Optimal allocation of ownership rights in dynamic R&D alliances

Stephanie Rosenkranz and Patrick W. Schmitz *

University of Bonn, Wirtschaftspolitische Abteilung, Adenauerallee 24-42, D-53113 Bonn, Germany

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Abstract

We explore the dynamic evolution of property rights regimes in R&D alliances using the incomplete contract approach pioneered by Grossman, Hart, and Moore. 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.

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1. Introduction

This paper offers a new perspective on the optimal allocation of ownership rights within dynamic R&D alliances. As an illustration, consider collaboration in software development between two companies. Each company has specific abilities that are valuable for two successive joint projects, e.g., knowledge about the application at which the new products will be aimed, experience with particular platforms, expertise regarding Internet technologies, and so on. While disclosure of such intangible know-how has an important impact on the success of the alliance, it is often not verifiable. Moreover,
success will certainly depend on how much effort the companies invest, which may also be
nonverifiable. What can be contractually determined is the allocation of control rights over
the productive assets, i.e., a property rights regime.

In the by now customary property rights approach based on incomplete contracts and the
hold-up problem 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.

We study the choice between the different vertical and horizontal property rights
regimes when the two firms 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. For example, assume that the companies in our illustration develop a second
edition of a software product, say with more features or for a different platform. 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.\(^2\)

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

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\(^1\) See the seminal papers by Grossman and Hart (1986) and Hart and Moore (1990), and cf. Schmitz (2001)
for a nontechnical survey of the recent literature.

\(^2\) The fact that alliances are often dynamic is, e.g., a topic addressed in the empirical studies of Bleeke and
Ernst (1995), who find that in their sample the median life span of an alliance is seven years, and Chan et al.
(1997), who report an average life span of about five years. Based on their study of alliances between US and
Chinese firms, Yan and Gray (1994) argue that joint ventures need to reconfigure over time to ensure overall
performance.
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 (a) the relative importance of the two stages and (b) the degree of the investments’ relationship specificity, we find that one of the following three scenarios will emerge:\(^3\) 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 asset (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 asset, 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 vertical relationship between two quite

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\(^3\) In Section 4 below, we discuss some real world examples from the IT industry that reflect this richness of possible outcomes.
heterogenous firms, a small wealth-constrained research unit and a large customer. While we certainly do not want to deny the importance of such alliances, our paper analyzes the choice between horizontal and vertical ownership arrangements when the parties are more homogenous in the sense that both may contribute know-how and choose effort levels. Moreover, Aghion and Tirole (1994) assume a one-shot situation, while we focus on alliances in a dynamic setting that involve renegotiation of the ownership structure.

In fact, most papers in the incomplete contract literature consider only a static setting. Notable exceptions include Halonen (1995) and Baker et al. (2002), who analyze infinitely repeated games. Renegotiation of 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.

Finally, it should be noted that there exists a vast literature on research joint ventures in the industrial organization literature. While this literature is largely concerned with competitive motives for engaging in horizontal R&D cooperation among partners that compete on the output market, our model is complementary to this work since we focus on alliances between firms where there is no potential for competitive conflict. Moreover, while the IO literature typically ignores organizational aspects and simply assumes that firms cooperating in R&D choose their efforts jointly in order to maximize joint profits, we follow the property rights theory of the firm and analyze how control rights over the

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4 The importance of sharing know-how is a common theme in the recent literature on R&D, cf. Bhattacharya et al. (1992), d’Aspremont et al. (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). In their empirical study, Chan et al. (1997) recently pointed out that alliances between firms that are homogenous in our sense tend to create more value if the alliance involves the transfer or pooling of technical knowledge.

5 See also Rosenkranz and Schmitz (1999) for a brief discussion of know-how disclosure in a one-shot incomplete contract framework. The relevance of the dynamic aspect of alliances has recently also been emphasized in the business economics literature, see, e.g., Comes-Casseres (1996), Khanna et al. (1998), and Kogut (1991).

6 Hart (2001) has recently criticized the infinitely repeated game approach since people have finite lives and threats to punish may not be renegotiation-proof. For twice repeated games, see Halonen (1997), where the players are honest with a small probability, and Rosenkranz and Schmitz (2001), where multiple equilibria in the second stage may be used to punish deviations in the first stage in a renegotiation-proof way.

7 Nöldeke and Schmidt (1998) assume that more complicated ownership arrangements are possible, while we follow Hart’s (1995) standard approach and consider only simple unconditional ownership structures. For more on sequential investments and the hold-up problem, see also De Fraja (1999) and the literature discussed there.


9 Based on their study of more than 200 alliances, Bleeke and Ernst (1995) conclude that enduring ventures are often alliances of complementary equals, i.e., two strong partners with nonoverlapping product and geographic positions. Jacobini and McCreary (1994) also point out that numerous examples indicate that successful joint ventures often do not involve direct competitors, but rather companies that produce parallel products and operate in nonoverlapping geographic markets.
productive assets in the research process should be allocated in order to induce know-how disclosure and maximum efforts.

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 Appendix A.

