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ABSTRACT

Optimal Allocation of Ownership Rights in Dynamic R&D Alliances

We explore the dynamic evolution of property rights regimes in R&D alliances using the incomplete contract approach pioneered by Grossman, Hart and Moore (Hart and Moore, *Journal of Political Economy* (1990), and Grossman and Hart, *Journal of Political Economy* (1986)). In contrast to the standard analysis, the productive asset is an excludable public good such as a patent. Moreover, both firms can decide whether to disclose their know-how and invest effort. Know-how that has once been released cannot be concealed later. We characterize different scenarios in which the optimal ownership structure may change over time due to a trade-off between inducing know-how disclosure and ensuring maximum effort.

JEL Classification: L14, L22, O32
Keywords: incomplete contracts, partnerships, property rights, R&D alliances

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NON-TECHNICAL SUMMARY

This Paper offers a new perspective on the optimal allocation of ownership rights within dynamic R&D alliances. In the by now customary property rights approach as outlined by Hart (1995), it is usually assumed that the assets that are controlled by the owner are pure private goods such as machines or buildings. In contrast, we argue that when discussing the organization of R&D activities, the most crucial assets controlled by the owner, such as patents on innovations, may well have the properties of excludable public goods. In addition to vertical relationships (unilateral control being held by one of the two partners), we also consider two forms of horizontal partnerships in which both partners have equal power. Either both parties have veto power (the usual definition of joint ownership), or both parties are free to use the asset without the other partner's consent.

We focus on those partnerships in which both parties decide whether to disclose know-how to each other and both choose effort levels. It turns out that under plausible circumstances, the ownership structure that is optimal for inducing know-how disclosure may not be optimal for inducing maximum effort and *vice versa*. Since know-how disclosure by one party does not only increase the parties' collaboration pay-off but also the other party's default pay-off if this party can use the asset, the former party may not be willing to disclose its know-how unless it has veto power. Hence, if the relevant know-how of one partner strongly increases the other partner's default pay-off in case the alliance is resolved, the firms might be rather reluctant to disclose their know-how. On the other hand, a party is more willing to exert effort if the other party has no veto power, because effort exertion increases the collaboration surplus as well as the party's default pay-off if it can use the asset. Hence, a partnership in which no one has veto power may be optimal if it is important to induce both parties to choose high investments in effort.

The trade-off between disclosure and effort has interesting consequences if the R&D cooperation consists of two stages or is extended over two projects. We find that change of the ownership structure over time may be an equilibrium phenomenon. To see why the ownership structure that is optimal in the first project may not be optimal for the second project, notice that know-how which has once been released to the other firm cannot be taken back, and is hence also available to the other firm in the second project.

Whether or not know-how has already been exchanged in the first stage thus affects the optimal ownership structure in the second stage. This may help to explain the prevalence of dynamic R&D alliances with evolving property rights even if straightforward explanations such as changing market environments do not apply. Depending upon the relative importance of the parties' decisions in the two stages, we find that one of the following three scenarios will emerge: in the first scenario the parties initially choose a vertical ownership

structure, such that only one party has a veto right. In this case at least the party with veto power immediately discloses its know-how, and at the second stage the parties either switch veto power (if only one party has released its know-how) or transform their relationship into a horizontal partnership in which both parties can freely use the patent (if both parties have released their know-how). Interestingly, know-how disclosure of one party may thus be delayed until the second stage, even though the parties would always induce bilateral know-how disclosure if there were only one stage. In the second scenario the parties from the outset choose a horizontal arrangement in that initially both parties have veto power. They disclose their know-how at the early stage and then renegotiate the ownership structure of their partnership such that both parties can freely use the patent, which ensures maximum effort in the second stage. Finally, in the third scenario the parties start their alliance as a horizontal partnership arrangement without veto power of any party. While under some circumstances know-how is immediately disclosed and it is optimal to keep the ownership structure, in other cases know-how may not be disclosed until the second stage when it can be optimal to renegotiate to one of the other ownership structures, including the vertical ones, even if the firms are entirely symmetric *ex ante*, i.e. if the pay-off functions are identical. This is in contrast to the static setting, in which identical firms would never choose a vertical property rights regime.

Several implications of our analysis could in principle be tested in future work. For instance, when firms that form an R&D alliance are *ex ante* symmetric, in the sense that both partners' know-how is relevant and that also both partners' R&D effort is important for the venture's success, we should only observe a vertical ownership structure if the relationship is extended over several stages. Moreover, if a firm is particularly reluctant to disclose its know-how (since it would increase the default pay-off of the other party significantly), or if the early stage of the alliance is particularly important for a firm, then it should have veto power. Furthermore, while in partnerships with bilateral veto power we predict renegotiations that reduce veto power, partnerships with no veto power are the only ownership arrangement that may never be renegotiated.

1 Introduction

This paper offers a new perspective on the optimal allocation of ownership rights within dynamic R&D alliances. In the by now customary property rights approach as outlined by Hart (1995),[1] it is usually assumed that the assets that are controlled by the owner are pure private goods such as machines or buildings. In contrast, we argue that when discussing the organization of R&D activities, the most crucial assets controlled by the owner such as patents on innovations may well have the properties of excludable public goods. In addition to unilateral control by either firm A or firm B (i.e., a vertical relationship), we thus consider *two* forms of horizontal partnerships in which A and B have equal power: Either both parties have veto-power (the usual definition of joint ownership), or both parties are free to use the asset without the partner's consent.

While we certainly do not want to deny that heterogenous alliances such as the relationship between a small research unit and a large customer (as in Aghion and Tirole, 1994) are important, this paper is focused on the choice between the different vertical and horizontal property rights regimes when the two firms are more homogenous with respect to the relevance of their know-how for the alliance's success. In particular, we consider two parties that *both* decide whether to disclose know-how to each other and *both* choose effort levels. It turns out that under plausible circumstances, the ownership structure that is optimal for inducing know-how disclosure may not be optimal for inducing maximum effort and vice versa.

The trade-off between disclosure and effort has interesting consequences if the R&D cooperation consists of two stages or is extended over two projects. We find that change of the ownership structure over time may be an equilibrium phenomenon. To see why the ownership structure that is optimal in the first project may not be optimal for the second project, notice that know-how which has once been released to the other firm cannot be taken back, and is hence also available to the other firm in the second project. Whether or not know-how has already been exchanged in the first stage thus affects the optimal ownership structure in the second stage. This may help to explain the prevalence of dynamic R&D alliances with evolving

[1] See also the seminal papers by Grossman and Hart (1986) and Hart and Moore (1990).

property rights even if straightforward explanations such as changing market environments do not apply.

More specifically, consider the following situation. Suppose that there is an early stage and a later stage. In each stage, given the property rights regime, party A and party B noncooperatively decide whether to disclose their know-how and choose their effort levels. A party can either release its know-how at the early stage (which is efficient), or at the later stage, or never. In contrast, effort exertion at the early stage does not necessarily imply effort exertion at the later stage. After the parties have made their decisions, they learn the surplus that can be generated by collaboration (which is always ex post efficient) as well as the default payoffs that they can realize on their own (which depend on the ownership structure). Following Hart (1995), we assume that the parties split the collaboration surplus according to the Nash bargaining solution, with the default payoffs serving as threatpoint. While the initial property rights regime is fixed ex ante, the firms may renegotiate it before the second stage starts.

