THE ROLE OF KNOWHOW ACQUISITION IN THE FORMATION AND DURATION OF JOINT VENTURES

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Abstract

We analyze the role of knowhow acquisition in the formation and duration of joint ventures. Two parties become partners in a joint venture in order to benefit from each other's knowhow. Joint operations in the joint venture provide each party with the opportunity to acquire part or all of its partner's knowhow. A party's increased knowhow provides the impetus for the dissolution of the joint venture, as it decreases the need for the partner's knowhow. Dissolution takes the form of the buy out of one partner by the other. We characterize the conditions under which such dissolution takes place, identify the party that buys out its partner, determine the expected time to dissolution and various measures of uncertainty regarding that time, establish its comparative statics, and examine the implications of knowledge acquisition for the desirability of joint venture formation.

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1 Introduction

It has been noted that joint ventures are temporary forms of organization, for the majority of such ventures are eventually dissolved, with one partner generally buying out the other. Kogut (1991) considers 92 joint ventures formed over the 9 year period 1975-1983. He finds that, at the time of his writing, approximately 10 years later than the midpoint of the period 1975-1983, 27 such ventures were terminated by liquidation and 37 by acquisition. These 64 dissolutions amount to nearly 70% of the joint ventures that were formed.

It has also been noted that the acquisition of knowhow is often a central aspect of joint ventures and alliances.[1] McConnell and Nantell (1985, Table I) report the findings of a questionnaire administered by Berg and Friedman (1977) regarding the motives for joint ventures. "To acquire skills and technical knowhow" is ranked first among ten different motives such as "to acquire distribution facilities" (ranked second), "to acquire capital" (ranked seventh), or "to exploit a product or a licensed process" (ranked tenth). Doz and Hamel (1998, p. 5) write that "alliances may [...] be an avenue for learning and internalizing new skills, in particular those which are tacit, collective and embedded (and thus hard to obtain and internalize by other means)."[2] As a result, in the words of Hamel (1991, p. 84), "the collaborative process might lead to a reapportionment of skills between the partners."

Our purpose in this paper is to combine these two observations and explore the role of knowhow acquisition in explaining the temporary nature of the majority of joint ventures and the choice of the buyout of one partner by the other as the generally preferred means of termination. Our central argument is this. Two firms combine knowhow in a joint venture. The joint operation of the venture provides the partners with the opportunity to acquire knowhow from each other. The joint venture is dissolved when enough knowhow has been acquired to allow one partner to dispense with the other.

The prospect of a buyout serves to provide the selling partner with the incentive to transfer knowhow to the buying partner. The greater the buying partner's knowhow, the higher the value of the asset to that partner, and the higher therefore the price paid to the

[1]An alliance is somewhat looser than a joint venture, in that it need not involve the creation of a new entity — the joint venture company — in which each of the partners holds an equity stake.

[2]Doz and Hamel (1998) distinguish among three main types of alliances: i) Co-option alliances, intended to neutralize rivals and/or to create networks, ii) co-specialization alliances, intended to combine resources, skills, and knowhow, and iii) learning and internalization alliances, intended to facilitate the learning of new skills and the acquisition of knowhow. We consider co-specialization and learning and internalization alliances in the present paper. We note that these are related, for a co-specialization alliance that grants a party access to its partner's skills and knowhow provides that party with the opportunity to learn and acquire these, at least in part. We do not consider co-option alliances.

selling partner. Interestingly, then, the ceding of knowhow in a joint venture represents a valuable opportunity, rather than the threat that it is often portrayed to be. It therefore increases the desirability of joint ventures.

More specifically, we examine a situation in which there are two firms and one asset. We consider the conditions under which a joint venture — which involves the joint operation of the asset by the two firms — is formed. The alternative to the joint venture is the separate operation of the asset by a single firm. In case a joint venture is formed, we examine the dynamics of the venture and the increase in each partner's knowhow through learning from the other partner. Such learning decreases the incremental benefit from having the partners join forces. It may then become profitable for one partner to dissolve the joint venture and buy out the other. On that reading, and as noted by Reuer (2001), the dissolution of a joint venture is not a failure attributable to the parent companies' inability to cooperate, but an efficient adaptation to a changed situation.

The duration of a joint venture being in the nature of a random time, we construct a continuous time model that allows us to characterize the conditions under which the dissolution of the joint venture takes place, identify the party that buys out the other, determine the expected time to dissolution and various measures of uncertainty regarding that time, establish its comparative statics, and examine the implications of knowledge acquisition for the desirability of joint venture formation.[3]

We find a joint ventures is temporary when there is a large discrepancy in the partners' costs of effort, for the burden the high cost of effort partner places on its low cost of effort counterpart eventually dominates what benefit the joint venture may have. Conversely, a joint ventures is permanent when there is a small discrepancy between the partners' costs of effort.

When the joint venture is temporary, it is always the low cost of effort partner that buys out its high cost of effort counterpart. Thus, the joint venture will not be dissolved before the low cost partner has acquired enough knowhow to become the superior user of the asset. However, the low cost partner does not necessarily acquire all of its partner's knowhow. The acquisition of knowhow is costly, in that it involves the joint operation of the asset when separate operation would be preferred but for the desire to acquire knowhow. When the cost of acquiring knowhow is sufficiently large, only partial knowhow will be acquired. In the

[3] We construct our model of knowhow acquisition to be consistent with — and possibly provide further microfoundation for — recent structural asset pricing models of the firm (e.g. Leland, 1994, 1998). Such models are used by Lambrecht (2001), Leland and Skarabot (2003), and Morellec (2001) to develop closed-form solutions for the option value of mergers and acquisitions. See Sundaresan (2000) for a general discussion of continuous times models in finance.

limit, of course, no joint venture will be formed, and the separate operation of the asset by one party will be chosen at the outset. Conversely, when the cost of knowhow acquisition is sufficiently low, the low cost partner will remain in the joint venture until it has acquired all of its partner's knowhow, and then buy its partner out. The expected time to dissolution naturally increases in the knowhow to be acquired by the low cost partner in the case where such buyout is expected to occur, and decreases in the ease with which that partner acquires its counterpart's knowhow.

We have noted that the starting point of our analysis is the observation that the majority of joint ventures are only temporary, and that the buyout of one partner by the other is the preferred mode of dissolution. We have already mentioned the findings of Kogut (1991). Kogut (1991) does not, however, distinguish between acquisition by one partner and acquisition by a third party. Hauswald and Hege (2003) do. They consider 151 US joint ventures by two publicly traded parents that were terminated during the period 1985 to 2000. They find that 92 (61%) joint ventures were terminated by the complete buyout of one partner by the other, 7 (5%) were acquired by third parties, and 52 (34%) were liquidated.

Similar results are reported in the more practitioner oriented literature. In their study of 49 joint ventures and alliances, Bleeke and Ernst (1995, p. 97) report that "nearly 80% of joint ventures [...] ultimately end in a sale by one of the partners."[4] This finding prompts them to ask whether "your strategic alliance [is] really a sale." Their question is answered in the affirmative by Nanda and Williamson (1995), who recommend "us[ing] joint ventures to ease the pain of restructuring." Bleeke and Ernst (1995) also report a median life span for joint ventures and alliances of seven years.

Our analysis of the dynamics of joint venture formation and dissolution can be viewed as extending the more static approach generally found in the economic literature. The literature has examined the rationale for joint venture formation, and has related the characteristics of the venture to those of the partners and the environment.[5] This perspective has essentially been static, in that it has not considered the evolution of the joint venture over time.

Two exceptions to the static approach found in the economic literature are Kogut (1989)

[4]Admittedly, Bleeke and Ernst (1995) do not specify whether the sale is to another partner or to a third party.

[5]For an analysis of joint ventures and strategic alliances, see Allen and Phillips (2000), Belleflamme and Bloch (2000), Bhattacharyya and Lafontaine (1995), Bruner (1999), Chan, Kensinger, Keown, and Martin (1997), Darrough and Stoughton (1989), Elfenbein and Lerner (2001), Gomes and Novaes (2001), Hauswald and Hege (2003), Holmström (1982), Johnson and Houston (2000), Legros and Matthews (1993), McConnell and Nantell (1985), Mohanram and Nanda (1998), Noe, Rebello, and Shrikhande (2002), Oxley (1997), Pisano (1989), Rey and Tirole (1998), Sampson (2000), and Van den Steen (2002).

and Kogut (1991). These two papers are primarily empirical in nature. The first paper relates the hazard rate of a venture to the partners' ability to maintain the collusive behavior required by the venture through dealings external to the venture, such as supply and other contracts. The second paper views a joint venture as an option to acquire and relates the hazard rate of the venture to an improvement in industry conditions that increases the moneyness of the option, thereby inducing the optionholder to exercise the option to buy out its counterpart. We do not consider the former issue, and rely instead on the partners' equity stakes in the venture to provide them with the requisite incentives. We explicitly model the learning that is implicit in Kogut's (1991) empirical analysis, and extend such learning from one-sided learning about industry prospects to two-sided learning about partners' knowhow.[6]

In contrast to the economic literature, the strategic management literature has paid much attention to the implications of learning for what it has called the 'stability' of joint ventures. Starting with Hamel (1991), a number of authors have considered the effects of learning by the partners on each partner's incentives to remain in the venture. (See for example Ariño and de la Torre (1998), Doz (1996), Inkpen and Beamish (1997), Khanna, Gulati, and Nohria (1998), and Makhija and Ganesh (1997).) These authors have preceded us in ascribing the decision to dissolve a joint venture to the acquisition of knowhow by the partners in the venture, rather than a failure of cooperation.[7] However, their mainly informal analysis has made it difficult to derive precise testable implications such as the ones presented above. For example, in their analysis of international joint ventures between a foreign partner and its local counterpart, Inkpen and Beamish (1997) *assume* that learning favors the foreign partner, in the sense that learning should eventually allow that partner to operate the venture alone. We need make no such assumption, as we derive the identity of the partner who buys out its counterpart at dissolution from the primitives of our model.

[6]An important exception to the static approach found in the economic literature on joint ventures is provided by the theoretical literature on research joint ventures (see Muennich (2000) for a survey). Research joint ventures are inherently dynamic, in that they are formed for the specific purpose of conducting some joint research and are dissolved upon completion of that research. The literature on research joint ventures has taken the dissolution time as given. It therefore does not address the issues of whether a joint venture will be dissolved and, if so, when. Our analysis addresses these issues.

[7]This is not to say that the failure to cooperate is never an issue in joint ventures. Rather, it is to say that it is less an issue than may generally be thought. Consider for example the aircraft engine joint venture between BMW and Rolls-Royce. The venture lasted 10 years and ended in 1999 with the buyout of BMW by Rolls-Royce. While it is possible that the venture ended because of a failure to cooperate on the part of the two partners, such an explanation is unlikely given that BMW was paid in Rolls-Royce shares, which have made BMW one of the largest shareholders of Rolls-Royce, with a 10% stake. A more likely explanation in our view is that Rolls-Royce, which long ago had stopped manufacturing small aircraft engines, wished to reenter that business and believed it could profit from BMW's small engines knowhow for that purpose. Once Rolls-Royce had acquired sufficient small engine knowhow from BMW, there was no longer a need for the joint venture.