2. The model

Consider two risk-neutral parties, A and B, who aim at generating a surplus of

\[ v_i(a_i, b_i, \alpha_i, \beta_i) = v^A_i(a_i, \beta_i) + v^B_i(b_i, \alpha_i) \]

through collaboration at stage \( i \in \{1, 2\} \) of their relationship.\(^{10}\) 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 \( \alpha \), while \( \alpha \subset \alpha \) denotes the subset of A’s know-how that is immediately disclosed to B by A’s mere presence in the alliance.\(^{11}\) Hence, party A decides whether \( \alpha_i = \alpha \) or \( \alpha_i = \overline{\alpha} \) is the additional know-how that party B can use in project \( i \), and similarly B chooses whether \( \beta_i = \beta \) or \( \beta_i = \overline{\beta} \) is the additional know-how that A can use. Of course, know-how that is once disclosed cannot be taken back, so A’s choice of \( \alpha_2 \) and B’s choice of \( \beta_2 \) are constrained by \( \alpha_2 \supseteq \alpha_1 \) and \( \beta_2 \supseteq \beta_1 \), respectively. 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 Fig. 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. 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. The ownership structure can be renegotiated when the second project begins at date \( t = 4 \). After the parties have decided whether to disclose their

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Fig. 1. The sequence of events.

\(^{10}\) Notice that the actual surplus may well be a random variable, but due to risk-neutrality we can confine our attention to the expected value.

\(^{11}\) In relation to the industrial organization literature, \( \alpha \) 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 \( \alpha \), is difficult to protect, while tacit know-how can be strategically disclosed.
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 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. If for project $i$ party $A$ is the owner ($o_i = A$), it earns $w^A_i(a_i, \beta_i)$ 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. Analogously, if party $B$ is the owner ($o_i = B$), it earns $w^B_i(b_i, \alpha_i)$, 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 $w^A_i(a_i, \beta_i)$ and $w^B_i(b_i, \alpha_i)$, respectively. In order to guarantee interior solutions, we assume that $v^A_i(a_i, \beta_i) \geq 0$ is strictly concave in $a_i$, with
\[
\lim_{a_i \to 0} \frac{\partial}{\partial a_i} v^A_i(a_i, \beta_i) = \infty \quad \text{and} \quad \lim_{a_i \to \infty} \frac{\partial}{\partial a_i} v^A_i(a_i, \beta_i) = 0,
\]
and similar conditions are assumed to hold for $v^B_i$, $w^A_i$, and $w^B_i$. 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 surplus are always larger if the parties collaborate:

12 Notice that we follow the by now standard approach of the incomplete contracts literature. De Meza and Lockwood (1998) and Chiu (1998) have argued that instead of the split-the-difference-rule the outside option principle should be applied if bargaining proceeds according to an alternating offers game with discounting. Yet, there are also several noncooperative bargaining games which can serve as a foundation for the standard approach, such as alternating offers with a risk of breakdown or a perturbed Nash demand game (see Osborne and Rubinstein (1990)). Alternatively, one could simply assume that each party can make a take-it-or-leave-it offer with probability $1/2$ (see Hart (1995)).

13 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.

14 Of course, $A$ can always use its own know-how, 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.

15 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.

16 Throughout, all functions are assumed to be twice continuously differentiable.
\[ v_i(a_i, b_i, \alpha_i, \beta_i) > w^A_i(a_i, \beta_i) + w^B_i(b_i, \alpha_i), \]
\[ \frac{\partial}{\partial a_i} v^A_i(a_i, \beta_i) \geq \frac{\partial}{\partial a_i} w^A_i(a_i, \beta_i) > 0, \quad \text{and} \]
\[ \frac{\partial}{\partial b_i} v^B_i(b_i, \alpha_i) \geq \frac{\partial}{\partial b_i} w^B_i(b_i, \alpha_i) > 0. \]

The collaboration surplus as well as party A’s default payoff are larger if party A can use B’s know-how, hence \( v^A_i(a_i, \beta) < v^A_i(a_i, \beta_i) \) and \( w^A_i(a_i, \beta) < w^A_i(a_i, \beta_i) \). 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. In other words, know-how disclosure by a party is a less than perfect substitute for the collaboration with this party. Formally, \([v^A_i(a_i, \beta) - w^A_i(a_i, \beta)] - [v^A_i(a_i, \beta_i) - w^A_i(a_i, \beta_i)]\) is positive and increasing in \( a_i \). Finally, we focus on the interesting case in which know-how disclosure is important. Specifically, the impact of know-how disclosure on the marginal return to effort when the parties collaborate is supposed to be sufficiently strong,

\[ \frac{\partial}{\partial a_i} [v^A_i(a_i, \beta) - v^A_i(a_i, \beta_i)] > \frac{\partial}{\partial a_i} w^A_i(a_i, \beta). \]

Note that this assumption is particularly plausible when a party cannot make any profits if it has neither the other party’s know-how nor its collaboration, i.e., if \( w^A_i(a_i, \beta_i) \equiv 0 \). 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: \( \alpha^*_{FB} = \alpha, \beta^*_{FB} = \beta, a^*_{FB} = \arg \max v^A_i(a_i, \beta), \) and \( b^*_{FB} = \arg \max v^B_i(b_i, \alpha) \). In a first-best world, know-how is immediately disclosed and the effort levels each time maximize the collaboration surplus.