Since know-how disclosure by party A does not only increase the parties' collaboration surplus, but also party B's default payoff if party B can use the asset, party A may not be willing to disclose its know-how unless it has veto power. A similar argument holds for party B, so that bilateral veto-power can be the optimal ownership structure if it is sufficiently important to induce both parties to release their know-how. On the other hand, a party is more willing to exert effort if the other party has no veto power, because effort exertion increases the collaboration surplus as well as the party's default payoff if it can use the asset. Hence, a partnership in which no one has veto power may be optimal if it is important to induce both parties to choose high investments in effort. We focus on the most interesting case in which know-how disclosure is sufficiently important, so that in a one-shot situation bilateral veto-power which induces both parties to release their know-how would be optimal.

Yet, the analysis becomes more involved in the dynamic framework. Depending upon the relative importance of the parties' decisions in the two stages, we find that one of the following three scenarios will emerge: In the *first* scenario the parties initially choose a vertical ownership structure, such that only one party has a veto right. In this case at least the party with veto power immediately discloses its know-how, and at the second stage the parties either

switch veto power (if only one party has released its know-how) or transform their relationship into a horizontal partnership in which both parties can freely use the patent (if both parties have released their know-how). Interestingly, know-how disclosure of one party may thus be delayed until the second stage, even though the parties would always induce bilateral know-how disclosure if there were only one stage. In the *second* scenario the parties from the outset choose a horizontal arrangement in that initially both parties have veto power. They disclose their know-how at the early stage and then renegotiate the ownership structure of their partnership such that both parties can freely use the patent, which ensures maximum effort in the second stage. Finally, in the *third* scenario the parties start their alliance as a horizontal partnership arrangement without veto power of any party. While under some circumstances know-how is immediately disclosed and it is optimal to keep the ownership structure, in other cases know-how may not be disclosed until the second stage when it can be optimal to renegotiate to one of the other ownership structures, including the vertical ones, even if the firms are entirely symmetric ex ante, i.e. if the payoff functions are identical. This is in contrast to the static setting, in which identical firms would never choose a vertical property rights regime.

To the best of our knowledge, this is the first paper that analyzes the optimal organization of dynamic R&D alliances in the incomplete contract framework pioneered by Grossman and Hart (1986) and Hart and Moore (1990). The paper complements the work of Aghion and Tirole (1994), who discuss the relationship between two quite heterogenous firms, a small research unit and a larger customer. In their empirical study, Lerner and Merges (1998) point out that several aspects of alliances involving biotechnology firms are different from Aghion and Tirole's (1994) model. In particular, Aghion and Tirole (1994) assume a one-shot situation, while actual alliances are often dynamic and involve renegotiation of the ownership structure.[2] Moreover, Lerner and Merges (1998) stress that while Aghion and Tirole (1994) assume a vertical relationship, there are also alliances between pairs of biotechnology entities involving horizontal elements, and they emphasize that both firms may contribute know-how.[3] Our

[2]The relevance of the dynamic aspect of alliances has recently also been emphasized in the business economics literature, see for example Comes-Casseres (1996), Khanna et al. (1998), and Kogut (1991).

[3]The importance of sharing know-how is a common theme in the recent literature on R&D, cf. Bhattacharya,

paper analyzes in a dynamic setting the choice between horizontal and vertical ownership arrangements when the parties are homogenous in the sense that both have to decide whether to share their know-how and choose effort levels. Rosenkranz and Schmitz (1999) also discuss know-how disclosure in an incomplete contract framework, but there no dynamic issues are considered. In fact, most papers in the incomplete contract literature consider only a static setting. A notable exception is the work by Halonen (1997), who also analyzes a twice repeated game. However, her paper is quite different from ours, since her results are driven by the assumption that parties are honest with a small probability.[4]

The remainder of the paper is organized as follows. In Section 2 we present the model. In Section 3 we analyze the second stage game. We then analyze the first stage of the dynamic game and discuss our main results in Section 4. Some concluding remarks follow in Section 5. Finally, several proofs have been relegated to the appendix.

2 The model

Consider two parties, A and B, who aim at generating a surplus of $v_i(a_i, b_i, \alpha_i, \beta_i) = v_i^A(a_i, \beta_i) + v_i^B(b_i, \alpha_i)$ through collaboration at stage $i \in \{1, 2\}$ of their relationship. For concreteness, let $i = 1, 2$ denote two sequential R&D projects. Each time before surplus is realized, A and B decide whether to disclose their know-how to each other and choose effort levels $a_i \geq 0$ and $b_i \geq 0$, respectively, which are measured by their costs. Party A's know-how is denoted by the set $\overline{\alpha}$, while $\underline{\alpha} \subseteq \overline{\alpha}$ denotes the subset of A's know-how that is immediately disclosed to B by A's

Glazer and Sappington (1992), d'Aspremont, Bhattacharya and Gérard-Varet (1998), and Gandal and Scotchmer (1993). The fact that alliance agreements are often structured in order to efficiently transfer tacit knowledge has also been observed in the business economics literature; see Kogut (1988) and Hennart (1988).

[4]Renegotiation of simple ownership arrangements is also an issue in Nöldeke and Schmidt (1998). However, there it is assumed that the parties invest sequentially and the surplus is realized only once. In contrast, here we assume that the parties' choices of effort and know-how disclosure are made simultaneously, and surplus is realized each time after the choices have been made.

mere presence in the alliance.[5] Hence, party A chooses a non-empty subset $\alpha_i \in \{\underline{\alpha}, \overline{\alpha}\}$ of its know-how that B can use in project i, and similarly B chooses a non-empty subset $\beta_i \in \left\{\underline{\beta}, \overline{\beta}\right\}$ of its know-how that A can use. Of course, know-how that is once disclosed cannot be taken back, so A's choice of α_2 and B's choice of β_2 are constrained by $\alpha_2 \supseteq \alpha_1$ and $\beta_2 \supseteq \beta_1$. We assume that the effort levels as well as the know-how disclosure decisions are observable by the parties, but not verifiable by the courts. The time structure is illustrated in Figure 1.

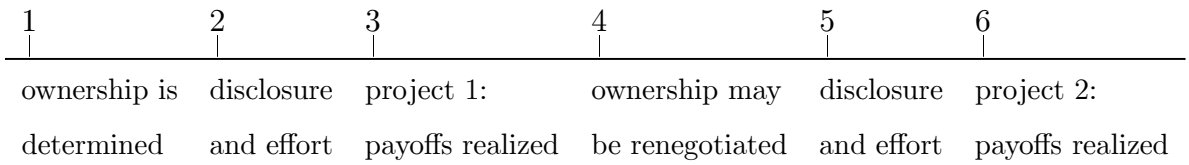

Figure 1

Surplus can only be generated with an asset that has the properties of an excludable public good, such as a patent on an innovation. At date $t = 1$, the parties write a contract that specifies the allocation of ownership rights over the asset.[6] The ownership structure can be renegotiated when the second project begins at date $t = 4$. After the parties have decided whether to disclose their know-how and chosen their effort levels at dates $t = 2$ and $t = 5$, the parties can decide whether or not to collaborate at dates $t = 3$ and $t = 6$, respectively. We assume that collaboration is always efficient, so that bargaining at these stages will according to the Coase - Theorem always lead to affirmative decisions. All negotiations are modelled using the Nash bargaining solution. The default payoffs that each party can realize on its own depend on the allocation of ownership rights. In the spirit of the incomplete contract approach

[5] In relation to the industrial organization literature, $\underline{\alpha}$ can be interpreted as that part of a firm's know-how which unintendedly spills over to the other firm when the alliance is formed (see, e.g., d'Aspremont and Jacquemin, 1988). One could also understand $\overline{\alpha}$ as the sum of codified and tacit knowledge in the sense of Chesbrough and Teece (1996). Codified know-how, which is represented by $\underline{\alpha}$, is difficult to protect, while tacit know-how can be strategically disclosed.

