterally reveals its know-how. See also Katz & Ordover [1990].

joint venture. Then their bid is b_{JV} and they win the patent for sure. The gains of the joint venture are shared according to the initial contributions of know-how.[8]

Note that a strategy of the two-stage game consists of two action plans. At the first stage an action plan of a player i is a mapping from the set of types $\{v_l; v_h\}$ into actions $A_i \in \{C; D\}$: At the second stage his action plan maps the set of types and first stage actions $\{v_l; v_h\} \times \{C; D\} \times \{C; D\}$ into the set of positive real numbers $b_i \in \mathbb{R}^+$. To find perfect Bayesian Nash equilibria, the game is analyzed by backward induction.

3 The second stage: A simple second-price auction

In a second-price auction the highest bidder wins the patent and pays the second highest bid, i.e., he wins if $b_i \geq \max_{i \neq j} b_j$: In case of a tie the player wins the patent with probability $\frac{1}{2}$ and pays his bid b_i: Bidder i's payoffs at this stage of the game are given by:

$$\begin{array}{ll} v_i - b_j & \text{if } i \text{ wins the patent without } j\text{'s know-how,} \\ v_i + \alpha v_j - b_j & \text{if } i \text{ wins the patent with } j\text{'s know-how,} \\ \frac{v_i}{v_i + v_j}(v_i + v_j - b_{JV}) & \text{if the joint venture wins the patent,} \\ 0 & \text{else,} \end{array}$$

with b_{JV} being the bid of the joint venture which is shared according to their contribution of know-how. At the second stage, Bayesian Nash equilibria are characterized by the fact that the optimal bidding strategy for player i; with $i = 1; 2$; is a weakly dominant strategy: Each player bids his valuation which is given by his technological know-how (and may be increased by a fraction α of the other player's know-how, depending on the opponent's strategy in the first stage). Therefore, equilibrium payoffs at this stage do not depend on the updated beliefs.

A player i's payoff given he is of type v_i and has chosen action A_i; and given player j is of type v_j and has chosen action A_j (with $i; j = 1; 2$) is $\Pi_i(A_i; A_j; v_i; v_j)$:

[8] We might as well assume a 50:50 sharing rule as it is usually assumed in the partnership literature. This would not alter the results qualitatively. In reality the sharing rule is often determined by share holdings, which may differ from technological contributions.

Given that none of the players has revealed any know-how at the first stage (both players chose D) the equilibrium payoff of a player with type v_i is given by:

$$\pi_i(D, D, v_i, v_j) = \max\{v_i - v_j, 0\}.$$

If the players form a joint venture ($A_i = A_j = C$ with $i, j = 1, 2$), their valuation is given by $v_i + v_j$ while they only bid the minimum R&D level v_s.[9] The payoff of player i with type v_i cooperating with a player j of type v_j is given by:

$$\pi_i(C, C, v_i, v_j) = v_i - \frac{v_i}{v_i + v_j} v_s.$$

In case that only one of the two players reveals (some) technological know-how with the intention to cooperate, his opponent can win the auction given that he can overbid. So in case player i is of type v_i and receives know-how while he chooses not to cooperate D, his payoff is:

$$\pi_i(D, C, v_i, v_j) = \max\{v_i - (1 - \alpha)v_j, 0\}.$$

Note that even a player of type v_l can overbid a player with type v_h if $\alpha > \alpha^* \equiv 1 - \frac{v_l}{v_h}$. The payoff of player i given that he has unilaterally revealed his know-how with the intention to cooperate is:

$$\pi_i(C, D, v_i, v_j) = \max\{(1 - \alpha)v_i - v_j, 0\}.$$

Now equilibria of the two-stage game can be characterized. But before we outline the players' optimal strategies, we will briefly discuss possible equilibria in the first stage game under the assumption of general reduced form profit functions which are generated in the second-stage equilibria.

4 The first stage: The cooperation decision

In the previous section it was shown that players' second stage equilibrium profits are independent from updated beliefs about their opponent's type. This fact simplifies the subsequent analysis. We can restrict ourselves to

[9] Actually we assume that they form a bidder ring. See Graham & Marshall [1987].

look for Bayesian Nash equilibria in a game of incomplete information with a finite number of types v_i for each player i, prior distribution p, and pure-strategy space S_i. A player i's equilibrium action in the first stage is given as $(A_i|v_i = v_l, A_i|v_i = v_h)$ with $i = 1,2$. In the following we confine the analysis to symmetric equilibria, in the sense that two players of the same type v_i choose the same equilibrium action.