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 \( a_1 \) and \( \beta_1 \) as given. Provided the parties anticipate that the surplus from bargaining at date \( t = 6 \) will be split according to the Nash

\[ ^{17} \text{Note that know-how disclosure is 'cooperative' in the sense of Che and Hausch (1999), i.e., it can only improve the other party's default payoff.} \]
\[ ^{18} \text{Inspection of Lemma 1 below reveals that if this assumption did not hold, there would be no trade-off between know-how disclosure and effort.} \]
\[ ^{19} \text{This assumption avoids tedious case distinctions and focuses our attention on the most interesting case in which bilateral veto power, which induces both parties to disclose know-how, would be optimal in the one-shot setting (see Proposition 1 below). Note that even if this assumption were relaxed, a vertical ownership structure would never be optimal in the static case when the firms are in a symmetric situation with identical payoff functions.} \]
bargaining solution with equal bargaining powers, the payoffs of party $A$ and $B$ at date $t = 5$ given $o_2$ are $U^A_t(a_2, b_2, \alpha_2, \beta_2 \mid o_2)$ and $U^B_t(a_2, b_2, \alpha_2, \beta_2 \mid o_2)$, where

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

$U^B_t(a_i, b_i, \alpha_i, \beta_i \mid o_i)$ 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 $\alpha^*_2$ and $\beta^*_2$ at date $t = 5$.

**Lemma 1.** Given $\alpha_1$, $\beta_1$, 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 Appendix A. \[\square\]

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:

$$\frac{\partial}{\partial a_i} [v^A_i(a^i_h, \overline{\beta}) + w^A_i(a^i_l, \overline{\beta})] = \frac{\partial}{\partial a_i} v^A_i(a^i_m, \overline{\beta}) = \frac{\partial}{\partial a_i} [v^A_i(a^i_l, \beta) + w^A_i(a^i_l, \beta)] = 2,$$

$$\frac{\partial}{\partial b_i} [v^B_i(b^i_h, \overline{\alpha}) + w^B_i(b^i_m, \overline{\alpha})] = \frac{\partial}{\partial b_i} v^B_i(b^i_l, \overline{\alpha}) = \frac{\partial}{\partial b_i} [v^B_i(b^i_l, \alpha) + w^B_i(b^i_l, \alpha)] = 2.$$

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 $\alpha^*_2$ and $\beta^*_2$ according to Lemma 1, the parties’ optimal effort levels $a_2$ and $b_2$ are uniquely determined by the first-order conditions

$$\frac{\partial}{\partial a_2} U^A_t(a_2, b_2, \alpha^*_2, \beta^*_2 \mid o_2) = 0 \quad \text{and} \quad \frac{\partial}{\partial b_2} U^B_t(a_2, b_2, \alpha^*_2, \beta^*_2 \mid o_2) = 0.$$
Using Definition 1 we can characterize the parties’ optimal effort choices as follows:

**Lemma 2.** Given $\alpha_1$, $\beta_1$, and $o_2$, at date $t = 5$ the parties $A$ and $B$, respectively, choose

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

**Proof.** See Appendix A. $\square$

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 Lemmas 1 and 2 completely characterizes the solution of the second stage game.

**Proposition 1.** Given $\alpha_1$ and $\beta_1$, the optimal ownership structure $o_2^*$ for the second project is

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

**Proof.** See Appendix A. $\square$

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 completely 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 4 the parties decide whether to disclose their know-how and choose their first stage effort levels. Provided that the surplus from bargaining at date 3 and from ownership renegotiation at date 4 is again split according to the regular Nash bargaining solution, the total payoff of party A is given by

\[ U^A(a_1, b_1, \alpha, \beta_1) = U^A_t(a_1, b_1, \alpha, \beta_1) + U^A_C(a_1, \beta_1), \]

where party A’s continuation payoff is given by

\[ U^A_C(a_1, \beta_1 | o_1) = U^A_2(\cdot | o_1) + \frac{1}{2}[U^A_2(\cdot | o_2) + U^B(\cdot | o_2) - U^A(\cdot | o_1) - U^B(\cdot | o_1)], \]

with

\[ U^A_2(\cdot | o_1) = U^A_2(a_1^*, b_1^*, \alpha_1^*, \beta_1^* | o_1) \quad \text{and} \quad U^A_2(\cdot | o_2) = U^A_2(a_2^*, b_2^*, \alpha_2^*, \beta_2^* | o_2), \]

and similarly for party B. Party B’s total payoff \( U^B(a_1, b_1, \alpha, \beta_1 | o_1) \) 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 \( U^A(a_1, b_1, \alpha, \beta_1 | o_1) > U^A(a_1, b_1, \beta_1 | o_1) \geq 0 \). It turns out that in some instances an equilibrium only exists if we let the parties mix between disclosure and nondisclosure. Let \( p \) denote the probability with which party A discloses its know-how at date 4, 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:

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

where

\[ C_A(b_1) = [v^B_{a_1}(b_1, \alpha) - w^B_{a_1}(b_1, \alpha)] - [v^B(b_1, \alpha) - w^B(b_1, \alpha)] \\
- [v^B_{b_1}(b_2, \alpha) - w^B_{b_1}(b_2, \alpha)] + [v^B(b_2, \alpha) - w^B(b_2, \alpha)] - [w^B_{b_1}(b_2, \alpha) - w^B_{b_1}(b_2, \alpha)]. \]

Analogously, taking \( a_1 \) as given, party B chooses

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

\[ 20 \text{ Notice that, of course, } a_1^*, b_1^*, \alpha_1^*, \beta_1^* \text{ and } \beta_2^* \text{ depend on the second-stage ownership structure } o_2 \text{ as derived in Section 3. While the parties will always agree to choose the optimal ownership structure } o_2 = o_2^* \text{ at date } t = 4, \]

the ownership structure \( o_2 = o_2^* \) serves as a threatpoint in the negotiations.