[6] Following the property rights approach as outlined by Hart (1995), we assume that the parties can make transfer payments to each other, so that they always agree on the ownership structure that maximizes total surplus.

introduced by Grossman and Hart (1986), we consider four different property rights regimes, $o_i \in \{A, B, J, N\}$.

Consider first the two vertical ownership structures which give one of the two parties veto power over the use of the asset.[7] If for project i party A is the owner ($o_i = A$), it earns $w_i^A(a_i, \beta_i)$ when the parties do not collaborate, and it can prevent the other party from using the asset such that B's default payoff is 0.[8] Analogously, if party B is the owner ($o_i = B$), it earns $w_i^B(b_i, \alpha_i)$, while A gets a payoff of 0 when the parties do not collaborate. Consider next the two kinds of horizontal partnerships. Usually, if there is one physical asset, joint ownership means that each party has veto power such that it can block the other party from using the asset. However, if the asset is a patent, joint ownership can also mean that each party can use the asset on its own. We call the former case *joint ownership with bilateral veto power* ($o_i = J$) and the latter case *joint ownership with no veto power* ($o_i = N$). If both players have veto power, each party receives a payoff of 0 if they do not collaborate, while in the case of no veto power, A's and B's default payoffs are $w^A(a_i, \beta_i)$ and $w^B(b_i, \alpha_i)$, respectively.[9]

In order to guarantee interior solutions, we assume that $v_i^A(a_i, \beta_i) \geq 0$ is strictly concave in a_i, with $\lim_{a_i \to 0} \frac{\partial}{\partial a_i} v_i^A(a_i, \beta_i) = \infty$ and $\lim_{a_i \to \infty} \frac{\partial}{\partial a_i} v_i^A(a_i, \beta_i) = 0$, and similar conditions are assumed to hold for v_i^B, w_i^A, and w_i^B.[10] To capture the idea that effort is a form of relationship specific investment, we make the usual assumption that total surplus as well as marginal

[7] Note that Geringer and Hebert (1989) report that the right of veto over strategic decisions often is explicitly incorporated in the formal agreement accompanying the creation of alliances.

[8] Of course, A can always use its own know-how $\overline{\alpha}$, which we suppress in the notation. Furthermore, note that w^A does not depend on b_i, i.e. we follow most of the incomplete contract literature and interpret effort as 'selfish' investment (in human capital, say) that does not improve the other party's default payoff.

[9] Hence, firm A's default payoff depends only on whether it can use the asset. Whether B can (also) use the asset could have an influence on A's default payoff if the parties were competitors on the same product market. Notice that this is also ruled out by the standard assumption that A's default payoff is not smaller under B-ownership than under bilateral veto power. In fact, as has been pointed out by Jacobini and McCreary (1994), numerous examples indicate that successful joint ventures generally seem not to involve direct competitors, but, rather, companies that produce parallel products and operate in nonoverlapping geographic markets. See also Bleeke and Ernst (1995).

[10] Throughout, all functions are assumed to be twice continuously differentiable.

surplus are always larger if the parties collaborate, $v_i(a_i, b_i, \alpha_i, \beta_i) > w_i^A(a_i, \beta_i) + w_i^B(b_i, \alpha_i)$, $\frac{\partial}{\partial a_i} v_i^A(a_i, \beta_i) \geq \frac{\partial}{\partial a_i} w_i^A(a_i, \beta_i) > 0$, and $\frac{\partial}{\partial b_i} v_i^B(b_i, \alpha_i) \geq \frac{\partial}{\partial b_i} w_i^B(b_i, \alpha_i) > 0$.

The collaboration surplus as well as party A's default payoff are larger if party A can use B's know-how, hence $v_i^A(a_i, \underline{\beta}) < v_i^A(a_i, \overline{\beta})$ and $w_i^A(a_i, \underline{\beta}) < w_i^A(a_i, \overline{\beta})$.[11] Moreover, it is natural to assume that collaboration with party B increases party A's (marginal) benefit more if A does not already have B's know-how.[12] In other words, know-how disclosure by a party is a less than perfect substitute for the collaboration with this party. Formally, $\left[v_i^A(a_i, \underline{\beta}) - w_i^A(a_i, \underline{\beta})\right] - \left[v_i^A(a_i, \overline{\beta}) - w_i^A(a_i, \overline{\beta})\right]$ is positive and increasing in a_i. Finally, we focus on the interesting case in which know-how disclosure is important.[13] Specifically, the impact of know-how disclosure on the marginal return to effort is supposed to be sufficiently strong, $\frac{\partial}{\partial a_i}\left[v_i^A(a_i, \overline{\beta}) - v_i^A(a_i, \underline{\beta})\right] > \frac{\partial}{\partial a_i} w_i^A(a_i, \underline{\beta})$. Note that this assumption is in particular satisfied whenever a party cannot make any profits if it has neither the other party's know-how nor its collaboration, i.e. if $w_i^A(a_i, \underline{\beta}) \equiv 0$. Similar conditions are supposed to hold for party B.

Given these assumptions, the *first best* effort levels and disclosure decisions at the stages $i \in \{1, 2\}$ are uniquely defined as follows: $\alpha_i^{FB} = \overline{\alpha}$, $\beta_i^{FB} = \overline{\beta}$, $a_i^{FB} = \arg\max v_i^A(a_i, \overline{\beta}) - a_i$, and $b_i^{FB} = \arg\max v_i^B(b_i, \overline{\alpha}) - b_i$. In a first-best world, know-how is immediately disclosed and the effort levels each time maximize the collaboration surplus.

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[11] Note that know-how disclosure is 'cooperative' in the sense of Che and Hausch (1999), i.e. it can only improve the *other* party's default payoff.

[12] Inspection of Lemma 1 below reveals that if this assumption did not hold, there would be no trade-off between know-how disclosure and effort.

[13] This assumption avoids tedious case distinctions and focuses our attention on the most interesting case in which bilateral veto power, which induces both parties to disclose know-how, would be optimal in the one-shot setting (see Proposition 1 below). Note that the fact that a vertical ownership structure is never optimal in the static case if the firms have identical payoff functions does not depend on this assumption.

3 The second stage: Optimal ownership in the static game

Consider the second project which begins at date $t = 4$. The parties first determine the ownership structure o_2 and then, at date $t = 5$, they decide whether to disclose know-how and choose how much effort to exert, taking α_1 and β_1 as given. Provided the parties anticipate that the surplus from bargaining at date $t = 6$ will be split according to the Nash bargaining solution with equal bargaining powers, the payoffs of party A and B at date $t = 5$ given o_2 are $U_2^A(a_2, b_2, \alpha_2, \beta_2|o_2)$ and $U_2^B(a_2, b_2, \alpha_2, \beta_2|o_2)$, where

$$U_i^A(a_i, b_i, \alpha_i, \beta_i|o_i) = \begin{cases} \frac{1}{2}\left[v_i(a_i, b_i, \alpha_i, \beta_i) + w_i^A(a_i, \beta_i)\right] - a_i & \text{if } o_i = A, \\ \frac{1}{2}\left[v_i(a_i, b_i, \alpha_i, \beta_i) - w_i^B(b_i, \alpha_i)\right] - a_i & \text{if } o_i = B, \\ \frac{1}{2}v_i(a_i, b_i, \alpha_i, \beta_i) - a_i & \text{if } o_i = J, \\ \frac{1}{2}\left[v_i(a_i, b_i, \alpha_i, \beta_i) - w_i^B(b_i, \alpha_i) + w_i^A(a_i, \beta_i)\right] - a_i & \text{if } o_i = N. \end{cases}$$

$U_i^B(a_i, b_i, \alpha_i, \beta_i|o_i)$ is defined analogously, such that the total surplus of the second stage is given by $v_2(a_2, b_2, \alpha_2, \beta_2) - a_2 - b_2$. The following lemma characterizes the parties' optimal know-how disclosure decisions α_2^* and β_2^* at date $t = 5$:

Lemma 1 *Given α_1, β_1, and the ownership structure o_2, the parties A and B, respectively, choose*

$$\alpha_2^* = \begin{cases} \overline{\alpha} & \text{if } o_2 \in \{A, J\}, \\ \alpha_1 & \text{if } o_2 \in \{B, N\}, \end{cases} \quad \text{and} \quad \beta_2^* = \begin{cases} \overline{\beta} & \text{if } o_2 \in \{B, J\}, \\ \beta_1 & \text{if } o_2 \in \{A, N\}. \end{cases}$$

Proof. See the appendix. ■

Hence, if a party has not already disclosed its know-how, it will do so at date $t = 5$ if and only if it has veto power. The intuitive reason is that by disclosing know-how a party that cannot prevent the other party from using the asset would improve the date $t = 6$ bargaining position of the *other* party. Yet, if a party has veto power, it can safely disclose its know-how since the other party cannot make use of the disclosed know-how without the asset.