Our analysis shares a concern with dynamics issues with the analyses of Bernardo and Chowdhry (2002), Fluck and Lynch (1999), and Rossetto, Perotti, and Kranenburg (2002). These authors have analyzed the successive forms of organization that are focused and diversified firms, equity carve-outs (ECOs) and reacquisitions, and mergers and divestures, respectively. The differences between our analysis and theirs go beyond the differing objects of the analyses. Unlike the firms of Bernardo and Chowdhry (2002) and Rossetto, Perotti, and Kranenburg (2002), ours acquire knowhow from other firms rather than learn about latent resources or synergies. Unlike the firms of Fluck and Lynch (1999), ours have no wealth constraint and need not form joint organizations for the sole purpose of overcoming such constraints. We believe these differing modelling assumptions better describe the situation and the problems in joint ventures. They therefore permit the derivation of results that are more specifically proper to joint ventures.

We proceed as follows. We present the model in Section 2. We examine the case of separate operations in Section 3 and of joint operations in Section 4. We compare the two forms of organization for the purpose of determining that chosen at the outset in Section 5. We compute the duration of the joint venture in Section 6. We discuss the costs of moral hazard in Section 7. We provide some empirical evidence and testable implications in Section 8.We conclude in Section 9.

2 The Model

Consider two firms a and b and one asset. At the initial date $t = 0$, the asset can be operated separately by a single firm or jointly by the two firms cooperating in a joint venture. The separate operation of the asset by firm i, $i \in \{a; b\}$, yields instantaneous revenue at date $t \geq 0$

$$R(e_i, k_i(t)) \quad = \quad e_i \, k_i(t) \;, \tag{1}$$

at instantaneous cost

$$C_i(e_i) \quad = \quad \omega_i \, e_i^2 \tag{2}$$

where e_i denotes the level of effort selected by firm i at the start of operations, $\mathbf{k}(t) \equiv (k_a(t), k_b(t))$ denotes the vector of the two firms' knowhow at date t, and ω_i denotes firm i's cost of effort. One can view "effort" as the setting up of — and the initial allocation of resources to — operations. The cost of effort can then be viewed as the opportunity cost of such resources.

We now turn to the joint operation of the asset by the two firms, now partners in a joint venture. The joint operation of the asset yields instantaneous revenue at date $t \geq 0$

$$R_J(\mathbf{e}) = s(\mathbf{e})\,\bar{\kappa}\ , \tag{3}$$

$$\text{where}\quad s(\mathbf{e}) = 2\sqrt{e_a\, e_b}\ , \tag{4}$$

and $\mathbf{e} \equiv (e_a, e_b)$ denotes the levels of effort selected by the two partners at the start of joint operations. Here, $\bar{\kappa}$ denotes the two firms' combined knowhow, with $\bar{\kappa} \leq k_a(0) + k_b(0)$. The strict inequality $\bar{\kappa} < k_a(0) + k_b(0)$ corresponds to the case where there is some overlap between the initial knowhows of the two firms.

We note that the combination of knowhow in the joint venture ($\bar{\kappa}$ vs. $k_i(t)$) can be viewed as making possible increased revenues (e.g. from cross-selling), decreased costs (e.g. from the adoption of more efficient production techniques), or both.[8]

The formulation of $s(.)$ in (4) ensures that combining knowhow increases revenues only when the two partners do not have the same knowhow. When $\bar{\kappa} = k_a(0) = k_b(0)$, revenues are equal in the case where a single firm operating the asset alone selects a level of effort $2e$ and in that where each of two partners jointly operating the asset selects a level of effort e. Figure 1 plots $R_J(\mathbf{e})$ as a function of partner i's relative effort.

The cost to firm i of selecting a level of effort e_i is unaffected by whether the asset is operated jointly or separately by the firm. It is $C_i(e_i)$ in either case. The convexity of the cost of effort imparts a preference for joint operations, for it implies that it is preferable to have each of two firms having identical cost parameter ω exert effort e rather than have a single firm exert effort $2e$. The total cost of effort is $2\omega e^2$ in the former case. It is $4\omega e^2$ in the latter. This preference for joint operations is to be contrasted with the preference for separate operations that stems from the moral hazard problem inherent to joint operations.

We assume that the joint operation of the asset in a joint venture enables each partner to acquire part or all of its partner's knowhow. We assume joint operation to be the only channel through which knowhow can be acquired, and that such knowhow acquisition as takes place under joint operations consists in having each partner acquire part or all of the other partner's knowhow. Thus, the two firms' combined knowhow, $\bar{\kappa}$, remains constant and no acquisition of knowhow takes place under separate operations. Figure 2 shows the relation between the knowhow a partner has initially, that he can potentially acquire in the joint venture, and the partners' combined knowhow.

[8] More formally, introducing the notation, $r_i(t)$, $c_i(t)$, $\bar{r}$ and $\bar{c}$, such that $k_i(t) = r_i(t) - c_i(t)$ and $\bar{\kappa} = \bar{r} - \bar{c}$, the overall impact of combining knowhow consists of an impact on *gross* revenues ($\bar{r}$ vs. $r_i(t)$) and an impact on costs ($\bar{c}$ vs. $c_i(t)$). The revenues $R(.)$ and $R_J(.)$ should therefore be viewed as *net* revenues, or EBIT. $C_i(.)$ remains the cost of effort to partner i alone.

We assume that a firm's knowhow never decreases. A firm's knowhow at any point in time is therefore the sum of its initial knowhow and the knowhow it gained while in a joint venture

$$k_i(t) \;=\; k_i(0) \;+\; g_i(t) \;. \tag{5}$$

The gain in knowhow $g_i(t)$ is positive and non-decreasing. It is at most equal to the difference between the partners' combined knowhow and partner i's initial knowhow: $g_i(t) \in [0, \bar{\kappa} - k_i(0)]$. We assume it is

$$g_i(t) \;=\; \left[\, 0 \;\;\vee\;\; k_i(0) \left(\sqrt{\alpha\, s(\mathbf{e}) \max_{\tau \in \mathcal{T}_J(t)} \{\, x(\tau) \,\}} - 1 \right) \right] \;\;\wedge\;\; (\, \bar{\kappa} \,-\, k_i(0)\,) \;. \tag{6}$$

Our model is constructed to reflect the following. The acquisition of knowhow is proportional to the levels of effort selected by the partners, for the greater the partners' contributions to joint operations, the more can be learned from such operations. Each partner can complement its initial knowhow by acquiring part or all of its partner's knowhow, but it cannot increase its knowhow beyond the partners' combined knowhow. Finally, the acquisition of knowhow is an uncertain process.[9]

Learning conditions, which reflect the uncertainty in knowhow acquisition, are represented by the state variable $x(t)$. We normalize $x(t)$ to equal 1 at the date at which the joint venture is formed, $t = 0$ in the present case.[10] Over the interval of time, $\mathcal{T}_J(t)$, during which the joint venture has been in operation at date t, the variable $x(t)$ follows the geometric, upwards drifting Brownian motion

$$dx(t) \;=\; \mu_x x(t)\, dt \;+\; \sigma_x x(t)\, dB_x(t) \;, \tag{7}$$

where $\mu_x > 0$, $B_x(t)$ denotes a standard Brownian motion. We assume that learning conditions and the state variable $x(t)$ remain unchanged under separate operations. The constant $\alpha > 0$ is an index of the ease of knowhow acquisition.

Figures 3 and 4 show how the uncertainty represented by (7) affects the gain in knowhow and knowhow itself by (6) and (5), respectively. Firms gain knowhow but do not lose it. They do not gain knowhow over some periods of time. Figure 5 shows firm i's knowhow as a function of the levels of effort selected by the two partners, $s(\mathbf{e})$, the ease of knowhow acquisition, α, and firm i's initial knowhow, $k_i(0)$.

[9] In addition to reflecting the considerations above, the functional form (6) delivers closed form solutions and finite levels of effort.

[10] Note that, should joint operations be desirable, the parties will wish these to start at date $t = 0$ and not to postpone them. We return to this issue in Section 5.

As a firm acquires knowhow through the joint operation of the asset, the firm increases the profitability of its separate operation of the asset. A phase of joint operations therefore makes separate operations more desirable than was the case at the start of joint operations. Should the joint venture eventually be dissolved, the separate operation of the asset by firm i yields instantaneous revenue $R(\hat{e}_i, k_i(t))$ at instantaneous cost $C_i(\hat{e}_i)$ at date $t \geq \hat{t}$. Here, $\hat{e}_i$ denotes the level of effort selected by firm i at the date $\hat{t}$ at which the joint venture is dissolved and separate operations are initiated.

Throughout, we shall assume that there are no asymmetries of information, that capital markets are frictionless, that agents are risk neutral, and that they may borrow and lend freely at the constant, risk-free rate of interest, r.

We allow for ex ante negotiation but do not allow for ex post renegotiation. We assume ex ante negotiation takes the form of costless bargaining between the parties. We adopt the generalized Nash bargaining solution, and denote β_i the bargaining power of firm i, $\beta_a + \beta_b = 1$. We do not allow for ex post renegotiation in order to keep the analysis tractable.

Finally, it is useful to define the following variable, which will play a central role in what follows. Let

$$\pi_i(t) \;=\; \underset{e_i}{Max} \left\{ R(e_i, k_i(t)) - C_i(e_i) \right\} \;\equiv\; \frac{k_i(t)^2}{4\,\omega_i}. \tag{8}$$

Intuitively, $\pi_i(t)$ is the "instantaneous profitability" of the separate operation of the asset by firm i at date t. Without loss of generality, we assume that $\pi_a(0) > \pi_b(0)$, and refer to firm a as the *originally superior* firm.

In the sections that follow, we shall analyze the determinants of the formation and duration of joint ventures. We first examine the value of the asset under separate and joint operations. We then compare these values for the purpose of determining the form of organization chosen at the outset.