Note that a player i of both types will choose the action D not to cooperate in equilibrium, if the following inequality holds for all players $i,j = 1,2$ with $v_i \in \{v_l, v_h\}$:

$$p(\pi_i(C,D;v_i,v_h) - \pi_i(D,D;v_i,v_h)) + (1-p)(\pi_i(C,D;v_i,v_l) - \pi_i(D,D;v_i,v_l)) < 0. \quad (1)$$

On the other hand, (C, C) is an equilibrium action of player i, if he cooperates and chooses C in equilibrium independently of his type. This is the case if the following inequality holds for all players $i,j = 1,2$ with $v_i \in \{v_l, v_h\}$:

$$p(\pi_i(C,C;v_i,v_h) - \pi_i(D,C;v_i,v_h)) + (1-p)(\pi_i(C,C;v_i,v_l) - \pi_i(D,C;v_i,v_l)) > 0. \quad (2)$$

The more interesting cases are those in which only players of a certain type cooperate: In equilibrium only a player i of type $v_i = v_l$ cooperates and chooses C while a player i of type $v_i = v_h$ does not cooperate and chooses D, if for a player i of type $v_i = v_l$ with $i,j = 1,2$

$$p(\pi_i(C,D;v_l,v_h) - \pi_i(D,D;v_l,v_h)) + (1-p)(\pi_i(C,C;v_l,v_l) - \pi_i(D,C;v_l,v_l)) > 0 \quad (3)$$

holds, while simultaneously for a player i of type $v_i = v_h$

$$p(\pi_i(C,D;v_h,v_h) - \pi_i(D,D;v_h,v_h)) + (1-p)(\pi_i(C,C;v_h,v_l) - \pi_i(D,C;v_h,v_l)) < 0 \quad (4)$$

holds. Finally, only a player i with low know-how $v_i = v_l$ chooses D while a player i of type $v_i = v_h$ with high know-how cooperates and chooses C with $i,j = 1,2$, if:

$$p(\pi_i(C,C;v_h,v_h) - \pi_i(D,C;v_h,v_h)) +$$

$$(1-p)(\Pi_i(C,D,v_h,v_l)-\Pi_i(D,D,v_h,v_l))>0; \text{ and} \tag{5}$$

$$p(\Pi_i(C,C,v_l,v_h)-\Pi_i(D,C,v_l,v_h))+$$
$$(1-p)(\Pi_i(C,D,v_l,v_l)-\Pi_i(D,D,v_l,v_l))<0. \tag{6}$$

It is easily seen that whenever $\Pi_i(C,C,v_i,v_j)>\Pi_i(D,C,v_i,v_j)\ \forall v_i,v_j\in\{v_l,v_h\}$ and $\forall i,j=1,2$ then (2) is satisfied and (C,C) is always an equilibrium.[10] If additionally $\Pi_i(C,D,v_i,v_j)>\Pi_i(D,D,v_i,v_j)$ then (C,C) is also the unique equilibrium and the game can be characterized as a prisoner's dilemma (PD) with an efficient equilibrium. Analogously, if $\Pi_i(C,D,v_i,v_j)<\Pi_i(D,D,v_i,v_j)\ \forall v_i,v_j\in\{v_l,v_h\}$ and $\forall i,j=1,2$ then (1) is satisfied and (D,D) is always an equilibrium and if additionally $\Pi_i(C,C,v_i,v_j)<\Pi_i(D,C,v_i,v_j)$ then non-cooperation is the unique equilibrium. In this case the game corresponds to the classical PD situation. On the other hand, if $\Pi_i(C,C,v_i,v_j)>\Pi_i(D,C,v_i,v_j)\ \forall v_i,v_j\in\{v_l,v_h\}$ and $\forall i,j=1,2$ holds and at the same time also $\Pi_i(C,D,v_i,v_j)<\Pi_i(D,D,v_i,v_j)$ then both these equilibria exist, which is known as a 'coordination game'.

There is also the potential for equilibria with (C,D) or (D,C) if only for one type v_i of player i $\Pi_i(C,D,v_i,v_j)<\Pi_i(D,D,v_i,v_j)$ as well as $\Pi_i(C,C,v_i,v_j)<\Pi_i(D,C,v_i,v_j)$ hold, but not for the other.