\[ 21 \text{ It is easily checked that this difference is independent of } \beta_1 \text{ but depends on } b_1 \text{ (see the proof of Lemma 3). Notice that in the standard model of Hart (1995) the agents' actions are not interdependent due to the additive technology (cf. also Aghion and Tirole (1994)). In De Meza and Lockwood’s (1998) variant of Hart’s (1995) model an interdependency also arises and as a consequence they also have to consider mixed strategies, yet for quite different reasons (they postulate a different rule for splitting the renegotiation surplus).} \]
where

\[
C_B(a_1) = \left[ v^A_1(a_1, \overline{\sigma}) - w^A_1(a_1, \overline{\sigma}) \right] - \left[ v^A_1(a_1, \overline{\overline{\sigma}}) - w^A_1(a_1, \overline{\overline{\sigma}}) \right] \\
- \left[ v^A_2(a_2^B, \overline{\overline{\sigma}}) - w^A_2(a_2^B, \overline{\overline{\sigma}}) \right] + \left[ v^A_2(a_2, \overline{\overline{\sigma}}) - w^A_2(a_2, \overline{\overline{\sigma}}) \right].
\]

**Proof.** See Appendix A. □

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 (in order to see this, note that \(C_A\) is an increasing function). The reason that at date \(t = 2\) party A may decide to disclose its know-how even though it has no veto power (which never happened in the static analysis) is that know-how disclosure induces an ownership structure \(o_2\) that leads to a larger surplus in the second stage. This second stage benefit of know-how disclosure may overcompensate the first stage loss that party A incurs by improving B’s bargaining position, provided that B’s first stage advantage from having A’s know-how is sufficiently small, which can be the case for a sufficiently small effort level \(b_1\).

Notice that \(C_A\) is always positive (and, thus, party A will never disclose its know-how without veto-power) if party B’s technology is such that its second stage payoffs are sufficiently small.\(^{22}\) Thus, broadly speaking, we should keep in mind that \(C_A\) tends to be positive if for party B the first stage is relatively important, while the second stage is relatively unimportant. Intuitively, if party A has no veto-power it will be more reluctant to disclose its know-how if party B’s second stage payoff is relatively small, because the possible increase of the second stage surplus due to disclosure results from the fact that party B has access to A’s know-how (recall that A can always use all of its own know-how). Thus, if party B’s second stage benefit from having A’s know-how is sufficiently small, party A will not disclose its know-how.

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

\[
\frac{\partial}{\partial b_1} U^B_1(a_1, b_1, \overline{\sigma}) \mid o_1 = 0,
\]

which for \(o_1 \in \{A, J\}\) is equivalent to

\[
\frac{\partial}{\partial b_1} v^B_1(b_1, \overline{\sigma}) = 2.
\]

Hence, \(b_1 = b_1^a\) 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 \(p\), then party B’s effort level \(b_1\) is determined by

\[
\frac{\partial}{\partial b_1} \left( p \left[ v^B_1(b_1, \overline{\sigma}) + w^B_1(b_1, \overline{\sigma}) \right] + (1 - p) \left[ v^B_1(b_1, \overline{\sigma}) + w^B_1(b_1, \overline{\sigma}) \right] \right) = 2.
\]

\(^{22}\) Formally, \(C_A(b_1) \geq 0 \forall b_1 \) if \( v^A_2 = \phi v^B_2, u^A_2 = \phi u^B_2, \) and \( \phi \to 0.\)
Using Lemma 3, if $C_A(b^A_t) \leq 0$, party A always discloses its know-how and party B chooses $b_1 = b^B_t$ in equilibrium. If $C_A(b^A_t) > 0$, the parties choose $\alpha_1 = \bar{\alpha}$ and $b_1 = b^B_t$, respectively. If $C_A(b^A_t) < 0 < C_A(b^B_t)$, 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 nondisclosure, and party A chooses $p = \bar{p}$ such that (1) holds with equality given $b_1 = \hat{b}$.

Notice that the effort level $\hat{b}$ which makes party A indifferent between disclosure and nondisclosure may be smaller or larger than the effort level $b^A_t$, which party B would choose if party A had veto power. For later reference we should keep in mind that $\hat{b}$ tends to be smaller than $b^B_t$ if party B’s first-stage investment is sufficiently relationship-specific; i.e., if the marginal effect of B’s effort on its default payoff $w^B_1$ is relatively small, which follows from inspection of (1) and Definition 1. Conversely, if the relationship-specificity of party B’s first-stage investment is relatively low, so that B’s effort significantly improves its default payoff, $\hat{b}$ tends to be larger than $b^B_t$.

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 $\hat{\alpha}$ and $\hat{\beta}$ are implicitly determined by

$$C_B(\hat{\alpha}) = 0 \quad \text{and} \quad \frac{\partial}{\partial a_1} [\hat{\beta} (v^A_1(\hat{\alpha}, \beta) + w^A_1(\hat{\alpha}, \beta)) + (1 - \hat{\beta}) (v^B_1(\hat{\alpha}, \beta) + w^B_1(\hat{\alpha}, \beta))] = 2,$$

respectively. 23

**Definition 2.** Let $\hat{\rho}$, $\hat{b}$, $\hat{\beta}$, and $\hat{\alpha}$ be defined by

$$(\hat{\rho}, \hat{b}) = \begin{cases} (1, b^A_t) & \text{if } C_A(b^A_t) \leq 0, \\ (0, b^B_t) & \text{if } C_A(b^A_t) > 0, \end{cases} \quad \text{and} \quad (\hat{\beta}, \hat{\alpha}) = \begin{cases} (1, a^B_t) & \text{if } C_B(a^B_t) \leq 0, \\ (0, a^B_t) & \text{if } C_B(a^B_t) > 0, \\ (\hat{\beta}, \hat{\alpha}) & \text{otherwise}. \end{cases}$$

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 $a_1 = a^N_t$, $b_1 = b^N_t$, $\alpha_1 = \bar{\alpha}$, $\beta_1 = \bar{\beta}$.