3 Separate Operations

We first consider the value of separate operations, assuming they are the organizational form chosen at date $t = 0$. The value to firm i of operating the asset separately at date $t \geq 0$ is

$$\begin{aligned} V_{i,S}(k_i(0)) &\equiv E_t \left[\int_t^{+\infty} \exp^{-r(\tau - t)} P_{i,S}(e_i, k_i(\tau)) d\tau \right] , & (9) \\ \text{where} \quad P_{i,S}(e_i, k_i(\tau)) &\equiv R(e_i, k_i(\tau)) - C_i(e_i) \ , & (10) \\ e_i &= \arg\max_{e_i} \left[V_{i,S}(k_i(0)) \right] \ , & (11) \\ \text{and} \quad k_i(t) &= k_i(0) \ , \quad \text{for all } t \geq 0 \ . & (12) \end{aligned}$$

Equation (12) reflects the fact that knowhow is constant under separate operations. We now establish[11]

Proposition 1 *The value to firm i of operating the asset separately at date $t \geq 0$ is*

$$V_{i,S}(k_i(0)) = \frac{\pi_i(0)}{r} \ . \tag{13}$$

The level of effort selected by firm i is

$$e_{i,S} = \frac{k_i(0)}{2\,\omega_i} \ . \tag{14}$$

The results are intuitive. Since there is no change in knowhow over time when a firm operates the asset separately, the value of the asset under separate operation by firm i is proportional to the instantaneous profitability of the separate operation of the asset by firm i at the initial date $t = 0$.

We have the equivalence

$$V_{a,S}(k_a(0)) > V_{b,S}(k_b(0)) \Leftrightarrow \pi_a(0) > \pi_b(0) \qquad \text{for all } t \geq 0 \ . \tag{15}$$

The constancy of knowhow under separate operations implies that the asset should be owned by the originally superior firm, namely firm a. Under separate operations, the optimal allocation of ownership is constant through time and depends only on the exogenous firm characteristics $(k_a(0), \omega_a)$ and $(k_b(0), \omega_b)$.

Furthermore, to the extent that the *original owner* of the asset differs from the *superior user* of the asset, the asset will immediately be traded at date $t = 0$. Should firm b originally

[11] All proofs are in the Appendix.

own the asset, it should sell the asset to firm a, for the latter firm is the superior user of the asset. We let p_S denote the sale price of the asset in such case. This price must be such that

$$V_{b,S}(k_b(0)) \leq \; p_S \; \leq V_{a,S}(k_a(0)) \; . \tag{16}$$

The generalized Nash solution is

$$p_S = \beta_b \, V_{a,S}(k_a(0)) \; + \; \beta_a \, V_{b,S}(k_b(0)) \quad = \quad \frac{\beta_b \, \pi_a(0) \; + \; \beta_a \, \pi_b(0)}{r}. \tag{17}$$

The value of separate operations to firm i, $i \in \{a; b\}$, at date $t = 0$, including the value of the option to trade the asset, is then

$$U_{a,S}(\mathbf{k}(0) \mid \mathcal{O}) \quad \equiv \quad \begin{cases} \pi_a(0)/r & \text{if } \; \mathcal{O} = a \; , \\ - \; p_S \; + \; \pi_a(0)/r & \text{if } \; \mathcal{O} = b \; , \end{cases} \tag{18}$$

$$U_{b,S}(\, \mathbf{k}(0) \mid \mathcal{O}) \quad \equiv \quad \begin{cases} 0 & \text{if } \; \mathcal{O} = a \; , \\ p_S & \text{if } \; \mathcal{O} = b \; . \end{cases} \tag{19}$$

where $\mathcal{O} \in \{\, a; b \,\}$ denotes the original owner of the asset. As the two firms internalize the option to trade the asset, the aggregate value of separate operations to the two firms at date $t = 0$, including the option value of trading the asset, equals the value of separate operations to the originally superior firm a

$$W_S(\mathbf{k}(0)) \; \equiv \; U_{a,S}(\mathbf{k}(0) \mid \mathcal{O}) \; + \; U_{b,S}(\mathbf{k}(0) \mid \mathcal{O}) \quad = \quad \frac{\pi_a(0)}{r} \; . \tag{20}$$

4 Joint Operations

We now consider the value of joint operations, assuming they are the organizational form chosen at date $t = 0$. We proceed by backward induction. We first determine the value of the joint venture at dissolution, should such dissolution occur. We then determine the value of the joint venture prior to dissolution, as well as the second-best contract and initial transfer between the partners.

4.1 The Value of a Dissolved Joint Venture

Should the partners forego joint operations and the joint venture be dissolved, separate operations would nonetheless remain possible. If firm i were to operate the asset separately, after the joint venture is dissolved at a date $\hat{t}$, firm i would have value at a date $t \geq \hat{t}$[12]

$$
\begin{aligned}
V_{i,S}(k_i(\hat{t})) &\equiv E_t\left[\int_t^{+\infty} \exp^{-r(\tau-t)} P_{i,S}(\hat{e}_i, k_i(\tau))d\tau\right], && (21)\\
\text{where} \quad P_{i,S}(\hat{e}_i, k_i(\tau)) &\equiv R(\hat{e}_i, k_i(\tau)) - C_i(\hat{e}_i)\ , && (22)\\
\hat{e}_i &= \arg\max_{\hat{e}_i}\left[V_{i,S}(k_i(\hat{t}))\right]\ , && (23)\\
\text{and} \quad k_i(t) &= k_i(\hat{t})\ , \quad \text{for all } t \geq \hat{t}\ . && (24)
\end{aligned}
$$

Equation (24) reflects the fact that knowhow remains constant once the joint venture has been dissolved. By analogy to the results of Proposition 1, we can write

$$
V_{i,S}(k_i(\hat{t})) = \frac{\pi_i(\hat{t})}{r}\ . \tag{25}
$$

4.2 Contracts

We assume that joint revenue $R_J(\mathbf{e})$ is observable and verifiable, but that the levels of effort $\mathbf{e}$ are neither observable nor verifiable. We further assume that the state variable $x(t)$ is observable but not verifiable. The partners in the joint venture are therefore limited to writing a contract that conditions each partner's payoff on the venture's revenues.

We consider contracts that promise each partner a constant share ϕ_i, $0 < \phi_i < 1$, of the joint revenues $R_J(\mathbf{e})$, with $\phi_a + \phi_b = 1$.[13]

We denote $V_i^*(\mathbf{k}(t))$, $t \geq \hat{t}$, the value of partner i in case of dissolution. This value clearly depends on the rules that govern exit from the venture. We consider exit rules whose effective payoffs to the partners are linear combinations of $V_{a,S}(k_i(t))$ and $V_{b,S}(k_i(t))$, the value of the asset under separate operation by firm a and b, respectively. An exit rule can thus be characterized by two complementary triples $\left(\lambda_i, \psi_i^a, \psi_i^b\right)$ such that

$$
V_i^*(\mathbf{k}(t)) = \lambda_i \ + \ \psi_i^a\ V_{a,S}(k_i(t)) \ + \ \psi_i^b\ V_{b,S}(k_i(t)). \tag{26}
$$

An efficient exit rule must allocate the asset to the superior user at dissolution. We take this to be a feature of the exit rule, and show how to implement such a feature in Section 4.4. Hence, at the date of dissolution, $\hat{t}$,

$$
V_a^*(\mathbf{k}(\hat{t})) \ + \ V_b^*(\mathbf{k}(\hat{t})) = \frac{\pi_a(\hat{t}) \vee \pi_b(\hat{t})}{r} \ \equiv \ W^*(\mathbf{k}(\hat{t})), \tag{27}
$$

[12]Note that a dissolution of the joint venture is necessarily permanent. Should a partner prefer separate operations at date $\hat{t}$, he will do so at all dates $t \geq \hat{t}$. This is because both knowhow and learning conditions remain unchanged during the phase of separate operations that follows dissolution.

[13]Note that the inequalities are strict as each partner must be induced to select some non-zero level of effort.

where $W^*(\mathbf{k}(\hat{t}))$ denotes the value of the dissolved joint venture.

Let $H \in \{a;b\}$ and $L \in \{a;b\}$ refer to the partner with higher and lower profitability at the date of dissolution, $\hat{t}$, respectively. That is, $\pi_H(\hat{t}) \equiv \pi_a(\hat{t}) \vee \pi_b(\hat{t})$ and $\pi_L(\hat{t}) \equiv \pi_a(\hat{t}) \wedge \pi_b(\hat{t})$.[14] We now redefine the exit rule in terms of H and L instead of a and b. That is, we characterize an exit rule by two complementary triples $\left(\lambda_i, \psi_i^H, \psi_i^L\right)$ such that

$$V_i^*(\mathbf{k}(t)) = \lambda_i \ + \ \psi_i^H \ V_{H,S}(k_i(t)) \ + \ \psi_i^L \ V_{L,S}(k_i(t)). \tag{28}$$

This is convenient, because H buys out L at dissolution and with (27) the triples $\left(\lambda_i, \psi_i^H, \psi_i^L\right)$ are such that $\lambda_a + \lambda_b = 0$, $\psi_a^H + \psi_b^H = 1$ and $\psi_a^L + \psi_b^L = 0$.

4.3 The Second-Best Contract and the Value of Joint Operations

Denote $V_{i,J}(x(t))$ the value to partner i of operating the asset jointly with partner j, at a date $t \geq 0$. Each partner i maximizes $V_{i,J}(x(t))$ over his effort and the date at which to dissolve the joint venture in a non-cooperative fashion, hence

$$V_{i,J}(x(t)) \ \equiv \ E_t\left[\int_t^{\hat{t}} \exp^{-r(\tau-t)} P_{i,J}(\mathbf{e})\, d\tau\right] + E_t\left[\exp^{-r(\hat{t}-t)} V_i^*(\mathbf{k}(\hat{t}))\right], \tag{29}$$

$$\text{where} \qquad P_{i,J}(\mathbf{e}) \ \equiv \ \phi_i R_J(\mathbf{e}) - C_i(e_i)\ , \tag{30}$$

$$e_i \ = \ \arg\max_{e_i} \left[V_{i,J}(1)\right]\ , \tag{31}$$

$$\hat{t} \ \equiv \ \hat{t}_a \wedge \hat{t}_b\ , \quad \text{with} \ \ \hat{t}_i \ = \ \arg\max_{\hat{t}_i} \left[V_{i,J}(x(t))\right]\ . \tag{32}$$

Notice that both parties take into account that the actual dissolution time, $\hat{t}$, is the earlier of the two partners' privately optimal dissolution times, $\hat{t}_a$ and $\hat{t}_b$. This is because no ex post renegotiation is possible. The fact that (5) can be rewritten as

$$k_i(t) \ = \ k_i(0) \ \sqrt{\alpha \ s(\mathbf{e}) \ \max_{\tau \in \mathcal{T}_J(t)} \{x(\tau)\}} \ \ \wedge \ \ \bar{\kappa}\ \ , \tag{33}$$

makes the problem weakly path dependent in the historical maximum of $x(t)$ over the period of joint operations.[15] Each partner's optimization problem regarding the choice of dissolution time is then time homogeneous. Hence each partner's privately optimal time of dissolution, $\hat{t}_i$, is the first time $x(t)$ reaches some upper time-independent threshold level. That is, there

[14] Note that H is not necessarily the originally superior partner, a.