Let us now establish the following relations between players' profits in the above described auction framework: Note first that $\Pi_i(C,D,v_i,v_j)\le\Pi_i(D,D,v_i,v_j)\ \forall v_i,v_j\in\{v_l,v_h\}$ and $\forall i,j=1,2$. Secondly, we find:

$$\begin{aligned}
\Pi_i(C,C,v_h,v_l) &> \Pi_i(D,C,v_h,v_l) \text{ for } \alpha<\alpha_1\equiv 1-\frac{v_h v_s}{v_l(v_h+v_l)};\\
\Pi_i(C,C,v_l,v_l) &> \Pi_i(D,C,v_l,v_l) \text{ for } \alpha<\alpha_2\equiv 1-\frac{v_s}{2v_l};\\
\Pi_i(C,C,v_h,v_h) &> \Pi_i(D,C,v_h,v_h) \text{ for } \alpha<\alpha_3\equiv 1-\frac{v_s}{2v_h};\\
\Pi_i(C,C,v_l,v_h) &> \Pi_i(D,C,v_l,v_h) \text{ for } \alpha<\alpha_4\equiv 1-\frac{v_l\ v_s}{v_h(v_h+v_l)}.
\end{aligned} \tag{7}$$

A comparison yields $\alpha_1\le\alpha_2\le\alpha_3\le\alpha_4\le 1$ for $v_s\ge 0$. In order for a player i to benefit from unilateral cheating, spillovers have to be higher, the higher is the rival's know-how in relative and absolute terms.

[10] Since we restricted the analysis to symmetric strategies, we can characterize equilibria by the first-stage action plan of player i $(A_i|v_l, A_i|v_h)$ with $i,j=1,2$.

5 Bayesian equilibria of the two-stage auction game

Having established payoffs and equilibrium conditions in both subgames, we can now state some results. First off all it turns out that two factors are critical: The fraction α of know-how necessary to indicate willingness to cooperate (or the degree of spillovers), as well as the level of minimum R&D.

Remark 1 If $v_s = 0$ the game is a 'coordination game'. In one equilibrium players of both types cooperate (C, C) and in the other equilibrium players of both types do not cooperate (D, D).

Obviously, if there are no minimum R&D expenditures $v_s = 0$, we find $\Pi_i(C, C; v_i, v_j) > \Pi_i(D, C; v_i, v_j)$ $\forall\, v_i, v_j \in \{v_l, v_h\}$ and $\forall\, i, j = 1, 2$. The joint venture is better off because collusion in the auction leads to a certain payoff at no costs. At the same time, $\Pi_i(C, D; v_i, v_j) \leq \Pi_i(D, D; v_i, v_j)$ always holds $\forall\, v_i, v_j \in \{v_l, v_h\}$ and $\forall\, i, j = 1, 2$. While the latter continues to hold true, the former changes if we consider positive minimum R&D expenditures:

Proposition 1 Assume $v_s > 0$. Non-cooperation (D, D) is always an equilibrium. If spillovers are sufficiently large, $\alpha > \alpha_3$, then non-cooperation (D, D) is a unique equilibrium for all p, and $v_s > 0$.

Proof: First note that $\Pi_i(C, D; v_i, v_j) \leq \Pi_i(D, D; v_i, v_j)$ always holds $\forall\, v_i, v_j \in \{v_l, v_h\}$ and $\forall\, i, j = 1, 2$. Additionally, if $v_s > 0$, then $\alpha_3 < \alpha_4 < 1$. If $\alpha > \alpha_4$ then $\Pi_i(C, C; v_i, v_j) < \Pi_i(D, C; v_i, v_j)$ holds and D (non-cooperation) is a dominant strategy for both types. If $\alpha_3 < \alpha < \alpha_4$ then $\Pi_i(C, C; v_l, v_h) > \Pi_i(D, C; v_l, v_h)$ holds, but this is not enough to satisfy (2). Checking conditions (3) to (6) it becomes clear that there is no other candidate for an equilibrium. $\square$

This first result is straightforward. If spillovers are large, or a firm has to reveal a large fraction of its know-how to indicate its intention to cooperate, the gains from cheating outweigh the gains from cooperating for all players and the game resembles a PD situation. Hence, no cooperation must be a dominant strategy. It follows that it is very unlikely that firms cooperate if their know-how is easily transferable whenever it is revealed. It might be interesting to note that spillovers need not be perfect for this situation to occur. The higher the minimum R&D required for an innovation, the smaller can be the spillovers such that firms are in this PD situation.