(ii) If $o_1 = N$, then $a_1 = \hat{\alpha}$, $b_1 = \hat{b}$, $\alpha_1 = \bar{\alpha}$ with probability $\hat{\beta}$, and $\beta_1 = \bar{\beta}$ with probability $\hat{\beta}$.

(iii) If $o_1 = A$, then $a_1 = \hat{\alpha}$, $b_1 = b^N_t$, $\alpha_1 = \bar{\alpha}$, and $\beta_1 = \bar{\beta}$ with probability $\hat{\beta}$.

(iv) Finally, if $o_1 = B$, then $a_1 = a^N_t$, $b_1 = \hat{b}$, $\alpha_1 = \bar{\alpha}$ with probability $\hat{\beta}$, and $\beta_1 = \bar{\beta}$.

**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.

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23 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.
Table 1

<table>
<thead>
<tr>
<th>C(d) &lt; 0</th>
<th>C(d) = 0</th>
<th>C(d) &gt; 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>A = A</td>
<td>B = B</td>
<td>C = C</td>
</tr>
</tbody>
</table>

If the parties choose $C(d) < 0$, ownership will immediately be disclosed according to Proposition 2, and ownership will be renegotiated to $C(d) = 0$ according to Proposition 1.

If the parties choose $C(d) > 0$, ownership will be renegotiated to $C(d) = 0$ according to Proposition 1.

Hence, in this case total surplus is given by $S(J) = v(N)$, where Lemma 2 has been used.

We can now determine the optimal ownership structure of the problem, the content of which is depicted in Table 1, thus completes the solution of our problem.

Proposition 3. Define

$$L = \frac{1}{2} \left( x^b - x^a \right) + \frac{1}{2} \left( \alpha - \beta \right) + \left( 1 - p \right) \left( \alpha - \beta \right)$$

and analogously $L_a$.

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The following proposition, the content of which is depicted in Table 1, thus completes the solution of our problem.
\[ I_B = \hat{q}(v^1_1(\hat{a}, \overline{\beta}) + v^2_2(a^0_2, \overline{\beta}) - a^0_2) + (1 - \hat{q})(v^1_1(\hat{a}, \overline{\beta}) + v^2_2(a^m_2, \overline{\beta}) - a^m_2) - \hat{a} \\
- (v^1_1(a^m_1, \overline{\beta}) - a^m_1 + v^2_2(a^0_2, \overline{\beta}) - a^0_2).
\]

(i) First, assume that \( C_B(a^0_1) \leq 0 \) or that \( C_B(a^1_1) < 0 < C_B(a^0_2) \) and \( I_B > 0 \). If \( C_A(b^0_1) \leq 0 \) or if \( C_A(b^1_1) < 0 < C_A(b_1^0) \) 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 \( C_B(a^0_1) \geq 0 \) or that \( C_B(a^1_1) < 0 < C_B(a_1^0) \) and \( I_B < 0 \). If \( C_A(b^0_1) \geq 0 \) or if \( C_A(b^1_1) < 0 < C_A(b_1^0) \) and \( I_A < 0 \), then \( o_1 = J \), otherwise \( o_1 = B \).

**Proof.** See Appendix A. □

Note that \( I_A \) can only be positive when \( \hat{b} > b^m_1 \), so that the disadvantage of a sometimes smaller effort level in the second stage may be overcompensated by the advantage of a larger effort level in the first stage. Recall that \( \hat{b} \) is larger than \( b^m_1 \) if the relationship-specificity of party \( B \)'s first-stage investment is relatively low, i.e., if the marginal effect of \( B \)'s effort on its default payoff is sufficiently strong. Conversely, \( I_A \) tends to be negative if party \( B \)'s first-stage investment is very relationship-specific, such that \( \hat{b} < b^m_1 \).

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 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 technology is such that its first-stage payoff is relatively more important than its second-stage payoff, and vice versa for party \( B \), so that \( C_B(a^1_1) > 0 \) and \( C_A(b^1_1) < 0 \) hold. In this case it is optimal to give only party \( B \) veto power, which guarantees immediate know-how disclosure by both parties (recall that \( A \) discloses its know-how since this significantly increases the second-stage surplus) and induces \( B \) to invest more than under \( o_1 = J \), while \( A \) does not invest less. Alternatively, assume that \( C_B(a^1_1) < 0 < C_B(a^0_1) \) and \( I_B < 0 \) so that, roughly speaking, party \( A \)'s payoffs in both stages are substantial and \( A \)'s first-stage investments are highly relationship-specific. This means that the marginal effect of \( A \)'s first-stage effort on its default payoff is small, so that party \( B \)'s veto-power cannot reduce party \( A \)'s effort significantly. Hence, \( o_1 = B \) is optimal, given that for party \( B \) the first stage is again substantially more important than the second stage or both stages are important but the relationship-specificity of \( B \)'s first-stage investment is low (so that giving party \( A \) veto-power would considerably reduce \( B \)'s effort incentive). It is true that under \( o_1 = B \) 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 \( o_2 = A \) 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.\(^{24}\)