[15] Equilibrium strategies are therefore Markov, open loop (i.e., state dependent) and perfect state (i.e., with perfect information).

exists a constant $\hat{x}_i$ such that $\hat{t}_i = \inf\{\, t \mid x(t) = \hat{x}_i \,\}$. We denote the aggregate value of joint operations to the two firms

$$W_J(x(t)) \equiv V_{a,J}(x(t)) \;+\; V_{b,J}(x(t)) \;. \tag{34}$$

We derive the value of the joint venture for each partner and characterize each partner's optimal dissolution time and selected effort level. To do this, we make use of the fact that a necessary condition for the contract to be efficient is that $\hat{t}_a = \hat{t}_b$.[16] We then derive the optimal contract, which is second-best because of the double-sided moral hazard problem inherent to joint operations.

Proposition 2 *The second-best contract (sharing and exit rule) is* $\phi_i = 1/2$ *and* $\left(\lambda_i, \psi_i^H, \psi_i^L\right) = (0, 1/2, 0)$. *In case the joint venture is dissolved, dissolution takes the form of the buyout of partner L by partner H.*

That the partners' optimal shares are equal, despite the inequality of the partners' cost parameters, $\omega_a \neq \omega_b$, is an artifact of our model, which has both revenues and costs proportional to $\sqrt{\phi_a \phi_b}$ in equilibrium.[17,18]

That $\psi_i^H = \phi_i$, $\lambda_i = 0$, and $\psi_i^L = 0$ ensure that the partners' privately optimal dissolution times coincide with each other and with the jointly optimal dissolution time, and that the partners' concern at dissolution is only with the value of the asset in its most profitable use. This is because no wedge is introduced (i) between a partner's claim on the profit stream from the continuing joint venture and its claim on the dissolved venture (as would be the case if $\psi_i^H \neq \phi_i$), and (ii) between the maximization of a partner's payoff and that of the venture at dissolution, either by a fixed transfer (as would be the case if $\lambda_i \neq 0$), or by a concern with the value of the asset under separate operation by the low profitability partner (as would be the case if $\psi_i^L \neq 0$).

Given the optimal contract, we obtain the desired values and effort levels, identify the partner that buys out the other at dissolution, and characterize the extent to which the partners have completed their know-how at dissolution.

[16] This is needed to make the actual dissolution time, $\hat{t} \equiv \hat{t}_a \wedge \hat{t}_b$, coincide with the jointly optimal dissolution time, that which maximizes the aggregate value of joint operations.

[17] This specific functional form can to some extent be justified by the observed prevalence of 50-50 joint ventures (Hauswald and Hege, 2003).

[18] Interestingly, we show the sharing rule $\phi_i = 1/2$ maximizes *instantaneous* total revenue, $R_J(\mathbf{e})$, and minimizes *instantaneous* total costs, $C_a(e_a) + C_b(e_a)$, in addition to maximizing the aggregate value of the joint venture.

Proposition 3 *Under $\phi_i = 1/2$ and $\left(\lambda_i, \psi_i^H, \psi_i^L\right) = (0, 1/2, 0)$, the value of joint operations to partner i, at a date $t \in [0; \hat{t}]$, is*

$$
\begin{aligned}
V_{i,J}(x(t)) &= \frac{1}{2}\frac{\Pi_J}{r}\left[1 + \Gamma\left(\frac{x(t)}{\hat{x}_J}\right)^{\xi}\right], && (35)\\
\textit{where}\ \ \Pi_J &\equiv \frac{3}{2}\frac{\bar{\kappa}^2}{4\sqrt{\omega_a\,\omega_b}}, && (36)\\
\xi &\equiv \sigma_x^{-2}[\sigma_x^2/2 - \mu_x + \sqrt{(\mu_x - \sigma_x^2/2)^2 + 2r\sigma_x^2}]\ . && (37)
\end{aligned}
$$

The level of effort selected by partner i is

$$e_{i,J} = \frac{\bar{\kappa}}{4\,(\omega_i^3\,\omega_j)^{\frac{1}{4}}}. \tag{38}$$

The level of knowhow attained by partner i at time t is

$$k_i(t) = k_i(0)\sqrt{\frac{\alpha\,\bar{\kappa}}{2\sqrt{\omega_a\,\omega_b}}\max_{\tau\in\mathcal{T}_J(t)}\{x(\tau)\}}\ \wedge\ \bar{\kappa}\ . \tag{39}$$

Case 1: If $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} > \frac{3\,\xi}{2\,(\xi-1)}$, the joint venture is temporary *(it is eventually dissolved). After completing its knowhow* partially, *the low cost partner buys out its counterpart to operate the asset alone i.e. H is such that $\omega_H = \omega_a \wedge \omega_b$, and $k_H(\hat{t}) < \bar{\kappa}$. Here $\Gamma = (\xi - 1)^{-1}$ and dissolution takes place the first time $x(t)$ reaches*

$$\hat{x}_J = \frac{\xi}{\xi\,-\,1}\,\frac{3\,\bar{\kappa}\,\omega_H}{\alpha\,k_H^2(0)}\ . \tag{40}$$

Case 2: If $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} \in \left(\frac{3}{2}, \frac{3\,\xi}{2\,(\xi-1)}\right)$, the joint venture is temporary. *After completing its knowhow* fully, *the low cost partner buys out its counterpart to operate the asset alone i.e. H is such that $\omega_H = \omega_a \wedge \omega_b$, and $k_H(\hat{t}) = \bar{\kappa}$. Here $\Gamma = \frac{2}{3}\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} - 1$ and dissolution takes place the first time $x(t)$ reaches*

$$\hat{x}_J = \frac{2\,\bar{\kappa}\sqrt{\omega_a\,\omega_b}}{k_H^2(0)\,\alpha}\ . \tag{41}$$

Case 3: If $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} < \frac{3}{2}$, the joint venture is permanent *(it is never dissolved) and both partners complete their knowhow* fully. *Here, $\hat{x}_J \to +\infty$ (so $\hat{t} \to +\infty$) and $\Gamma = 0$.*

We provide the intuition for the results in Proposition 3 in what follows.

Identity of the buying partner: Proposition 3 establishes the result that it is always the low cost partner that buys out its high cost counterpart in a temporary joint venture. This is because the alternative to buyout by the low cost partner — buyout by the high cost partner — can under no circumstances be value-creating. Such buyout would increase the cost of effort, which would then be exerted exclusively by the high cost firm. It would at best leave knowhow unchanged, as the joint venture partners' combined knowhow, $\bar{\kappa}$, represents the highest level of knowhow that can be achieved. Consequently, in the cases where the originally superior firm a is also the high cost firm, the joint venture will not be dissolved before enough knowhow acquisition has taken place for the low cost firm to displace the originally superior firm as superior user of the asset.

Dissolution of the joint venture: Proposition 3 relates the dissolution of the joint venture to the diversity in the partners' costs of effort.

When $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} > \frac{3}{2}$, there *always* exists a finite state $\hat{x}_J$ and a finite time $\hat{t}_J$ at which the joint venture is dissolved. Given the large difference in the partners' costs of effort, continued joint operation of the asset by the two partners in a joint venture would eventually place too high a burden on the low cost partner. The low cost partner therefore buys out its counterpart.

Whether the low cost partner does so once it has fully completed its knowhow or only partially done so is perhaps best understood with reference to Figure 6, which represents the value of joint operations to partner i. Figure 6 varies the cost of effort of the high cost, low profitability partner L such that $\omega_L = \omega_a \vee \omega_b$, and holds all other parameters constant. Figure 6 (a) has high $\omega_L = \omega_a \vee \omega_b$, representing a large discrepancy in the partners' costs of effort: $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} > \frac{3\,\xi}{2\,(\xi-1)}$, i.e. Case 1. Figure 6 (b) has intermediate $\omega_L = \omega_a \vee \omega_b$, representing an intermediate discrepancy in the partners' costs of effort: $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} \in \left(\frac{3}{2}, \frac{3\,\xi}{2\,(\xi-1)}\right)$, i.e. Case 2. In both figures, the dotted horizontal line corresponds to the value of joint operations to partner i. The solid horizontal line represents the value to partner i of the asset under separate operation by the low cost partner, if that partner were fully to complete its knowhow. The dotted horizontal line is closer to the solid horizontal line in Figure 6 (b) than it is in Figure 6 (a). This is because the lower cost of effort of the high cost partner in the former case raises the profitability of joint operations closer to that of separate operations by the low cost partner, if that partner were fully to complete its knowhow.[19]

The low cost partner — who knows it will eventually buy out its counterpart — is confronted with the following trade-off. It wishes to increase through knowhow acquisition the value of operating the asset alone after dissolution. But acquiring knowhow requires

[19]There is no figure corresponding to Case 3 in Figure 6. This is because such a figure would be extremely simple. For low $\omega_L = \omega_a \vee \omega_b$, representing a small discrepancy in the partners' costs of effort: $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} < \frac{3}{2}$, the dashed horizontal line lies *above* the solid horizontal line for *all* x(t). The value of joint operations to partner i, $V_{i,J}(x(t))$, is then equal to the dashed horizontal line $\frac{1}{2}\frac{3}{2}\frac{\bar{\kappa}^2}{4\sqrt{\omega_a\,\omega_b}}\,\frac{1}{r}$.

remaining in the joint venture and bearing the attending burden of operating the asset jointly with the high cost partner. In Case 1, the large discrepancy in the partners' cost of effort makes the full completion of knowhow prohibitively costly. The low cost partner therefore buys out its high cost counterpart before having fully completed its knowhow. In Case 2, there is only an intermediate discrepancy in the partners' cost of effort. This renders affordable the full completion of knowhow.

When $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} \leq \frac{3}{2}$ there *does not* exist a finite state $\hat{x}_J$ and a finite time $\hat{t}_J$ at which the joint venture is dissolved. The joint venture will *never* be dissolved, even after both partners have fully completed their knowhow. This is despite the moral hazard problem inherent to joint operations, and is due to the convex cost of effort.[20]

4.4 Implementing the Second-Best Contract

We now show how to implement the second-best contract derived in Proposition 2, particularly as regards the optimal exit rule.

A mechanism commonly used in joint venture agreements is the "Cake-Cutting Mechanism" (CCM).[21,22] The heart of the mechanism is as follows:

The "Cake-Cutting Mechanism" (CCM): *At dissolution, partner $j \in \{a; b\}$, chooses an an exit price $W^*(k(\hat{t}))$. Partner $i \in \{a; b\}$ with $i \neq j$ either buys out partner j for $\phi_j W^*(k(\hat{t}))$, or sells out to partner j for $\phi_i W^*(k(\hat{t}))$.*

We show in the Appendix that the CCM amounts to an exit rule that has partner H buy out partner L at dissolution and corresponds to the triples

$$\left(\lambda_i, \psi_i^H, \psi_i^L\right) \ , \ \left(\lambda_j, \psi_j^H, \psi_j^L\right) = \begin{cases} (0, \phi_i, 0) \ , \ (0, \phi_j, 0) & \text{if } (i,j) = (H, L) \ , \\ (0, 0, \phi_i) \ , \ (0, 1, -\phi_i) & \text{if } (i,j) = (L, H) \ . \end{cases} \tag{42}$$

The CCM effectively gives all bargaining power to partner j, as it grants him the privilege to make a take-it-or-leave-it offer when setting the exit price.[23]

[20]As noted in Section 2, convexity of the cost of effort implies that, in the absence of a large difference in the firms' costs of effort, a given level of effort should be exerted by both firms acting as partners in a joint venture rather than by one firm alone.We return to the effects of moral hazard and convexity in Sections 5 and 7.