Proposition 2 Assume $v_s > 0$. Cooperation (C, C) is an equilibrium iff

(i) for all p, v_s spillovers are sufficiently small, $\alpha \leq \alpha_1$, or
(ii) $\alpha < \alpha_3$ and $p > p^*$, with

$$p^* \equiv \frac{2(1-\alpha)(v_h v_l + v_l^2) - 2 v_h v_s}{2(1-\alpha)(v_l^2 - v_h^2) - v_s(v_h - v_l)}.$$

Proof: Note that $\alpha \leq \alpha_1$ implies $\Pi_i(C, C; v_i, v_j) \geq \Pi_i(D, C; v_i, v_j)$ $\forall v_i \in \{v_l, v_h\}$ and $\forall i, j = 1, 2$ and, hence, cooperation (C, C) is an equilibrium. If $\alpha_1 < \alpha < \alpha_3$, we find $\Pi_i(C, C; v_i, v_h) > \Pi_i(D, C; v_i, v_h)$ and $\Pi_i(C, C; v_h, v_l) < \Pi_i(D, C; v_h, v_l)$ and $0 < p^* < 1$. For $p > p^*$ inequality (2) is satisfied for players of type v_h. Obviously (2) is more restrictive for players of type v_h than for players of type v_l and therefore $p > p^*$ is enough to guarantee (2) to be satisfied for players of both types. ∎

If spillovers are sufficiently small or only little know-how has to be revealed to indicate ones willingness to cooperate such that unilateral cheating does not lead to a significant advantage, cooperation is an equilibrium. This is definitely always true if there are no minimum R&D requirements, because then the benefits of cooperation are largest. Even if spillovers are large enough to give the high know-how type an incentive to cheat on the low know-how type, this incentive may be outweighed by the low probability of meeting a low know-how type.

As was already pointed out, the relative magnitude of minimum R&D required for an innovation does play an important role. The higher the minimum R&D the smaller is the relative benefit of cooperation because it directly determines the bid of the joint venture.

Proposition 3 Assume $v_s > 0$. For spillovers in the interval $\alpha \in [\alpha_1, \alpha_2]$ and all p there exists an equilibrium in which only players i with low know-how $v_i = v_l$ cooperate (C, D), with $i = 1, 2$.

Proof: Note that $\Pi_i(C, D; v_l, v_h) = \Pi_i(D, D; v_l, v_h) = \Pi_i(C, D; v_h, v_h) = \Pi_i(D, D; v_h, v_h) = 0$. For $v_s > 0$ we find $\alpha_1 < \alpha_2 < 1$ and for $\alpha \in [\alpha_1, \alpha_2]$ we find $\Pi_i(C, C; v_h, v_l) \leq \Pi_i(D, C; v_h, v_l)$ and $\Pi_i(C, C; v_l, v_l) \geq \Pi_i(D, C; v_l, v_l)$ due to (7). It follows that (3) and (4) are satisfied. ∎

If minimum R&D is sufficiently high, there is an intermediate interval of spillovers for which players with low know-how do not loose anything by unilaterally revealing their know-how: If they are confronted with a high know-how type they do not make any profits anyhow, but being confronted with a player of their own type they are better off cooperating. On the other hand, for players with high know-how, spillovers are large enough to benefit from cheating against a low know-how type since minimum R&D is sufficiently high. Hence, there exists an equilibrium in which only players with low know-how cooperate. Although both cut-off levels α_1 and α_2 are decreasing the higher are minimum R&D requirements, the interval $\Delta_\alpha = \alpha_2 - \alpha_1$ is increasing. Furthermore, the higher is the dispersion of know-how $\Delta_v = v_h - v_l$ between the two types, the larger is Δ_α.

Proposition 4 There never exists an equilibrium in which only players i of type v_h cooperate $(D; C)$ with $i = 1; 2$.