\(^{24}\) Of course, analogous considerations can be made for \( o_1 = A \).
Corollary 1. If one party is relatively more reluctant to disclose its know-how since the respective importance of first and second stage payoffs differs among the parties (or if the degree of relationship-specificity is different), 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 
\[ \text{sign}(C_B(a_1^1)) = \text{sign}(C_A(b_1^1)), \ \text{sign}(C_B(a_1^b)) = \text{sign}(C_A(b_1^b)), \ \text{and} \ \text{sign}(I_A) = \text{sign}(I_B) \] 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 \( o_1 = J \). This is optimal if both parties’ first stage payoffs are relatively more important than their second stage payoffs, so that \( C_A(b_1^1) \geq 0 \) and \( C_B(a_1^b) \geq 0 \) hold (which is intuitively clear, since we already know that \( J \) is the optimal ownership structure in the static game when both parties have know-how to disclose). Moreover \( o_1 = J \) is optimal if, roughly speaking, both stages are important for both parties, but both parties’ investments are highly relationship-specific (so that \( I_A < 0 \) and \( I_B < 0 \)). In this case, giving one party veto-power cannot reduce the other party’s investment incentive significantly, so that bilateral veto-power, which always induces both parties to disclose their know-how, is optimal.\(^{25}\) 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 since the first stage payoffs are more important than the second stage payoffs or if the investments are highly relationship-specific. 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 if the second stage is sufficiently more important or if both stages are important and the relationship-specificity of the parties’ first-stage investments is relatively low (which means that a party has a considerable incentive to exert effort as long as the other party has no veto power). Note that \( o_1 = N \) is the only ownership structure that may not be renegotiated at date \( t = 4 \).\(^{26}\) 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.,

\(^{25}\) For similar reasons, \( o_1 = J \) is optimal if for one party both stages are important and the first-stage investments are highly relationship-specific, while for the other party the first stage is significantly more important than the second stage.

\(^{26}\) Moreover, 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 \( \frac{\partial}{\partial y_i^A} w_i^A = \frac{\partial}{\partial y_i^B} w_i^B \) and \( \frac{\partial}{\partial y_i^A} y_i^A = \frac{\partial}{\partial y_i^B} y_i^B \)).
\( v_i^A \equiv v_i^B, w_i^A \equiv w_i^B \), 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 (i.e., if the second stage payoffs are particularly important or relationship-specificity is low), 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. Before concluding, we briefly discuss some real world examples that may reflect the richness of the possible outcomes derived in our model.27

As an example that seems to be consistent with the first scenario, consider the alliance between IBM Denmark and the Danish application software company Damgaard Data Development. In 1994, IBM and Damgaard signed a co-development agreement giving IBM the rights to distribute their business solutions for mid-market companies in Scandinavia. In November 1998, the companies changed the ownership structure giving Damgaard the rights formerly owned by IBM. Hence, the situation resembles our case \( o_1 = A, o_2 = B \). The president of Damgaard said that the outcome of the collaboration had been positive and that they would not be where they are now without IBM, indicating that Damgaard did learn from IBM’s know-how. At the same time, the IBM manager in charge said that he was looking forward to their future relationship with Damgaard, which is justified according to our model since Damgaard’s incentives have clearly been improved by the new arrangement.28

The second scenario may be reflected by the multistage alliance between AOL and NTT DoCoMo announced in September 2000. In a first step, the two firms formed a joint venture called DoCoMo AOL Japan with the aim to develop a range of wireless Internet services. While DoCoMo gave AOL access to the wireless technology, AOL gave DoCoMo access to its instant messaging technology and its content. The joint venture offers AOLi, a joint service which allows users of DoCoMo’s i-mode wireless Internet service access to AOL e-mail. In the language of our model, the firms thus chose \( o_1 = J \) and disclosed their know-how. In a second step, both firms established a joint working group to develop the GPRS and 3G convergence technology and applications. Results of this second phase are forecasted with the introduction of GPRS and 3G in Europe and the US. The two firms will use the developed technologies not only jointly but also on their respective markets, which

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27 Note that the allocation of the relevant control rights over productive assets, which plays the central role in the property rights approach initiated by Grossman and Hart (1986), is usually difficult to pinpoint given the information publicly released by firms. We certainly do not claim that our interpretation of the released facts is the only possible one.

28 For more on this case, see the homepage of IBM and www.navision.com.
looks like \( o_2 = N \), the optimal second stage arrangement that ensures maximum effort by both parties.\(^{29}\)

Finally, the third scenario seems to be consistent with another alliance of AOL, which it formed with Sony Computer Entertainment in May 2001. With the aim to enable fast Internet access and e-mail through Sony’s PlayStation 2 game console, this alliance combined AOL’s infrastructure and Internet service technology with Sony’s video game experience. In the first stage of the alliance SCEI offers consumers a network adapter for PlayStation 2, while AOL markets Netscape browsers for the console. In November 2001, the two companies announced an agreement to expand their strategic relationship, in order to allow films, music and other contents to be delivered over high-speed Internet connections and to develop standards aimed at allowing various Sony devices to communicate with each other. These agreements specify that the two companies’ relationships are nonexclusive and that the network software and services to be developed will have an open architecture. Hence, this two-stage alliance seems to correspond closely to the case \( o_1 = o_2 = N \) in our notation.\(^{30}\)

5. Conclusion

In this paper we have analyzed the organization of dynamic R&D alliances between two parties that both decide whether to disclose important know-how to each other 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 one firm is more reluctant to disclose its know-how since the early stage of the alliance is particularly important for the other firm (or if the other firm’s investments are highly relationship-specific), 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.\(^{31}\) 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

\(^{29}\) See Financial Times 09/23/00 or CNET News.com 09/28/00 and Asiaweek 06/22/01 or IT World.com 07/17/01 for more details on this alliance.