[21]The CCM is also known as the "Russian Roulette" clause, the "Texas Shootout" clause, the "Dynamite" clause, or the "Shotgun" clause.

[22]See Crawford and Heller (1979) for a formal analysis of the CCM under symmetric information. See Cramton, Gibbons, and Klemperer (1987), McAfee (1992), and Minehart and Neeman (1999) for an analysis of how to dissolve a partnership under asymmetric information. The latter two papers consider the role of the CCM in such circumstances.

[23]Note that the CCM provides the partner presented with the exit price, partner i, with the ability to

It is clear from (42) that the CCM corresponds to the optimal exit rule $((0, \phi_i, 0), (0, \phi_j, 0))$ derived in Proposition 2 only if $j = L$. We have seen that Proposition 3 identifies the partner $H \in \{a; b\}$ who, under the optimal exit rule, buys out its counterpart to operate the asset alone. It consequently identifies the partner L who should set the exit price at dissolution for the optimal exit rule to be implemented. L should be the the high cost firm.

Corollary 1 *A sharing rule $\phi_i = 1/2$ and a CCM exit rule where the partner that sets the exit price is fixed at the time of writing the contract to be high cost partner L (such that $\omega_L = \omega_a \vee \omega_b$), implements the second-best contract, $\phi_i = 1/2$ and $\left(\lambda_i, \psi_i^H, \psi_i^L\right) = (0, 1/2, 0)$.*

4.5 Initial Transfers

The result in Proposition 2 that the partners should have equal shares in the venture, despite their likely unequal initial contributions, suggests that the formation of the joint venture will be accompanied by a transfer from one partner to the other. Denote p_J the (possibly negative) transfer payment from firm a to b. This payment must be such that[24]

$$V_{b,S}(k_b(0) \mid \mathcal{O}) - V_{b,J}(1) \leq p_J \leq V_{a,J}(1) - V_{a,S}(k_a(0) \mid \mathcal{O}) , \qquad (43)$$

where $V_{i,S}(k_i(0) \mid \mathcal{O}) \equiv V_{i,S}(k_i(0))$ if $\mathcal{O} = i$ and $V_{i,S}(k_i(0) \mid \mathcal{O}) \equiv 0$ if $\mathcal{O} \neq i$. The generalized Nash solution is

$$p_J = \beta_b \left[V_{a,J}(1) - V_{a,S}(k_a(0) \mid \mathcal{O})\right] + \beta_a \left[V_{b,S}(k_b(0) \mid \mathcal{O}) - V_{b,J}(1)\right] . \qquad (44)$$

Given that $V_{a,J}(1) = V_{b,J}(1) = W_J(1)/2$,

$$p_J = \begin{cases} \left(\frac{1}{2} - \beta_a\right) W_J(1) - (1 - \beta_a) V_{a,S}(k_a(0)) & \text{if } \mathcal{O} = a , \\ \left(\frac{1}{2} - \beta_a\right) W_J(1) + \beta_a V_{b,S}(k_b(0)) & \text{if } \mathcal{O} = b . \end{cases} \qquad (45)$$

where $\mathcal{O} \in \{ a; b \}$ denotes the original owner of the asset. In case of equal bargaining power, i.e. $\beta_a = \beta_b = 1/2$, the initial owner of the asset receives a positive transfer.

"turn the table" on the partner that sets the exit price, partner j. This ensures that partner j neither inflates the price if wishing to sell, nor deflates it if wishing to buy.

[24] Note that the bounds on the transfer payment p_J reflect the fact that the ultimate default option to failing to reach agreement consists in the separate operation of the asset by the original owner of the asset. Were the default option the separate operation of the asset by the originally superior partner, the terms at which the asset might be transferred from the original owner to the originally superior user would themselves reflect separate operation by the original owner.

The value of joint operations to firm i, $i \in \{a; b\}$, at date $t = 0$, including the initial transfer payment from firm a to b, is then

$$U_{a,J}(\mathbf{k}(0) \mid \mathcal{O}) \;\equiv\; \begin{cases} \beta_a\, W_J(1) \;+\; (1-\beta_a)\, V_{a,S}(k_a(0)) & \text{if } \; \mathcal{O} = a \;, \\ \beta_a\, W_J(1) \;-\; \beta_a\, V_{b,S}(k_b(0)) & \text{if } \; \mathcal{O} = b \;, \end{cases} \tag{46}$$

$$U_{b,J}(\mathbf{k}(0) \mid \mathcal{O}) \;\equiv\; \begin{cases} \beta_b\, W_J(1) \;-\; \beta_b\, V_{a,S}(k_a(0)) & \text{if } \; \mathcal{O} = a \;, \\ \beta_b\, W_J(1) \;+\; (1-\beta_b)\, V_{b,S}(k_b(0)) & \text{if } \; \mathcal{O} = b \;. \end{cases} \tag{47}$$

We clearly have

$$U_{a,J}(\mathbf{k}(0) \mid \mathcal{O}) \;+\; U_{b,J}(\mathbf{k}(0) \mid \mathcal{O}) \;=\; W_J(1) \;. \tag{48}$$

5 Initial Organizational Form

We now turn to the comparison of separate and joint operations for the purpose of determining the optimal organizational form at date $t = 0$. From the results in Section 3, we can write the value of the asset under separate operations at the date $t = 0$. From the results in Section 4, we have the corresponding value under joint operations. Joint operations will be chosen in preference to separate operations at date $t = 0$ when

$$W_J(1) \;\geq\; W_S(\mathbf{k}(0)) \;. \tag{49}$$

This is equivalent to

$$\Pi_J \left[1 + \Gamma\, \hat{x}_J^{-\xi} \right] \geq \pi_a(0) \;, \tag{50}$$

where

$$\Pi_J \;=\; \frac{3}{2}\, \frac{\bar{\kappa}^2}{4\, \sqrt{\omega_a\, \omega_b}} \;, \qquad \pi_a(0) \;=\; \frac{k_a^2(0)}{4\, \omega_a} \;, \tag{51}$$

$$\text{and} \;\; \Gamma \;=\; \begin{cases} (\xi - 1)^{-1} & \text{if } \; \sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} \;>\; \frac{3\,\xi}{2\,(\xi-1)} & \text{(Case 1)} \;, \\ \frac{2}{3}\, \sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} - 1 & \text{if } \; \sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} \;\in\; \left(\frac{3}{2} ,\; \frac{3\,\xi}{2\,(\xi-1)} \right) & \text{(Case 2)} \;, \\ 0 & \text{if } \; \sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} \;<\; \frac{3}{2} & \text{(Case 3)} \;. \end{cases} \tag{52}$$

Inequality (50) compares the instantaneous profitability of the asset under joint operations with the instantaneous profitability of the asset under separate operation by the originally superior firm. The relative advantages of the two forms of operation are as follows:

(i) An advantage of joint operations over separate operations is the combination of the partners' knowhow ($\bar{\kappa} > k_a(0)$).

(ii) A disadvantage of joint operations is the inability to have all effort exerted by the low cost partner ($\sqrt{\omega_a \omega_b} > (\omega_a \wedge \omega_b)$).

(iii) A disadvantage of joint operations is the associated double-sided moral hazard problem. This gives rise to a factor $\frac{3}{4}$ that scales the profitability of joint operations.[25]

(iv) An advantage of joint operation is the ability to exploit the convexity of costs. This advantage gives rise to a factor 2.[26] That $2 \times \frac{3}{4} = \frac{3}{2} > 1$ implies that the advantage of convexity dominates the disadvantage of double-sided moral hazard.

(v) Finally, an advantage of joint operations is the option value of dissolving the venture and abandoning joint operations for separate operations when the latter dominate. This advantage is reflected in the term in squared brackets.

Considerations (i) to (iv) make instantaneous profitability under joint operations net of the option value of dissolving the venture, Π_J, either larger or smaller than instantaneous profitability under separate operation by the originally superior firm, $\pi_a(0)$. Consideration (v) may impart a preference for joint operations even where $\Pi_J < \pi_a(0)$, because of the option value of dissolution.

Note that there are no circumstances under which joint operations are preceded by a phase of separate operations. Such an occurrence would require inequality (50) to be false at the outset, and become true after some period of separate operations. But neither side of the inequality will change during separate operations. This is because both knowhow and learning conditions remain unchanged under separate operations.[27] Thus, should inequality (50) be false at date $t = 0$, and separate operations therefore be chosen at the outset, the inequality will remain false for all $t > 0$.

Furthermore, regardless of whether joint or separate operations dominate, there are no circumstances until which the dominant form of operations should be delayed. This is because not operating is never worthwhile, as the values $V_{i,S}(k_i(0))$ and $V_{i,J}(x(t))$ in (9) and (35) are always positive. This motivates our initial statement in footnote 10.

[25] That moral hazard scales the profitability of joint operations by the factor $\frac{3}{4}$ can be concluded from the comparison of Π_J in Proposition 3 with $\Pi_J^{(1)}$ in Proposition 5, which examines the case of joint operations with no moral hazard.

[26] The scaling factor 2 is inferred from the expression for Π_J in (36) and the scaling factor $\frac{3}{4}$ due to moral hazard.

[27] The constancy of learning conditions under separate operations implies that $x(t) = x(0) = 1$ until the start of joint operations. There is therefore no option value to waiting for an improvement in learning conditions. See McDonald and Siegel (1986) for an analysis of the value of the option of waiting to invest.

To illustrate the conditions under which one or the other organizational form will be chosen at date $t = 0$, we rewrite (50) to obtain:

Proposition 4 *Joint operation will be chosen in preference to separate operation at date* $t = 0$ *when*

$$Sup_a \leq \frac{3}{2} \left[1 + \Gamma \, \hat{x}_J^{-\xi}\right] , \tag{53}$$

$$\text{where} \qquad Sup_a \equiv \pi_a(0) \, / \, \frac{\bar{\kappa}^2}{4\sqrt{\omega_a \, \omega_b}} , \tag{54}$$

is a measure of the superiority of the originally superior firm, a, over the other firm, b.

The conditions under which one or the other organizational form is chosen initially and, in the case a joint venture is formed, the duration of the venture, are represented graphically in Figure 7 in the shape of areas (a.i), (a.ii), and (b)

(a) When (50) holds, the superiority of the originally superior firm, Sup_a, is small. There is much to be gained by joining forces and a joint venture is formed.

  (i) When there is a large diversity in the partners' costs of effort, $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} > \frac{3}{2}$, the joint venture will *always* be dissolved.