Before proceeding, it will be useful for later reference to introduce the following definition.

Definition 1 *Let the effort levels a_i^h, a_i^m, a_i^l and b_i^h, b_i^m, b_i^l be implicitly defined as follows:*

$$\begin{aligned}\frac{\partial}{\partial a_i}\left[v_i^A(a_i^h,\overline{\beta})+w_i^A(a_i^h,\overline{\beta})\right] &= \frac{\partial}{\partial a_i}v_i^A(a_i^m,\overline{\beta})=\frac{\partial}{\partial a_i}\left[v_i^A(a_i^l,\underline{\beta})+w_i^A(a_i^l,\underline{\beta})\right]=2,\\ \frac{\partial}{\partial b_i}\left[v_i^B(b_i^h,\overline{\alpha})+w_i^B(b_i^h,\overline{\alpha})\right] &= \frac{\partial}{\partial b_i}v_i^B(b_i^m,\overline{\alpha})=\frac{\partial}{\partial b_i}\left[v_i^B(b_i^l,\underline{\alpha})+w_i^B(b_i^l,\underline{\alpha})\right]=2.\end{aligned}$$

Note that $a_i^h > a_i^m > a_i^l$ and $b_i^h > b_i^m > b_i^l$. Given ownership structure o_2 and the optimal disclosure decisions α_2^* and β_2^* according to Lemma 1, the parties' optimal effort levels a_2 and b_2 are uniquely determined by the first order conditions $\frac{\partial}{\partial a_2}U_2^A(a_2,b_2,\alpha_2^*,\beta_2^*|o_2)=0$ and $\frac{\partial}{\partial b_2}U_2^B(a_2,b_2,\alpha_2^*,\beta_2^*|o_2)=0$. Using Definition 1 we can characterize the parties' optimal effort choices as follows:

Lemma 2 *Given α_1, β_1, and o_2, at date $t=5$ the parties A and B, respectively, choose*

$$a_2^*=\begin{cases} a_2^h & \text{if } o_2\in\{A,N\},\beta_1=\overline{\beta},\\ a_2^m & \text{if } o_2\in\{B,J\},\\ a_2^l & \text{if } o_2\in\{A,N\},\beta_1=\underline{\beta},\end{cases}\quad \text{and}\quad b_2^*=\begin{cases} b_2^h & \text{if } o_2\in\{B,N\},\alpha_1=\overline{\alpha},\\ b_2^m & \text{if } o_2\in\{A,J\},\\ b_2^l & \text{if } o_2\in\{B,N\},\alpha_1=\underline{\alpha}.\end{cases}$$

Proof. See the appendix. ■

Note that party A's effort is largest if party B has no veto power, provided that party B has already disclosed its know-how. If party B has not yet disclosed its know-how, party A exerts more effort if party B has veto power, since only in this case will party B be willing to disclose its know-how at date $t=5$.

At date $t=4$, the parties will come to an agreement on the ownership structure o_2 that maximizes the sum of their anticipated payoffs. Since there can never be overinvestment with respect to the first best, an ownership structure that induces both parties to invest more effort also yields a larger total surplus, holding know-how disclosure decisions fixed. We can hence formulate our first result, which together with Lemma 1 and Lemma 2 completely characterizes the solution of the second stage game.

Proposition 1 *Given α_1 and β_1, the optimal ownership structure o_2^* for the second project is*

$$o_2^*=\begin{cases} J & \text{if } \alpha_1=\underline{\alpha},\ \beta_1=\underline{\beta},\\ N & \text{if } \alpha_1=\overline{\alpha},\ \beta_1=\overline{\beta},\\ A & \text{if } \alpha_1=\underline{\alpha},\ \beta_1=\overline{\beta},\\ B & \text{if } \alpha_1=\overline{\alpha},\ \beta_1=\underline{\beta}.\end{cases}$$

Proof. See the appendix. ■

In particular, together with Lemma 1 this proposition implies that the optimal ownership structure of the second project will always induce both parties to disclose their know-how, if they have not already done so in the previous stage. If the parties already have released their know-how, a partnership in which no party has veto-power is optimal, since this property rights regime induces maximum effort. Interestingly, it will turn out that the parties will not always induce immediate know-how disclosure in the first stage, even though under our assumptions this would always be optimal in the static game given that both parties still have to disclose their know-how. Moreover, we will find that in the dynamic game the parties might choose a vertical ownership structure with unilateral veto-power in the second stage, even if the parties are symmetric ex ante, i.e. if they have identical payoff functions. This is in contrast to the static game analyzed in this section, where a vertical ownership structure cannot be optimal in the symmetric case.

4 The first stage: Optimal ownership in the dynamic game

We now solve the first stage of the dynamic game using backward induction. Anticipating the outcome of the second stage game, at date $t = 2$ the parties decide whether to disclose their know-how and choose their first stage effort levels. Provided that the surplus from bargaining at date $t = 3$ and from ownership renegotiation at date $t = 4$ is again split according to the regular Nash bargaining solution, the total payoff of party A is given by

$$U^A(a_1, b_1, \alpha_1, \beta_1|o_1) = U_1^A(a_1, b_1, \alpha_1, \beta_1|o_1) + U_C^A(\alpha_1, \beta_1|o_1),$$

where party A's continuation payoff is given by

$$U_C^A(\alpha_1, \beta_1|o_1) = U_2^A(\cdot|o_1) + \frac{1}{2}\left[U_2^A(\cdot|o_2^*) + U_2^B(\cdot|o_2^*) - U_2^A(\cdot|o_1) - U_2^B(\cdot|o_1)\right],$$

$$\text{with } U_2^A(\cdot|o_1) = U_2^A(a_2^*, b_2^*, \alpha_2^*, \beta_2^*|o_1) \text{ and } U_2^A(\cdot|o_2^*) = U_2^A(a_2^*, b_2^*, \alpha_2^*, \beta_2^*|o_2^*).$$

Party B's total payoff $U^B(a_1, b_1, \alpha_1, \beta_1|o_1)$ is defined analogously. Taking party B's behavior as given, under ownership structure o_1 party A is willing to disclose its know-how if

$U^A(a_1, b_1, \overline{\alpha}, \beta_1|o_1) - U^A(a_1, b_1, \underline{\alpha}, \beta_1|o_1) \geq 0$.[14] It turns out that in some instances an equilibrium only exists if we let the parties mix between disclosure and non-disclosure. Let p denote the probability with which party A discloses its know-how at date $t = 2$, and let q denote B's probability of know-how disclosure.