\(^{30}\) See New York Times 05/15/01 and Wall Street Journal 11/13/01.

to organize our thoughts about the design of institutions. We hope that the reader finds this view confirmed by our paper.

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Appendix A

Proof of Lemma 1. First, consider party A. Since $a_2 \geq a_1$, we know that $a_2 = \sigma$ if $a_1 = \sigma$. If $a_1 = \alpha$, party A discloses its know-how whenever $\Delta := U_2(\alpha, b_2, \sigma, \beta_2 | o_2) - U_2(\alpha, b_2, \sigma, \beta_2 | o_2) \geq 0$. Since

$$\Delta = \begin{cases} \frac{1}{2} [\nu^2(b_2, \sigma) - \nu^2(b_2, \alpha)] > 0 & \text{if } o_1 \in \{A, J\}, \\ \frac{1}{2} [\nu^2(b_2, \sigma) - \nu^2(b_2, \alpha) - (w^2(b_2, \sigma) - w^2(b_2, \alpha))] < 0 & \text{if } o_1 \in \{B, N\}, \end{cases}$$

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 $\frac{\partial}{\partial a} U_2(\alpha, b_2, \sigma, \beta_2 | o_2) = 0$ is given by $w^2(\sigma) = w^2(a_2, \beta_2) = 2$ if $o_2 \in \{A, N\}$ and by $\frac{\partial}{\partial a} U_2(\alpha, \beta_2) = 2$ if $o_2 \in \{B, J\}$. Moreover, we know from Lemma 1 that $\beta_2^* = \bar{\beta}$ if $o_2 \in \{B, J\}$ and $\beta_2^* = \beta_1$ if $o_1 \in \{A, N\}$. This proves the first part of the lemma. The second part can be shown analogously. □

Proof of Proposition 1. If $a_1 = \sigma$ and $\beta_1 = \bar{\beta}$, it follows from Lemma 2 that party A’s effort level is largest if $\sigma_2 \in \{A, N\}$ and party B’s effort level is largest if $\alpha_2 \in \{B, N\}$. Hence, the optimal ownership structure is given by $\sigma_2 = N$. If $a_1 = \alpha$ and $\beta_1 = \beta_1$, party A’s largest effort level is induced by $\sigma_2 \in \{B, J\}$, and party B’s largest effort level is induced by $\alpha_2 \in \{\sigma, J\}$. Hence, $\sigma_2 = J$ is optimal, since by Lemma 1 it also induces both parties to disclose their know-how. If $a_1 = \sigma$ and $\beta_1 = \beta_1$, the ownership structure $\alpha_2 \in \{B, J\}$ is best for party A’s incentives to exert effort, and $\sigma_2 \in \{B, N\}$ is best for party B’s incentives. Therefore, $o_2 \in B$, which also induces $B$ to reveal its know-how, is optimal. Finally, similar arguments show that $\sigma_2 = A$ is optimal if $a_1 = \alpha$ and $\beta_1 = \bar{\beta}$. □

Proof of Lemma 3. First, assume that $o_1 \in \{J, A\}$. Given that party B chooses $\beta_1 = \bar{\beta}$, party A prefers $a_1 = \sigma$ if $\mathcal{U}_A(a_1, b_1, \sigma, \bar{\beta} | o_1) \geq \mathcal{U}_A(a_1, b_1, \sigma, \bar{\beta} | o_1)$. Since by Lemma 1 we know that $\sigma_2 = \sigma$ in the case under consideration, $\mathcal{U}_1(\cdot | o_1)$ and $\mathcal{U}_2(\cdot | o_1)$ do not depend on $a_1$. Hence,

$$\mathcal{U}_A(a_1, b_1, \sigma, \bar{\beta} | o_1) = \mathcal{U}_A(a_1, b_1, \sigma, \sigma | o_1) + \frac{1}{2} \mathcal{U}_2(a_2, b_2, \sigma, \bar{\beta} | N) + \mathcal{U}_2(a_2, b_2, \sigma, \sigma | N) - \mathcal{U}_2(a_2, b_2, \sigma, \sigma | A),$$

where Lemma 2 and Proposition 1 have been used (in particular, $o_2 = N$ if $a_1 = \sigma$ and $o_2 = A$ if $a_1 = \alpha$). Since $b^*_2 > b^*_1$, it follows that the preceding expression is always positive, so that party A chooses $a_1 = \sigma$. Given that party B chooses $\beta_1 = \bar{\beta}$, we obtain...
Consider first the case \( B = \emptyset \), which implies \( B = J = \emptyset \). Since \( a_1 = \alpha \) always chooses \( \alpha \), independent of party \( B \)'s behavior.

Second, consider the case \( a_1 = \in \{ N, B \} \). It is straightforward to verify in an analogous way that independent of \( \beta_1 \) we get

\[
U^A(a_1, b_1, \alpha, \beta_1 | \alpha_1) = U^A(a_1, b_1, \alpha, \beta_1 | \alpha_1)
\]

It follows that party \( A \) will choose \( p(b_1) \) as stated in the lemma. Finally, party \( B \)'s choice of \( q(a_1) \) can be handled similarly.