  (ii) When there is little diversity in the partners' costs of effort, $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} \leq \frac{3}{2}$, the joint venture will *never* be dissolved. Exploiting the convexity of costs is paramount.

(b) When (50) does not hold, the superiority of the originally superior firm, Sup_a, is large. The two firms have little to gain and much to lose by joining forces. The *originally superior* firm a operates the asset separately (after acquiring it if it does not own it originally).

6 The Duration of the Joint Venture

The duration of the joint venture is the time elapsed between the date $t = 0$ and the first time, $\hat{t}$, at which the state $\hat{x}_J$ is reached and the joint venture is dissolved. At the date $t = 0$ at which the joint venture is formed, the joint venture has expected duration $E_0\left[\hat{t}\right]$ and variance $V_0\left[\hat{t}\right]$ given by[28]

$$E_0\left[\hat{t}\right] = \frac{\ln[\hat{x}_J]}{\mu_x - \sigma_x^2/2} \text{ and } V_0\left[\hat{t}\right] = \frac{\sigma_x^2 \, \ln[\hat{x}_J]}{2\left(\mu_x - \sigma_x^2/2\right)^3} . \tag{55}$$

[28] See Cox and Miller (1984) and recall that $\mu_x > 0$.

Interestingly, the expected duration of a joint venture $E_0\left[\hat{t}\right]$, if not infinite, must then be smaller than a certain time, T^{Full}. By Proposition 3, any finite dissolution state, $\hat{x}_J$, must be lower than the state in which the buying partner fully completes its knowhow, $\hat{x}^{Full}$. Therefore, the expected duration of a temporary joint venture is

$$E_0\left[\hat{t}\right] \in \left(0\,;T^{Full}\right], \quad \text{where} \quad T^{Full} \equiv \frac{1}{\mu_x - \sigma_x^2/2} \ln\left[\frac{2\,\bar{\kappa}\,\sqrt{\omega_a\,\omega_b}}{k_H^2(0)\,\alpha}\right]. \tag{56}$$

We establish the following comparative statics results:

Lemma 1 *The expectation, $E_0\left[\hat{t}\right]$, and variance, $V_0\left[\hat{t}\right]$, of the duration of a temporary joint venture are*

(a) increasing in the overall knowhow of the partners, $\bar{\kappa}$,

(b) decreasing in the initial knowhow of the buying partner, $k_H(0)$,

(c) unaffected by the initial knowhow of the selling partner, $k_L(0)$,

(d) increasing in the cost of effort of the buying partner, ω_H,

(e) unaffected by the cost of effort of the selling partner, ω_L, if the buying partner partially acquires the selling partner's knowhow, and increasing in that cost if the buying partner fully acquires the selling partner's knowhow, and

(f) decreasing in the ease of knowhow acquisition, α.

All comparative statics results are relatively intuitive and can be ascribed to the desire on the part of the buying partner to acquire knowhow. The expected dissolution time increases as there is more knowhow to be acquired by the buying partner. It is unaffected by the initial knowhow of the selling partner, for the knowhow of that partner in no way affects the knowhow to be acquired by the buying partner. It increases in the cost of effort of the partners, for a higher cost of effort decreases effort and thereby impedes the acquisition of knowhow. Perhaps surprisingly, this is not true of the cost of effort of the selling partner when the buying partner only partially acquires the selling partner's knowhow. This is because that cost of effort identically affects the instantaneous profitability of joint operations and that of separate operations at the time of dissolution. Finally, it decreases in the ease of knowhow acquisition.

We calibrate the model in order to illustrate the sensitivity of the expected time of dissolution to each of its determinants. The baseline parameter values correspond to an expected duration $E_0\left[\hat{t}\right] = 7.12$ years and a variance $V_0\left[\hat{t}\right] = 5.93$.[29] In this case, $Sup_a =$

[29] We set $k_a(0) = 40$, $k_b(0) = 60$ and $\bar{\kappa} = 100$, signifying no overlap in initial knowhow; $\omega_a = 10$ and $\omega_b = 25$, implying that the originally superior firm a is also the low cost firm; $r = 8\%$, the historical average over the period 1973-1998; $\alpha = 1.5$; $\mu_x = 0.04$; and $\sigma_x = 0.05$. These values are chosen so as to obtain expected duration in line with what appears to be the average duration of joint ventures.

0.25 and joint operations are preferred to separate operations. Partner $H = a$ fully completes its knowhow (Case 2 in Proposition 3).

We plot in Figure 9 (a) the probability density function of the dissolution time, $\hat{t}$, and (b) the expected dissolution frequency.[30] To assess the sensitivity of the expected time of dissolution to each of its determinants, we plot in Figure 10 $E_0\left[\hat{t}\right]$ for parameter values ranging from 0.9 to 1.1 times the baseline values. The variations are substantial.

7 Moral Hazard

We now consider the costs of the double-sided moral hazard problem inherent to joint ownership. For that purpose, we repeat the analysis above, but make the assumption that each partner maximizes the total value of the venture, rather than the partner's stake alone. The first-best value of joint operations at a date $t \in [0; \hat{t}^{(1)}]$, is

$$\begin{aligned} W_J^{(1)}(x(t)) \;&\equiv\; E_t\left[\int_t^{\hat{t}^{(1)}} \exp^{-r(\tau-t)}\;\{P_{a,J}(\mathbf{e})+P_{b,J}(\mathbf{e})\}\;d\tau\right] \\ &+\; E_t\Big[\exp^{-r(\hat{t}^{(1)}-t)}\;\left\{V_a^*(\mathbf{k}(\hat{t}^{(1)}))+V_b^*(\mathbf{k}(\hat{t}^{(1)}))\right\}\Big]\;, \end{aligned} \tag{57}$$

where $P_{i,J}(\mathbf{e})$ is as in (30),

$$e_i = \arg\max_{e_i}\left[W_J^{(1)}(1)\right]\;, \tag{58}$$

and $\hat{t}^{(1)}$ is the random time at which the joint venture is dissolved. The cooperative optimal time at which to dissolve the joint venture is the first time $x(t)$ reaches some upper threshold level $\hat{x}_J^{(1)}$. We now show:

Proposition 5 *The first-best value of joint operations to partner i, at a date $t \in [0; \hat{t}]$, is*

$$W_J^{(1)}(x(t)) \;=\; \frac{\Pi_J^{(1)}}{r}\left[1+\Gamma^{(1)}\left(\frac{x(t)}{\hat{x}_J^{(1)}}\right)^{\xi}\right]\;, \tag{59}$$

[30]The expected dissolution frequency at date t is the probability that dissolution occurs at or before that date. It can be viewed as the counterpart in joint ventures to the expected default frequency analyzed by Huang and Huang (2002) and Leland (2002) in their assessment of structural asset pricing models of the firm. Our model has been constructed to be consistent with such models in that, in the absence of uncertainty in learning conditions, all asset values follow a Geometric Brownian. The expected dissolution frequency at year 10, $EDF(10)$, is about 80%. This is not far from the 70% that can be inferred from Kogut's (1991) data (see the discussion in the Introduction).

where $\Pi_J^{(1)} \equiv \frac{4}{3}\Pi_J$, *with* Π_J *given in (36), and* ξ *given in (37). The first-best effort level selected by partner* i *is* $e_{i,J}^{(1)} = 2\,e_{i,J}$, *with* $e_{i,J}$ *given in (38). The level of knowhow attained by partner* i *at time* t *is* $k_i^{(1)}(t) = [\sqrt{2}\,k_i(t)\,] \wedge \bar{\kappa}$, *with* $k_i(t)$ *given in (39).*

Case 1: If $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} > \frac{2\,\xi}{(\xi-1)}$, *the joint venture is* temporary *(it is eventually dissolved). After completing only* partially *its knowhow, the low cost firm should buy-out the other to operate the asset alone i.e.* H *is such that* $\omega_H = \omega_a \wedge \omega_b$, *and* $k_H^{(1)}(\hat{t}^{(1)}) < \bar{\kappa}$. *Here* $\Gamma^{(1)} = (\xi-1)^{-1}$ *and dissolution takes place the first time* $x(t)$ *reaches* $\hat{x}_J^{(1)} = \frac{2}{3}\,\hat{x}_J$, *with* $\hat{x}_J$ *given in (**??**).*

Case 2: If $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} \in \left(2\,,\,\frac{2\,\xi}{(\xi-1)}\right)$, *the joint venture is* temporary. *Once it has* fully *completed its knowhow, the low cost firm should buy-out the other to operate the asset alone i.e.* H *is such that* $\omega_H = \omega_a \wedge \omega_b$, *and* $k_H^{(1)}(\hat{t}^{(1)}) = \bar{\kappa}$. *Here* $\Gamma^{(1)} = \frac{1}{2}\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} - 1$ *and dissolution takes place the first time* $x(t)$ *reaches* $\hat{x}_J^{(1)} = \frac{1}{2}\,\hat{x}_J$, *with* $\hat{x}_J$ *given in (**??**).*

Case 3: If $\sqrt{\frac{\omega_a \vee \omega_b}{\omega_a \wedge \omega_b}} < 2$, *the joint venture is* permanent *(it is never dissolved) and both partners* fully *complete their knowhow. Here,* $\hat{x}_J^{(1)} \to +\infty$ *(so* $\hat{t} \to +\infty$*) and* $\Gamma^{(1)} = 0$.

Proposition 5 clearly bears many similarities to Proposition 3. Despite this, for a given set of initial characteristics, the case that prevails in one proposition may differ from that which prevails in the other.

We compare the results of Proposition 5 with those of Proposition 3 to establish the effect of moral hazard:

Lemma 2 *The effect of moral hazard is to (i) reduce the value of the joint venture – by* $\frac{W_J(x(t))}{W_J^{(1)}(x(t))} \leq \frac{1}{2}$ *–, (ii) increase the threshold level at which the joint venture is dissolved – by* $\nu_x \equiv \frac{\hat{x}_J}{\hat{x}_J^{(1)}} \in \left(\frac{3}{2}\,,\,2\right)$ *when both* $\hat{x}_J$ *and* $\hat{x}_J^{(1)}$ *are finite –, hence (iii) increase the expected duration of the joint venture – by* $E_0[\hat{t}] - E_0[\hat{t}^{(1)}] = \ln[\nu_x]\,/(\mu_x - \sigma_x^2/2)$ *–, (iv) reduce the effort level selected by each partner – by* $\frac{e_{i,J}}{e_{i,J}^{(1)}} = \frac{1}{2}$ *–, and (v) reduce the level of knowhow attained by each partner at dissolution – by* $\frac{k_i(\hat{t})}{k_i^{(1)}(\hat{t})} \in \left(\frac{1}{\sqrt{2}}\,,\,1\right)$ *–.*

Not surprisingly, value and effort are lower in the presence of moral hazard. Lower effort impedes the acquisition of knowhow in the course of joint operations. In response, the partners increase the duration of joint operations, but also choose to dissolve at lower levels of knowhow acquisition.