Lemma 3 *Taking b_1 as given, party A chooses $p(b_1)$ as follows:*

$$p(b_1) \in \begin{cases} \{1\} & \text{if } o_1 \in \{J, A\} \text{ or if } o_1 \in \{N, B\} \text{ and } C_A(b_1) < 0, \\ [0,1] & \text{if } o_1 \in \{N, B\} \text{ and } C_A(b_1) = 0, \\ \{0\} & \text{if } o_1 \in \{N, B\} \text{ and } C_A(b_1) > 0, \end{cases}$$

$$\begin{aligned} \text{where } C_A(b_1) \;=\; & [v_1^B(b_1, \underline{\alpha}) - w_1^B(b_1, \underline{\alpha})] - [v_1^B(b_1, \overline{\alpha}) - w_1^B(b_1, \overline{\alpha})] \\ & -[v_2^B(b_2^h, \overline{\alpha}) - w_2^B(b_2^h, \overline{\alpha})] + [v_2^B(b_2^m, \overline{\alpha}) - b_2^m] - [w_2^B(b_2^l, \underline{\alpha}) - b_2^l]. \end{aligned}$$

Analogously, taking a_1 as given, party B chooses

$$q(a_1) \in \begin{cases} \{1\} & \text{if } o_1 \in \{J, B\} \text{ or if } o_1 \in \{N, A\} \text{ and } C_B(a_1) < 0, \\ [0,1] & \text{if } o_1 \in \{N, A\} \text{ and } C_B(a_1) = 0, \\ \{0\} & \text{if } o_1 \in \{N, A\} \text{ and } C_B(a_1) > 0, \end{cases}$$

$$\begin{aligned} \text{where } C_B(a_1) \;=\; & [v_1^A(a_1, \underline{\beta}) - w_1^A(a_1, \underline{\beta})] - [v_1^A(a_1, \overline{\beta}) - w_1^A(a_1, \overline{\beta})] \\ & -[v_2^A(a_2^h, \overline{\beta}) - w_2^A(a_2^h, \overline{\beta})] + [v_2^A(a_2^m, \overline{\beta}) - a_2^m] - [w_2^A(a_2^l, \underline{\beta}) - a_2^l]. \end{aligned}$$

Proof. See the appendix. ■

Hence, if party A has veto power, it will disclose its know-how. If party A has no veto power, it is only willing to disclose its know-how if the effort level b_1 of the other party is sufficiently small.[15] The reason that at date $t = 2$ party A may decide to disclose its know-how

[14] It is easily checked that this difference is independent of β_1, but depends on b_1 (see the proof of Lemma 3). Notice that in the standard model of Hart (1995) the agents' actions are not interdependet due to the usually assumed additive technology (cf. also Aghion and Tirole, 1994). In De Meza and Lockwood's (1998) variant of Hart's (1995) model an interdependency also arises and as a consequence they also have to consider mixed strategies, yet for quite different reasons (they postulate a different rule for splitting the renegotiation surplus; see also Chiu, 1998).

[15] Notice that our assumptions imply that C_A is increasing in b_1.

even though it has no veto power is that know-how disclosure induces an ownership structure o_2 that leads to a larger surplus in the second stage. This may overcompensate the fact that A's know-how disclosure improves the bargaining position of party B, provided that B's default payoff is sufficiently small, which is the case for a sufficiently small effort level b_1.

Let us now characterize the equilibrium effort levels and disclosure decisions at date $t = 2$ given ownership structure o_1. First, consider the case $o_1 \in \{A, J\}$, so that party A has veto power. We know from Lemma 3 that party A will always disclose its know-how. Party B's effort level is thus characterized by $\frac{\partial}{\partial b_1} U_1^B(a_1, b_1, \overline{\alpha}, \beta | o_1) = 0$, which for $o_1 \in \{A, J\}$ is equivalent to $\frac{\partial}{\partial b_1} v_1^B(b_1, \overline{\alpha}) = 2$. Hence, $b_1 = b_1^m$ by Definition 1. Second, consider the case $o_1 \in \{B, N\}$, so that party A has no veto power. If party A discloses its know-how with probability p, party B's effort level b_1 is then determined by

$$\frac{\partial}{\partial b_1} \left(p \left[v_1^B(b_1, \overline{\alpha}) + w_1^B(b_1, \overline{\alpha}) \right] + (1-p) \left[v_1^B(b_1, \underline{\alpha}) + w_1^B(b_1, \underline{\alpha}) \right] \right) = 2. \tag{1}$$

Using Lemma 3, if $C_A(b_1^h) \leq 0$, party A always discloses its know-how and party B chooses $b_1 = b_1^h$ in equilibrium. If $C_A(b_1^l) \geq 0$, the parties choose $\alpha_1 = \underline{\alpha}$ and $b_1 = b_1^l$, respectively. If $C_A(b_1^l) < 0 < C_A(b_1^h)$, in equilibrium party B chooses the effort level $b_1 = \hat{b}$ which leads to $C_A(\hat{b}) = 0$, so that party A is indifferent between disclosure and non-disclosure, and party A chooses $p = \hat{p}$ such that (1) holds with equality given $b_1 = \hat{b}$.

Analogous arguments can be made for the other party. In order to formally state the result as a proposition, it is useful to introduce the following definition, where $\hat{a}$ and $\hat{q}$ are implicitly determined by $C_B(\hat{a}) = 0$ and $\frac{\partial}{\partial a_1} \left(\hat{q} \left[v_1^A(\hat{a}, \overline{\beta}) + w_1^A(\hat{a}, \overline{\beta}) \right] + (1-\hat{q}) \left[v_1^A(\hat{a}, \underline{\beta}) + w_1^A(\hat{a}, \underline{\beta}) \right] \right) = 2$, respectively.[16]

Definition 2 *Let $\tilde{p}$, $\tilde{b}$, $\tilde{q}$ and $\tilde{a}$ be defined by*

$$(\tilde{p}, \tilde{b}) = \begin{cases} (1, b_1^h) & \text{if } C_A(b_1^h) \leq 0, \\ (0, b_1^l) & \text{if } C_A(b_1^l) \geq 0, \\ (\hat{p}, \hat{b}) & \text{otherwise,} \end{cases} \quad \text{and} \quad (\tilde{q}, \tilde{a}) = \begin{cases} (1, a_1^h) & \text{if } C_B(a_1^h) \leq 0, \\ (0, a_1^l) & \text{if } C_B(a_1^l) \geq 0, \\ (\hat{q}, \hat{a}) & \text{otherwise.} \end{cases}$$

[16] Note that in the following definition (p, b) and (q, a) do not represent the actions of one player but pairs of interdependent actions of both players.

Using the definition, the equilibrium behavior of the parties at date $t = 2$ can now be fully characterized for any given ownership structure o_1.

Proposition 2 *(i) If $o_1 = J$, then $a_1 = a_1^m, b_1 = b_1^m, \alpha_1 = \overline{\alpha}, \beta_1 = \overline{\beta}$.*

(ii) If $o_1 = N$, then $a_1 = \tilde{a}, b_1 = \tilde{b}, \alpha_1 = \overline{\alpha}$ with probability $\tilde{p}$, and $\beta_1 = \overline{\beta}$ with probability $\tilde{q}$.

(iii) If $o_1 = A$, then $a_1 = \tilde{a}, b_1 = b_1^m, \alpha_1 = \overline{\alpha}$, and $\beta_1 = \overline{\beta}$ with probability $\tilde{q}$.

(iv) Finally, if $o_1 = B$, then $a_1 = a_1^m, b_1 = \tilde{b}, \alpha_1 = \overline{\alpha}$ with probability $\tilde{p}$, and $\beta_1 = \overline{\beta}$.