Proof: Note that $\Pi_i(C; D; v_l; v_l) = \Pi_i(D; D; v_l; v_l) = 0$ and that inequality (6) holds true for $\alpha > \alpha_4$. Inequality (5) holds true for values of α much smaller than α_3. Since $\alpha_4 > \alpha_3$ for all $v_s > 0$, inequalities (5) and (6) can never be satisfied simultaneously. $\square$

Obviously, if spillovers are high enough to give the players with little know-how an incentive to cheat, the players with high know-how will also have an incentive to cheat. If there is no minimum R&D required, cooperation is a best response for the low know-how types. But given this strategy, also the high know-how types have no incentive to cheat. Therefore, there is never an equilibrium in which only the players with high know-how cooperate.[11]

6 Conclusion

Although there is a broad literature on research joint ventures the aspect of incomplete information has been widely ignored in the analysis. This is es-

[11] At this point it is worthwhile to note that in this given two-stage game no asymmetric strategies (in the sense that two players of the same type choose different first-stage actions A_i) exist in equilibrium. It is straightforward to show for example that if a player with high know-how always cheats against cooperating players of both types (which is beneficial for $\alpha > \alpha_1$), his opponent with high know-how has an incentive to deviate from his strategy and to also choose not to cooperate. Analogously all other possible asymmetric equilibria can be excluded.

pecially striking since information about …rms' know-how and technological competencies (including research costs and strategies) is de…nitely not public information. Thus, if two …rms cooperate it should be natural to assume that there is incomplete information about the other's know-how. And since the know-how of each …rm directly determines the possible payo¤s of all parties, …rms may face a dilemma: While revelation of information is necessary to indicate ones willingness to cooperate and to determine the bene…ts of cooperation, there is at the same time the risk to be exploited.

Although the model presented in this paper is very simpli…ed with respect to the underlying assumptions concerning the process of information revelation as well as the assumptions concerning R&D competition, it still generates some clear-cut results for the relevance of (privately known) know-how on a …rm's incentive to participate in research joint ventures.[12]

Turning back to the initially described problems one can suggest the following interpretations of the main propositions. The …rst results clarify the relevance of spillovers on …rms' incentives to cooperate in an incomplete information framework. In case spillovers are rather low, …rms (or scientists) have a strong incentive to cooperate, no matter how much know-how they have. The risk of being exploited is small compared to possible gains from unilateral know-how revelation. In contrast, if spillovers are large or technological competencies are easily transferable, …rms are in the classical Prisoner's Dilemma situation. They do not cooperate since the gains from "going alone" are large and they end up in an ine¢cient equilibrium. These results relate to those of Pérez-Castrillo & Sandonís [1996]. In comparison to Pérez-Castrillo & Sandonís [1996] our results demonstrate that competition on the R&D market is strategically as important as competition on future product markets for …rms' decisions to disclose know-how.

In contrast to earlier research on RJVs we assume that spillovers only occur if …rms reveal know-how with the intention to cooperate. Thus, we abstract from spillovers which are independent of …rms' strategies (and, say, smaller than ®;) as a consequence of backward engineering or espionage. It

[12] In fact the results are qualitatively very robust with respect to assumptions on the underlying R&D competition: Considering a simple one-shot contest with either Bertrand or Cournot competition yields analogous conclusions. The second stage can also be modeled as a …rst price auction or as a patent race in which the v_i are representing the Poisson intensities of invention or the success probabilities in a stochastic contest model. For the ease of exposition the presented analysis has been con…ned to the simplest version of R&D competition.

is easy to check that our results would not change qualitatively, if we additionally introduce such 'traditional' spillovers: All positive pro…ts under non-cooperation decrease, while the unilaterally cooperating …rm with high know-how would be slightly better o¤. In the complete information framework it was found that the impact of RJVs on welfare is positive only if (strategy independent) spillovers are su¢ciently large.[13] The results of the present model may help to qualify this statement: They suggest that in situations with low strategy-independent spillovers …rms prefer not to cooperate if know-how is easily transferable, due to the assumed dilemma. Hence, there seems to be only need for regulatory intervention if strategy-dependent as well as strategy-independent spillovers are low.

The second result speci…es the existence of type-dependent cooperation strategies in an incomplete information framework and thus relates to the question of cooperation between heterogeneous …rms. The higher is minimum R&D for a patentable innovation the higher is the incentive to cooperate for …rms with low know-how. Given intermediate spillovers, there exists an equilibrium in which the low know-how types cooperate, provided that the high know-how types unilaterally cheat. The higher is the dispersion of know-how between the two types (the more superior is the existing technology of one …rm), the larger is the interval of spillovers for this equilibrium to exist.

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