Finally, inequality (50) that determines the initial organizational form becomes

$$Sup_a \leq \; 2\left[1 + \;\Gamma^{(1)}\,\hat{x}_J^{(1)\,-\xi}\right]\;. \tag{60}$$

Thus, the moral hazard problem makes temporary joint ventures more long-lived, but it also makes them less likely to be chosen in the first place. This is because only joint operations suffer from the moral hazard problem. The conditions under which one or the other organizational form is chosen at the outset in the absence of moral hazard are shown in Figure 8.

8 Empirical Evidence and Testable Implications

Empirical evidence: We are now in a position to provide some empirical evidence in support of our results. We first consider Proposition 3. At dissolution, the instantaneous profitability of the joint venture increases from Π_J to $\pi_H(\hat{t})$.[31] Naturally, the change in profitability is larger the larger the profitability of separate operation by the buying partner after dissolution, $\pi_H(\hat{t})$, and the smaller the profitability of joint operations, Π_J. To the extent that we may use abnormal returns on the announcement of dissolution as a proxy for $\pi_H(\hat{t}) - \Pi_J$, we can compare our results to existing empirical results by Reuer (2001).[32]

Reuer (2001) computes abnormal returns on the announcement of the buyout of one partner by the other in national and international joint ventures. He finds abnormal returns to be increasing in the acquiring partner's R&D and advertising expenses and in that partner's international experience. He finds abnormal returns to be decreasing in the 'cultural distance' between the acquiring partner's home country and the joint venture's host country and in the host country's political risk.

As the acquiring partner's international experience can be viewed as increasing the profitability of separate operations, $\pi_H(\hat{t})$, whereas cultural distance and political risk can be viewed as decreasing it, Reuer's (2001) findings regarding these three variables may be viewed as being in accordance with our results. As for R&D and advertising expenses, note that these can be viewed as proxying for intangible assets. To the extent that such assets are more exposed to hold-up and non-renumerated appropriation than are tangible assets (Hennart, 1988; Reuer, 2001), the partners in the joint venture can be expected to be somewhat selective in their choice of intangible assets to contribute to the venture, thereby depressing the profitability of the joint venture, Π_J. The higher abnormal returns reported by Reuer (2001) for acquiring partners with high R&D and advertising expenses are thus consistent with our results.

[31] The difference must be positive, for the joint venture would otherwise be permanent.

[32] The use of abnormal returns as proxy is not without its limitations. Strictly speaking, there are no abnormal returns in our model, as there is no asymmetry of information.

Now turning from abnormal returns at dissolution to abnormal returns at formation, we note that Mohanram and Nanda (1998) find abnormal returns on the announcement of the formation of a joint venture to be increasing in the degree of complementarity of the parent firms' resources, where complementarity is measured by SIC codes. In the context of our model, abnormal returns at formation may be represented by the difference $W_J(1) - W_S(\mathbf{k}(0))$, and complementarity by the difference $\bar{\kappa} - k_a(0) - k_b(0)$. The closer $\bar{\kappa}$ is to $k_a(0) + k_b(0)$, the smaller the overlap in knowhow, and the greater therefore the complementarity between the two firms. There is a positive relationship between these two differences in our model, which is consistent with the findings of Mohanram and Nanda (1998).[33]

We now turn to Lemma 1. Kogut (1991) finds that joint ventures that conduct more R&D and marketing and distribution have higher hazard rate. This can somewhat loosely be viewed as being in accordance with our analysis, to the extent that R&D, marketing, and distribution can be interpreted as effort that hastens the acquisition of knowhow, thereby bringing forward in time the point at which one partner can dispense with the other.

Testable implications: The principal implication of Proposition 3 is that the buying partner at dissolution should be the low cost partner. Testing this implication requires identifying the low cost firm. Following Hauswald and Hege (2003), this can be done by computing the ratio of the wealth gains by parent firms on the announcement of the formation of a joint venture. In the case where the two firms have comparable bargaining power, Hauswald and Hege (2003) show that the low cost firm is the one for which this ratio is higher.

An implication of results (a), (b), and (f) of Lemma 1 is that joint ventures between unrelated partners should have longer expected duration than those between related partners. This is because there should be more knowhow to be acquired by the buying partner in the former case, and because the acquisition of knowhow should be more difficult where each partner is relatively unfamiliar with its counterpart's industry or market. This implication may be tested by including a dummy for relatedness in a hazard rate model of joint venture duration such as used by Kogut (1989, 1991), where relatedness may be proxied by the 'distance' in SIC codes or the location of headquarters.

9 Conclusion

We have proposed an explanation for the temporary nature of the majority of joint ventures that revolves around the acquisition of knowhow. We have argued that joint ventures are dis-

[33] Increasing complementarity can be represented by an increasing $\bar{\kappa}$, for fixed $k_a(0)$ and $k_b(0)$. One can then show $\partial \left[W_J(1) - W_S(\mathbf{k}(0))\right] / \partial \bar{\kappa} \geq 0$.

solved when one partner in the venture has acquired sufficient knowhow from its counterpart to be able to dispense with that counterpart.

We have constructed a continuous time model of joint ventures with opportunities for knowhow acquisition. We have shown that joint ventures can be permanent when the partners have similar cost of effort. When there is a large discrepancy in the partners' costs of effort, the joint venture is always temporary. We have identified the partner who buys out its counterpart. For lower levels of knowhow acquisition, it is the firm that is originally superior at operating the asset alone. For higher levels of knowhow acquisition, it is the low cost firm. We have derived the expected duration of a joint venture, and various measures of the uncertainty regarding that time. We find expected duration to be substantially sensitive to each of its determinants. We have established the implications of the preceding analysis for the formation of joint ventures. The possibility to acquire knowhow under joint operations imparts a preference for joint ventures over separate operations.

A possible limitation of our analysis lies in the specificity of the functional forms assumed. These were made necessary be the need to obtain closed form solutions and finite levels of effort. We acknowledge the limitations these specific functional forms impose. Nonetheless, with the possible exception of the relative importance of double-sided moral hazard and the convexity of costs, our qualitative results do not seem model specific, as the intuition behind these results is generally quite natural.

Appendix

Proof of Proposition 1: We use (1) and (2) to write $V_{i,S}(k_i(0))$ in (9) as

$$V_{i,S}(k_i(0)) = \left(e_i\, k_i(0) - \omega_i\, e_i^2\right) \frac{1}{r}. \tag{61}$$

Maximizing, we obtain (14). Substituting and using (8), we obtain (13). $\square$

Proof of Proposition 2: Let $f_t(t(x^*))$ denote the density of $t(x^*) \equiv \inf\{\, t \mid x(t) = x^* \,\}$ conditional on the information known at date t. The Laplace transform of $f_t(t(x^*))$ gives the probability weighted discount factor for the value of one unit of currency received at $t(x^*)$,

$$\int_t^{\infty} \exp^{-r(t(x^*)-t)}\, f_t(t(x^*))\, dt(x^*) \quad = \quad \left(\frac{x(t)}{x^*}\right)^{\xi}, \tag{62}$$

$$\text{where} \quad \xi \quad \equiv \quad \sigma_x^{-2}[\sigma_x^2/2 - \mu_x + \sqrt{(\mu_x - \sigma_x^2/2)^2 + 2r\sigma_x^2}\,]\;. \tag{63}$$

Using (62) we can rewrite (29) as

$$V_{i,J}(x(t)) \quad = \quad \max_{e_i, \hat{x}_i} \left\{ P_{i,J}(\mathbf{e}) \left[1 - \left(\frac{x(t)}{\hat{x}}\right)^{\xi} \right] \frac{1}{r} + V_i^*(\mathbf{k}(\hat{t})) \left(\frac{x(t)}{\hat{x}}\right)^{\xi} \right\}, \tag{64}$$

$$\text{with} \;\; P_{i,J}(\mathbf{e}) \quad = \quad \phi_i\, 2\, \bar{\kappa}\, \sqrt{e_i\; e_j} \; - \; \omega_i\, e_i^2\,, \tag{65}$$

$$\text{and} \;\; \hat{x} \quad \equiv \quad \hat{x}_a \;\wedge\; \hat{x}_b\,. \tag{66}$$

Denoting $\theta_i^H \equiv \psi_i^H - \phi_i$ and $\theta_i^L \equiv \psi_i^L$, the exit rule (28) can be written as

$$V_i^*(\mathbf{k}(\hat{t})) = \left(\phi_i\, \pi_H(\hat{t}) \;+\; \lambda_i\, r \;+\; \theta_i^a\, \pi_a(\hat{t}) \;+\; \theta_i^b\, \pi_b(\hat{t})\right) \frac{1}{r}\;, \tag{67}$$

and deviations from the $\left(\lambda_i, \psi_i^H, \psi_i^L\right) = (0, \phi_i, 0)$ exit rule must be such that $\lambda_a + \lambda_b = 0$, $\theta_a^a + \theta_b^a = 0$ and $\theta_a^b + \theta_b^b = 0$.

• Proceeding backwards in time, we first examine each partner's non-cooperative optimal dissolution time. Now, given that $k_i^2(t) = k_i^2(0)\, \alpha\, 2\, \sqrt{e_i\; e_j}\; x(t) \;\wedge\; \bar{\kappa}^2$, we have $\frac{\partial}{\partial \hat{x}_i}\left[k_i^2(\hat{t}_i)\right] = \Delta_i\, k_i^2(\hat{t}_i)\,/\,\hat{x}_i$, where $\Delta_i = 1$ if partner i's knowhow $k_i(\hat{t}) < \bar{\kappa}$ and $\Delta_i = 0$ otherwise. Differentiating (64) w.r.t. $\hat{x}_i$, given that $\frac{\partial}{\partial \hat{x}_i}\left[\left(\frac{x(t)}{\hat{x}_i}\right)^{\xi}\right] = -\xi\, \left(\frac{x(t)}{\hat{x}_i}\right)^{\xi} / \,\hat{x}_i$, we obtain the f.o.c. for $\hat{x}_i$

$$\frac{\partial\, V_{i,J}(x(t))}{\partial\, \hat{x}_i} = \frac{1}{\hat{x}_i} \left(\frac{x(t)}{\hat{x}_i}\right)^{\xi} \left[\xi \frac{P_{i,J}(\mathbf{e})}{r} - \xi\, V_i^*(\mathbf{k}(\hat{t}_i)) + \hat{x}_i\, \frac{\partial\, V_i^*(\mathbf{k}(\hat{t}_i))}{\partial\, \hat{x}_i}\right] \quad = \quad 0\,, \tag{68}$$

where $\pi_l(\hat{t}_i) = \left[\, k_l^2(0)\, \alpha\, 2\, \sqrt{e_i\; e_j}\; \hat{x}_i \;\wedge\; \bar{\kappa}^2\,\right] / (4\, \omega_l)$ for $l \in \{H; a; b\}$, $\hat{x}_i\, \frac{\partial\, V_i^*(\mathbf{k}(\hat{t}_i))}{\partial\, \hat{x}_i} = \Delta_H\, \phi_i\, \pi_H(\hat{t}_i) \;+\; \Delta_a\, \theta_i^a\, \pi_a(\hat{t}_i) \;+\; \Delta_b\, \theta_i^b\, \pi_b(\hat{t}_i)$, if $\hat{x}_i = \hat{x}$, and $\frac{\partial\, V_{i,J}(x(t))}{\partial\, \hat{x}_i} = 0$ if $\hat{x}_i > \hat{x}$.