Proof. This follows immediately from the preceding discussion. ■

Anticipating the emerging equilibrium levels of know-how disclosure and effort, at date $t = 1$ the parties agree on the ownership structure o_1 that maximizes the total surplus. If the parties choose $o_1 = J$, know-how will immediately be disclosed according to Proposition 2, and ownership will be renegotiated to $o_2 = N$ according to Proposition 1. Hence, in this case total surplus is given by

$$S(J) = v_1(a_1^m, b_1^m, \overline{\alpha}, \overline{\beta}) - a_1^m - b_1^m + v_2(a_2^h, b_2^h, \overline{\alpha}, \overline{\beta}) - a_2^h - b_2^h.$$

If the parties choose $o_1 = B$, party B always discloses its know-how at date $t = 2$, but whether or not party A is willing to disclose its know-how depends upon the parameter constellation. If party A discloses its know-how, the ownership structure will be renegotiated to $o_2 = N$, otherwise to $o_2 = A$. Total surplus is hence given by

$$\begin{aligned} S(B) &= \tilde{p}\left(v_1(a_1^m, \tilde{b}, \overline{\alpha}, \overline{\beta}) + v_2(a_2^h, b_2^h, \overline{\alpha}, \overline{\beta}) - b_2^h\right) \\ &\quad +(1-\tilde{p})\left(v_1(a_1^m, \tilde{b}, \underline{\alpha}, \overline{\beta}) + v_2(a_2^h, b_2^m, \overline{\alpha}, \overline{\beta}) - b_2^m\right) - a_1^m - \tilde{b} - a_2^h. \end{aligned}$$

$S(A)$ is given by an analogous expression. Finally, if $o_1 = N$, whether or not the parties disclose their know-how at date $t = 2$ depends upon the parameter constellation. If both parties disclose, the ownership structure will not be renegotiated. Otherwise a party that has not disclosed will get veto power in the second stage. Thus, total surplus is given by

$$\begin{aligned} S(N) &= \tilde{p}\tilde{q}\left(v_1(\tilde{a}, \tilde{b}, \overline{\alpha}, \overline{\beta}) + v_2(a_2^h, b_2^h, \overline{\alpha}, \overline{\beta}) - a_2^h - b_2^h\right) \\ &\quad +(1-\tilde{p})\tilde{q}\left(v_1(\tilde{a}, \tilde{b}, \underline{\alpha}, \overline{\beta}) + v_2(a_2^h, b_2^m, \overline{\alpha}, \overline{\beta}) - a_2^h - b_2^m\right) \end{aligned}$$

$$+\tilde{p}(1-\tilde{q})\left(v_1(\tilde{a},\tilde{b},\overline{\alpha},\underline{\beta})+v_2(a_2^m,b_2^h,\overline{\alpha},\overline{\beta})-a_2^m-b_2^h\right)$$
$$+(1-\tilde{p})(1-\tilde{q})\left(v_1(\tilde{a},\tilde{b},\underline{\alpha},\underline{\beta})+v_2(a_2^m,b_2^m,\overline{\alpha},\overline{\beta})-a_2^m-b_2^m\right)-\tilde{a}-\tilde{b}.$$

We can now determine the optimal ownership structure o_1. Consider first the case $C_B(a_1^h) \leq 0$ and $C_A(b_1^h) \leq 0$, so that $\tilde{p}=\tilde{q}=1, \tilde{a}=a_1^h, \tilde{b}=b_1^h$. It is straightforward to see that then joint ownership with no veto power leads to the largest total surplus. Next, consider the case $C_B(a_1^l) \geq 0$ and $C_A(b_1^l) \geq 0$, so that $\tilde{p}=\tilde{q}=0, \tilde{a}=a_1^l, \tilde{b}=b_1^l$. It is easily checked that in this case joint ownership with veto power leads to the largest surplus. If $C_B(a_1^l) \geq 0$ and $C_A(b_1^h) \leq 0$, then $\tilde{p}=1, \tilde{q}=0, \tilde{a}=a_1^l, \tilde{b}=b_1^h$, so that B-ownership is optimal. An analogous argument can be made for A-ownership in the case $C_B(a_1^h) \leq 0$ and $C_A(b_1^l) \geq 0$.

The remaining intermediate cases require a somewhat closer examination. Let us consider the case $C_B(a_1^l) < 0 < C_B(a_1^h)$, so that $\tilde{q}=\hat{q}$ and $\tilde{a}=\hat{a}$. Suppose first that $C_A(b_1^h) \leq 0$, which implies $\tilde{p}=1$ and $\tilde{b}=b_1^h$. A comparison shows that the ownership structures in which party A has veto power are dominated. Moreover, $o_1=N$ leads to a larger surplus than $o_1=B$ if $S(N)-S(B)>0$,[17] which in the present case is equivalent to $I_B>0$, where

$$\begin{aligned} I_B &= \hat{q}\left(v_1^A(\hat{a},\overline{\beta})+v_2^A(a_2^h,\overline{\beta})-a_2^h\right)+(1-\hat{q})\left(v_1^A(\hat{a},\underline{\beta})+v_2^A(a_2^m,\overline{\beta})-a_2^m\right)-\hat{a} \\ &\quad -\left(v_1^A(a_1^m,\overline{\beta})-a_1^m+v_2^A(a_2^h,\overline{\beta})-a_2^h\right). \end{aligned}$$

Note that I_B can only be positive when $\hat{a}>a_1^m$, so that the disadvantage of a sometimes smaller effort level in the second stage can be overcompensated by the advantage of a larger effort level in the first stage. Now suppose $C_A(b_1^l) \geq 0$, which implies $\tilde{p}=0$ and $\tilde{b}=b_1^l$. It is easily checked in a similar way that the optimal ownership structure is $o_1=J$ if $I_B<0$ and $o_1=A$ otherwise.

Analogously, consider now the case $C_A(b_1^l) < 0 < C_A(b_1^h)$, which implies $\tilde{p}=\hat{p}, \tilde{b}=\hat{b}$. If $C_B(a_1^h) \leq 0$, it is always optimal that party B has no veto power. Whether $o_1=N$ or $o_1=A$ is optimal depends upon the sign of $S(N)-S(A)=I_A$, where

$$\begin{aligned} I_A &= \hat{p}\left(v_1^B(\hat{b},\overline{\alpha})+v_2^B(b_2^h,\overline{\alpha})-b_2^h\right)+(1-\hat{p})\left(v_1^B(\hat{b},\underline{\alpha})+v_2^B(b_2^m,\overline{\alpha})-b_2^m\right)-\hat{b} \\ &\quad -\left(v_1^B(b_1^m,\overline{\alpha})-b_1^m+v_2^B(b_2^h,\overline{\alpha})-b_2^h\right). \end{aligned}$$

[17] Of course, if equality holds, the parties are indifferent between $o_1=N$ and $o_1=B$. For brevity, we do not explicitly point out cases of indifference in what follows.

If $C_B(a_1^l) \geq 0$, the optimal ownership structure is $o_1 = B$ whenever $I_A > 0$, and $o_1 = J$ otherwise. Finally, suppose that $C_B(a_1^l) < 0 < C_B(a_1^h)$ and $C_A(b_1^l) < 0 < C_A(b_1^h)$. It is straightforward to verify that then $S(N)-S(J) = I_A+I_B, S(N)-S(A) = I_A, S(N)-S(B) = I_B$. Hence, the optimal ownership structure gives party A veto power whenever $I_A < 0$, and it gives party B veto power whenever $I_B < 0$.[18] The following proposition summarizes the discussion (cf. Table 1) and completes the solution of our problem.