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**Proof of Proposition 3.** Consider first the case \( C_B(a^1_1) < 0 \) and \( C_A(b^1_1) < 0 \), so that \( \hat{\rho} = \hat{q} = 1 \), \( \hat{a} = a^1_1 \), \( \hat{b} = b^1_1 \). It is straightforward to see that when joint ownership with no veto power leads to the largest total surplus, namely \( S(N) = v_1(a^1_1, b^1_1, \alpha, \beta) - a^1_1 - b^1_1 + v_2(a^1_1, b^1_1, \alpha, \beta) - a^1_1 - b^1_1 \). Next, consider the case \( C_B(a^1_1) > 0 \) and \( C_A(b^1_1) > 0 \), so that \( \hat{\rho} = \hat{q} = 0 \), \( \hat{a} = a^1_1 \), \( \hat{b} = b^1_1 \). It is easily checked that in this case joint ownership with veto power leads to the largest surplus. If \( C_B(a^1_1) > 0 \) and \( C_A(b^1_1) < 0 \), then \( \hat{\rho} = 1 \), \( \hat{q} = 0 \), \( \hat{a} = a^1_1 \), \( \hat{b} = b^1_1 \), so that \( B \)-ownership is optimal. An analogous argument can be made for\( A \)-ownership in the case \( C_B(a^1_1) < 0 \) and \( C_A(b^1_1) < 0 \).

The remaining intermediate cases require a somewhat closer examination. Before we proceed, note first that if \( \hat{\rho} = \hat{q} = 1 \) and \( \hat{a} = \hat{b} = \hat{\alpha} \), then \( S(N) = S(A) - S(J) = I_B \). It is also straightforward to verify that if \( \hat{\rho} = \hat{q} = 0 \) and \( \hat{a} = \hat{b} = \hat{\beta} \), then \( S(N) = S(A) = S(J) = I_A \).

Let us now consider the case \( C_B(a^1_1) < 0 < C_B(a^1_1) \), so that \( \hat{\rho} = \hat{q} = 0 \) and \( \hat{a} = \hat{b} = \hat{\alpha} \). Suppose first that \( C_A(b^1_1) < 0 \), which implies \( \hat{\rho} = 1 \) and \( \hat{b} = b^1_1 \). A comparison shows that the ownership structures in which party \( A \) has veto power are dominated. Moreover, \( a_1 = N \) leads to a larger surplus than \( a_1 = B \) if \( S(N) - S(B) > 0 \), which in

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\[ U^A(a_1, b_1, \alpha, \beta_1 | a_1) = U^A(a_1, b_1, \alpha, \beta_1 | a_1) \]

and

\[ U^A(a_1, b_1, \alpha, \beta_1 | a_1) = U^A(a_1, b_1, \alpha, \beta_1 | a_1) \]

\[ - a^1_1 + \frac{1}{2} \left[ v_2(a^2_1, b^1_1, \alpha, \beta) - w^1_1(b^1_1, \alpha) \right] + \frac{1}{2} \left[ v_2(a^2_1, b^1_1, \alpha, \beta) - w^1_1(b^1_1, \alpha) \right] \]

\[ - a^1_1 + \frac{1}{2} \left[ v_2(a^2_1, b^1_1, \alpha, \beta) - w^1_1(b^1_1, \alpha) \right] + \frac{1}{2} \left[ v_2(a^2_1, b^1_1, \alpha, \beta) - w^1_1(b^1_1, \alpha) \right] . \]

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\[ \text{For instance, consider } a_1 = B \text{ and } \beta_1 = \beta. \text{ so that } a^1_1 = B \text{ if } \alpha = \alpha \text{ and } a^1_1 = J \text{ if } \alpha = \beta. \text{ Hence, in this case} \]

\[ U^A(a_1, b_1, \alpha, \beta_1 | a_1) = U^A(a_1, b_1, \alpha, \beta_1 | a_1) \]

and

\[ U^A(a_1, b_1, \alpha, \beta_1 | a_1) = U^A(a_1, b_1, \alpha, \beta_1 | a_1) \]

\[ \text{Of course, if equality holds, the parties are indifferent between } a_1 = N \text{ and } a_1 = B. \] For brevity, we do not explicitly point out cases of indifference in what follows.
the present case is equivalent to $I_B > 0$. Next suppose $C_A(b_1^*) > 0$, which implies $\tilde{p} = 0$ and $\tilde{b} = b_1^*$. 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 $C_A(b_1^*) < 0 < C_A(b_2^*)$, which implies $\tilde{p} = \hat{p}$ and $\tilde{b} = b$. If $C_B(a_1^*) < 0$, 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 $S(N) - S(A) = I_A$. If $C_B(a_1^*) > 0$, the optimal ownership structure is $o_1 = B$ whenever $I_A > 0$, and $o_1 = J$ otherwise. Finally, suppose that $C_B(a_1^*) < 0 < C_B(a_2^*)$ and $C_A(b_1^*) < 0 < C_A(b_2^*)$. In this case we have $S(N) - S(A) = I_A$, $S(N) - S(B) = I_B$, and $S(N) - S(J) = I_A + I_B$. Hence, the optimal ownership structure gives party $A$ veto power whenever $I_A < 0$, and it gives party $B$ veto power whenever $I_B < 0$.

References


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