Proposition 3 *(i) First, assume that $C_B(a_1^h) \leq 0$ or that $C_B(a_1^l) < 0 < C_B(a_1^h)$ and $I_B > 0$. If $C_A(b_1^h) \leq 0$ or if $C_A(b_1^l) < 0 < C_A(b_1^h)$ and $I_A > 0$, then the optimal ownership structure at date $t = 1$ is given by $o_1 = N$, otherwise by $o_1 = A$.*

(ii) Second, assume that $C_B(a_1^l) \geq 0$ or that $C_B(a_1^l) < 0 < C_B(a_1^h)$ and $I_B < 0$. If $C_A(b_1^l) \geq 0$ or if $C_A(b_1^l) < 0 < C_A(b_1^h)$ and $I_A < 0$, then $o_1 = J$, otherwise $o_1 = B$.

Proof. This follows immediately from the preceding discussion. ■

		$C_A(b_1^h) \leq 0$	$C_A(b_1^l) < 0 < C_A(b_1^h)$		$C_A(b_1^l) \geq 0$
			$I_A > 0$	$I_A < 0$	
$C_B(a_1^h) \leq 0$		N	N	A	A
$C_B(a_1^l) < 0 < C_B(a_1^h)$	$I_B > 0$	N	N	A	A
	$I_B < 0$	B	B	J	J
$C_B(a_1^l) \geq 0$		B	B	J	J

Table 1. Optimal ownership structure in the first stage.

We can now interpret our findings and characterize three different scenarios. First, recall that under our assumptions a vertical ownership structure could never be optimal in the static game starting at date $t = 4$, provided that either no one or both parties had know-how to disclose. This result is no longer true in the dynamic game. Even though initially both firms

[18] For instance, if $I_A > 0$ and $I_B < 0$, then the optimal ownership structure is $o_1 = B$, since $S(N) > S(A), S(N) < S(B)$ and $S(B) - S(J) = I_A > 0$.

have know-how to disclose, a vertical relationship that gives only one party veto power can be optimal at date $t = 1$ if the firms are not completely symmetric. For instance, assume that party A's default payoff in the first stage is relatively more increased by party B's know-how disclosure than vice versa, so that B will be more reluctant to disclose its know-how, which favors the case $C_B(a_1^l) > 0$ and $C_A(b_1^l) < 0$. In this case it is optimal to give only party B veto power, which guarantees know-how disclosure by both parties and induces B to invest more than under $o_1 = J$, while A does not invest less. Alternatively, assume party B's technology is such that its first stage payoff is more important than its second stage payoff, and vice versa for party A, so that $I_B < 0$ and $I_A > 0$. Proposition 3 again shows that under these circumstances it may well be optimal to choose B-ownership in the first stage. It is true that then party A's know-how disclosure may sometimes be delayed to the second stage, but this is overcompensated by a higher effort level of party B compared to $o_1 = J$. If under B-ownership party A does not disclose its know-how in stage 1, ownership will be renegotiated to $o_1 = A$ in order to induce disclosure in stage 2, otherwise to $o_2 = N$, which implies the largest possible second stage efforts. The following corollary summarizes our findings for the *first* scenario.

Corollary 1 *If one party is relatively more reluctant to disclose its know-how or if the relative importance of first and second stage payoffs is different among the parties, a vertical ownership structure can be optimal in the first stage of the dynamic game. A vertical ownership structure will always be renegotiated. Either will veto rights eventually be switched, or the parties will form a partnership in which no one has veto power.*

Consider now situations in which the firms are more symmetric, such that $sign(C_B(a_1^l)) = sign(C_A(b_1^l))$, $sign(C_B(a_1^h)) = sign(C_A(b_1^h))$, and $sign(I_A) = sign(I_B)$ hold. Proposition 3 says that the parties will then agree to form a horizontal partnership at date $t = 1$. In the *second* scenario the parties choose $o_1 = J$. If both parties are reluctant to disclose their know-how in the first stage since disclosure has a strong impact on the other party's default payoff ($C_B(a_1^h) < 0$), it is optimal to choose joint ownership with bilateral veto power, which always induces both parties to disclose their know-how. Moreover, $o_1 = J$ can also be optimal if the parties' first stage payoffs are relatively more important than their second stage payoffs (this is intuitively clear, since $o_1 = J$ is the optimal ownership structure in the static game when both parties

have know-how to disclose). In the second stage, the firms' focus shifts from inducing know-how disclosure to ensuring maximum effort. Hence, we can state the following result.

Corollary 2 *In a sufficiently symmetric situation, the parties choose a horizontal ownership structure in the first stage. They favor joint ownership with bilateral veto power if both parties are sufficiently reluctant to disclose their know-how or if the parties's first stage payoffs are more important than their second stage payoffs. The parties then immediately disclose their know-how, such that ownership will always be renegotiated to $o_2 = N$ in the second stage.*

Finally, in the remaining *third* scenario the parties choose joint ownership with no veto power from the outset. In particular, this can be optimal whenever know-how disclosure has a sufficiently weak impact on the parties' default payoffs. Note that $o_1 = N$ is the only ownership structure that may not be renegotiated at date $t = 4$.[19] However, if no party discloses its know-how at date $t = 2$, the ownership structure will be renegotiated to $o_2 = J$ in the second stage. If only one party discloses know-how, in the second stage a vertical ownership structure will be chosen. It is interesting to note that this may even happen if the parties are ex ante completely symmetric (i.e., $v_i^A \equiv v_i^B, w_i^A \equiv w_i^B$), which is in stark contrast to the static setting. This scenario can hence be summarized as follows.

Corollary 3 *In the symmetric cases not covered by Corollary 2, the parties initially choose joint ownership with no veto power. While this is the only ownership structure that may not be renegotiated, in the second stage veto power will be given to any party that has not yet disclosed know-how. In particular, a vertical ownership structure can then emerge, even if the parties are completely symmetric ex ante.*

Notice that the three scenarios fully exhaust the possible equilibrium structures derived in Proposition 3.

[19] Notice that the case in which $o_1 = o_2 = N$ is optimal is the only one in which it can even be possible to achieve the first best within our framework (this happens if $\frac{\partial}{\partial a_i} v_i^A \equiv \frac{\partial}{\partial a_i} w_i^A$ and $\frac{\partial}{\partial b_i} v_i^B \equiv \frac{\partial}{\partial b_i} w_i^B$).

5 Conclusion

In this paper we have analyzed the organization of dynamic R&D alliances between two parties that both decide whether to disclose their know-how and both choose investment levels. Given that the asset controlled by the owner is an excludable public good such as a patent, we have characterized different scenarios that show how the allocation of control rights may be renegotiated over time.

Several implications of our analysis could in principle be tested in future work. For instance, when firms that form an R&D alliance are ex ante symmetric, we should only observe a vertical ownership structure if the relationship is extended over several stages. Moreover, if a firm is particularly reluctant to disclose its know-how (since it would increase the default payoff of the other party significantly), or if the early stage of the alliance is particularly important for a firm, then it should have veto power. Furthermore, while in partnerships with bilateral veto power we predict renegotiations that reduce veto power, partnerships with no veto power are the only ownership arrangement that may never be renegotiated.

A crucial assumption in our analysis is that contracts are incomplete, such that ex ante only simple ownership structures can be contractually determined. While this assumption seems to be particularly plausible in the R&D context (see Aghion and Tirole, 1994), we should note that theorists are still debating about the foundations of the incomplete contract approach.[20] Recently, Tirole (1999) has argued that the approach is a useful shortcut for building simple models that capture important aspects of reality and that can thus help us to organize our thoughts about the design of institutions. We hope that the reader finds this view confirmed by our paper.

[20] Cf. Maskin and Tirole (1999) and Hart and Moore (1999).

Appendix

Proof of Lemma 1.

First, consider party A. Since $\alpha_2 \supseteq \alpha_1$, we know that $\alpha_2 = \overline{\alpha}$ if $\alpha_1 = \overline{\alpha}$. If $\alpha_1 = \underline{\alpha}$, party A discloses its know-how whenever $\Delta := U_2^A(a_2, b_2, \overline{\alpha}, \beta_2|o_2) - U_2^A(a_2, b_2, \underline{\alpha}, \beta_2|o_2) \geq 0$. Since

$$\Delta = \begin{cases} \frac{1}{2}\left[v_2^B(b_2, \overline{\alpha}) - v_2^B(b_2, \underline{\alpha})\right] > 0 & \text{if } o_i \in \{A, J\} \\ \frac{1}{2}\left[v_2^B(b_2, \overline{\alpha}) - v_2^B(b_2, \underline{\alpha}) - \left(w_2^B(b_2, \overline{\alpha}) - w_2^B(b_2, \underline{\alpha})\right)\right] < 0 & \text{if } o_i \in \{B, N\} \end{cases},$$

the first part of the lemma is proved. Second, party B's decision problem can be treated in a similar way. ■

Proof of Lemma 2.

Consider party A. The first-order condition $\frac{\partial}{\partial a_2} U_2^A(a_2, b_2, \alpha_2^*, \beta_2^*|o_2) = 0$ is given by $\frac{\partial}{\partial a_2}\left[v_2^A(a_2, \beta_2^*) + w_2^A(a_2, \beta_2^*)\right] = 2$ if $o_2 \in \{A, N\}$ and by $\frac{\partial}{\partial a_2} v_2^A(a_2, \beta_2^*) = 2$ if $o_2 \in \{B, J\}$. Moreover, we know from Lemma 1 that $\beta_2^* = \overline{\beta}$ if $o_2 \in \{B, J\}$ and $\beta_2^* = \beta_1$ if $o_2 \in \{A, N\}$. This proves the first part of the Lemma. The second part can be shown analogously. ■

Proof of Proposition 1.

If $\alpha_1 = \overline{\alpha}$ and $\beta_1 = \overline{\beta}$, it follows from Lemma 2 that party A's effort level is largest if $o_2 \in \{A, N\}$ and party B's effort level is largest if $o_2 \in \{B, N\}$. Hence, the optimal ownership structure is given by $o_2 = N$. If $\alpha_1 = \underline{\alpha}$ and $\beta_1 = \underline{\beta}$, party A's largest effort level is induced by $o_2 \in \{B, J\}$, and party B's largest effort level is induced by $o_2 \in \{A, J\}$. Hence, $o_2 = J$ is optimal, since by Lemma 1 it also induces both parties to disclose their know-how. If $\alpha_1 = \overline{\alpha}$ and $\beta_1 = \underline{\beta}$, the ownership structure $o_2 \in \{B, J\}$ is best for party A's incentives to exert effort, and $o_2 \in \{B, N\}$ is best for party B's incentives. Therefore $o_2 = B$, which also induces B to reveal its know-how, is optimal. Finally, similar arguments show that $o_2 = A$ is optimal if $\alpha_1 = \underline{\alpha}$ and $\beta_1 = \overline{\beta}$. ■

Proof of Lemma 3.

First, assume that $o_1 \in \{J, A\}$. Given that party B chooses $\beta_1 = \overline{\beta}$, party A prefers $\alpha_1 = \overline{\alpha}$ if $U^A(a_1, b_1, \overline{\alpha}, \overline{\beta}|o_1) \geq U^A(a_1, b_1, \underline{\alpha}, \overline{\beta}|o_1)$. Since by Lemma 1 we know that $\alpha_2^* = \overline{\alpha}$ in the case under consideration, $U_2^A(\cdot|o_1)$ does not depend on α_1. Hence,

$$U^A(a_1, b_1, \overline{\alpha}, \overline{\beta}|o_1) - U^A(a_1, b_1, \underline{\alpha}, \overline{\beta}|o_1)$$

$$
\begin{aligned}
&= U_1^A(a_1, b_1, \overline{\alpha}, \overline{\beta}|o_1) - U_1^A(a_1, b_1, \underline{\alpha}, \overline{\beta}|o_1) \\
&\quad + \frac{1}{2}\left[U_2^A(a_2^h, b_2^h, \overline{\alpha}, \overline{\beta}|N) + U_2^B(a_2^h, b_2^h, \overline{\alpha}, \overline{\beta}|N)\right. \\
&\quad \left. - U_2^A(a_2^h, b_2^m, \overline{\alpha}, \overline{\beta}|A) - U_2^B(a_2^h, b_2^m, \overline{\alpha}, \overline{\beta}|A)\right],
\end{aligned}
$$

where Lemma 2 and Proposition 1 have been used (in particular, $o_2 = N$ if $\alpha_1 = \overline{\alpha}$ and $o_2 = A$ if $\alpha_1 = \underline{\alpha}$). Since $b_2^h > b_2^m$, it follows that the preceding expression is always positive, so that party A chooses $\alpha_1 = \overline{\alpha}$. Given that party B chooses $\beta_1 = \underline{\beta}$, we obtain

$$
\begin{aligned}
&U^A(a_1, b_1, \overline{\alpha}, \underline{\beta}|o_1) - U^A(a_1, b_1, \underline{\alpha}, \underline{\beta}|o_1) \\
= \;& U_1^A(a_1, b_1, \overline{\alpha}, \underline{\beta}|o_1) - U_1^A(a_1, b_1, \underline{\alpha}, \underline{\beta}|o_1) \\
&+ \frac{1}{2}\left[U_2^A(a_2^m, b_2^h, \overline{\alpha}, \overline{\beta}|B) + U_2^B(a_2^m, b_2^h, \overline{\alpha}, \overline{\beta}|B)\right. \\
&\left. - U_2^A(a_2^m, b_2^m, \overline{\alpha}, \overline{\beta}|J) - U_2^B(a_2^m, b_2^m, \overline{\alpha}, \overline{\beta}|J)\right],
\end{aligned}
$$

since $\alpha_1 = \overline{\alpha}$ leads to $o_2 = B$ and $\alpha_1 = \underline{\alpha}$ leads to $o_2 = J$. It is easy to verify that $U^A(a_1, b_1, \overline{\alpha}, \underline{\beta}|o_1) - U^A(a_1, b_1, \underline{\alpha}, \underline{\beta}|o_1) = U^A(a_1, b_1, \overline{\alpha}, \overline{\beta}|o_1) - U^A(a_1, b_1, \underline{\alpha}, \overline{\beta}|o_1)$. Hence, party A always chooses $\alpha_1 = \overline{\alpha}$, independent of party B's behavior.

Second, consider the case $o_1 \in \{N, B\}$. It is straightforward to verify in an analogous way that independent of β_1 we get

$$
\begin{aligned}
&U^A(a_1, b_1, \overline{\alpha}, \beta_1|o_1) - U^A(a_1, b_1, \underline{\alpha}, \beta_1|o_1) \\
= \;& \frac{1}{2}\Big([v_1^B(b_1, \overline{\alpha}) - w_1^B(b_1, \overline{\alpha})] - [v_1^B(b_1, \underline{\alpha}) - w_1^B(b_1, \underline{\alpha})] \\
&+ [w_2^B(b_2^l, \underline{\alpha}) - b_2^l] - [v_2^B(b_2^m, \overline{\alpha}) - b_2^m] \\
&+ [v_2^B(b_2^h, \overline{\alpha}) - w_2^B(b_2^h, \overline{\alpha})]\Big) \\
= \;& -\frac{1}{2}C_A(b_1).
\end{aligned}
$$

Finally, party B's choice of $q(a_1)$ can be handled similarly. ■

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