A necessary condition for the contract ϕ_i and $\left(\lambda_i, \psi_i^H, \psi_i^L\right)$ to be efficient is that $\hat{t}_a = \hat{t}_b$: The contract is efficient if the actual (privately optimal) joint venture value equals the socially optimal value, for which it is necessary that the actual dissolution time, $\arg\max_{\hat{t}_a}\left[V_{a,J}(x(t))\right] \wedge$

$\arg\max_{\hat{t}_b}\,[V_{b,J}(x(t))]$, equals the socially optimal time, $\arg\max_{\hat{t}}\,[V_{a,J}(x(t)) + V_{b,J}(x(t))]$. This requires $\arg\max_{\hat{t}_a}\,[V_{a,J}(x(t))] = \arg\max_{\hat{t}_b}\,[V_{b,J}(x(t))]$, hence $\hat{t}_a = \hat{t}_b$. We therefore impose on the contract selected at date $t = 0$ the condition $\hat{t}_a = \hat{t}_b$ tantamount to

$$\hat{x}_a = \hat{x}_b \ . \tag{69}$$

We henceforth consider only those contracts within the subset of contracts that satisfy (69). We denote $\hat{x} \equiv \hat{x}_a = \hat{x}_b$ and $\hat{t} \equiv \inf\{\, t \mid x(t) = \hat{x}\,\}$.

• We secondly examine each partner's optimal effort level. Differentiating (64) at date 0 (where $x(0) = 1$) w.r.t. e_i, recalling that $\pi_i(t) = k_i^2(\hat{t})/(4\,\omega_i) = \left[\,k_i^2(0)\,\alpha\,2\sqrt{e_i\,e_j}\;\hat{x}\ \wedge\ \bar{\kappa}^2\,\right]/(4\,\omega_i)$ and taking into account that $\frac{\partial V_{i,J}(x(t))}{\partial \hat{x}} = 0$, we obtain the f.o.c. for e_i

$$\begin{aligned}&\left(\phi_i\,\bar{\kappa}\,e_i^{-\frac{1}{2}}\,e_j^{\frac{1}{2}} - 2\,\omega_i\,e_i\right)\left[1 - \left(\frac{1}{\hat{x}}\right)^{\xi}\right] \\ &\qquad + \left(\Delta_H\,\phi_i\,\pi_H(0)\ +\ \theta_i^a\,\Delta_a\,\pi_a(0) + \ \theta_i^b\,\Delta_b\,\pi_b(0)\right)\hat{x}\,\alpha\,e_i^{-\frac{1}{2}}\,e_j^{\frac{1}{2}}\left(\frac{1}{\hat{x}}\right)^{\xi} = 0\,,\end{aligned} \tag{70}$$

where $\Delta_i = 1$ if partner i's knowhow $k_i(\hat{t}) < \bar{\kappa}$, $\Delta_i = 0$ otherwise. (70) is equivalent to

$$\phi_i\ (\bar{\kappa} + h_i)\ e_j^{\frac{1}{2}} - 2\,\omega_i\,e_i^{\frac{3}{2}} = 0\ , \tag{71}$$

$$\text{where}\quad h_i \equiv \left(\Delta_H\,\pi_H(0)\ +\ \frac{\theta_i^a}{\phi_i}\,\Delta_a\,\pi_a(0) + \ \frac{\theta_i^b}{\phi_i}\,\Delta_b\,\pi_b(0)\right)\ \alpha\,\left[\frac{\hat{x}}{\hat{x}^{\xi}\ -\ 1}\right]. \tag{72}$$

Substituting the f.o.c. for e_i into the one for e_j gives the equilibrium effort level

$$e_i = \frac{1}{2}\left(\frac{\phi_i^3\,\phi_j}{\omega_i^3\,\omega_j}\ (\bar{\kappa} + h_i)^3\ (\bar{\kappa} + h_j)\right)^{\frac{1}{4}}. \tag{73}$$

• We thirdly examine the second-best sharing rule, ϕ_i, and the optimal exit rule, $\left(\lambda_i, \psi_i^H, \psi_i^L\right)$. Substituting (73) in (64), we obtain the joint venture value to partner i

$$V_{i,J}(x(t)) \ = \ \phi_i\left\{\frac{3\,K_i^2}{4}\left(\frac{\phi_a\,\phi_b}{\omega_a\,\omega_b}\right)^{\frac{1}{2}} +\ \Gamma_i\ \left(\frac{x(t)}{\hat{x}}\right)^{\xi}\right\}\frac{1}{r}, \tag{74}$$

$$\text{where}\quad K_i^2 \ \equiv\ \sqrt{(\bar{\kappa} + h_a)\ (\bar{\kappa} + h_b)}\left(\bar{\kappa} - \frac{h_i}{3}\right)\ , \tag{75}$$

$$\Gamma_i \ \equiv\ \left(\pi_H(\hat{t})\ +\ \frac{\lambda_i\,r}{\phi_i}\ +\ \frac{\theta_i^a}{\phi_i}\,\pi_a(\hat{t})\ +\ \frac{\theta_i^b}{\phi_i}\,\pi_b(\hat{t})\right)\ -\ \frac{3\,K_i^2}{4}\left(\frac{\phi_a\,\phi_b}{\omega_a\,\omega_b}\right)^{\frac{1}{2}}, \tag{76}$$

and the knowhow attained by partner i at dissolution

$$k_i(\hat{t}) = k_i(0)\ \left(\alpha\,\hat{x}\ (\bar{\kappa} + h_a)^{\frac{1}{2}}\ (\bar{\kappa} + h_b)^{\frac{1}{2}}\left(\frac{\phi_a\,\phi_b}{\omega_a\,\omega_b}\right)^{\frac{1}{2}}\right)^{\frac{1}{2}}\ \wedge\ \bar{\kappa}\ . \tag{77}$$

The total value of the joint venture, $W_J(x(t)) = V_{a,J}(x(t)) + V_{b,J}(x(t))$, is

$$W_J(x(t)) = \frac{1}{r}\left(\frac{3}{4}\,(\phi_a\,K_a^2 + \phi_b\,K_b^2)\,\left(\frac{\phi_a\,\phi_b}{\omega_a\,\omega_b}\right)^{\frac{1}{2}}\right)\left[1 - \left(\frac{x(t)}{\hat{x}}\right)^{\xi}\right] + \frac{\pi_H(\hat{t})}{r}\left(\frac{x(t)}{\hat{x}}\right)^{\xi}. \tag{78}$$

Note that given that $\lambda_a + \lambda_b = 0$, $\theta_a^a + \theta_b^a = 0$ and $\theta_a^b + \theta_b^b = 0$, for an efficient contract, adding up the f.o.c (68) for partner a with that for partner b, we have

$$\xi\,\frac{3}{4}\,(\phi_a\,K_a^2 + \phi_b\,K_b^2)\,\left(\frac{\phi_a\,\phi_b}{\omega_a\,\omega_b}\right)^{\frac{1}{2}} + (\Delta_H - \xi)\,\pi_H(\hat{t}) = 0\,. \tag{79}$$

Replacing in (78),

$$W_J(x(t)) = \frac{3}{4\,r}\,(\phi_a\,K_a^2 + \phi_b\,K_b^2)\,\left(\frac{\phi_a\,\phi_b}{\omega_a\,\omega_b}\right)^{\frac{1}{2}}\left[1 + \frac{\Delta_H}{\xi - \Delta_H}\left(\frac{x(t)}{\hat{x}}\right)^{\xi}\right]\,. \tag{80}$$

Denoting

$$h \equiv \Delta_H\,\pi_H(0)\,\alpha\left[\frac{\hat{x}}{\hat{x}^{\xi} - 1}\right], \tag{81}$$

$$\phi_a\,K_a^2 + \phi_b\,K_b^2 = \sqrt{(\bar{\kappa} + h_a)\,(\bar{\kappa} + h_b)}\left(\bar{\kappa} - \frac{h}{3}\right)\,. \tag{82}$$

Let $X \equiv \bar{\kappa} + h$ and $\Theta_i \equiv \phi_i\,(h_i - h)$. We calculate

$$\frac{\partial\,(\phi_a\,K_a^2 + \phi_b\,K_b^2)}{\partial\,\phi_i} = \frac{\phi_a\,K_a^2 + \phi_b\,K_b^2}{2\,(\bar{\kappa} + h_a)\,(\bar{\kappa} + h_b)}\,\frac{\left[(1 - 2\,\phi_i)\,(\Theta_i - X) - 2\,\phi_i^2\,X\right]\,\Theta_i}{\phi_i^2\,(1 - \phi_i)^2}\,, \tag{83}$$

$$\frac{\partial\,(\phi_a\,K_a^2 + \phi_b\,K_b^2)}{\partial\,\theta_i^k} = \frac{\phi_a\,K_a^2 + \phi_b\,K_b^2}{2\,(\bar{\kappa} + h_a)\,(\bar{\kappa} + h_b)}\,\frac{[(1 - 2\,\phi_i)\,X - 2\,\Theta_i]}{\phi_i\,(1 - \phi_i)}\,\Delta_k\,\pi_k(0)\,\alpha\left(\frac{\hat{x}}{\hat{x}^{\xi} - 1}\right), \tag{84}$$

$$\frac{\partial}{\partial\,\phi_i}\left[\left(\frac{\phi_a\,\phi_b}{\omega_a\,\omega_b}\right)^{\frac{1}{2}}\right] = \frac{(1 - 2\,\phi_i)}{2\,(\phi_a\,\phi_b\,\omega_a\,\omega_b)^{\frac{1}{2}}}\,. \tag{85}$$

Given that the contract satisfies condition (69), hence $\frac{\partial\,W_J(x(t))}{\partial\,\hat{x}} = 0$, the terms of the contract, $(\phi_i, \lambda_i, \theta_i^a, \theta_i^b)$, maximize $W_J(x(t))$ if they solve the system

$$\left\{\begin{array}{lcl} \frac{\partial\,(\phi_a\,K_a^2 + \phi_b\,K_b^2)}{\partial\,\phi_i} & = & 0 \\ \frac{\partial\,(\phi_a\,K_a^2 + \phi_b\,K_b^2)}{\partial\,\theta_i^a} & = & 0 \\ \frac{\partial\,(\phi_a\,K_a^2 + \phi_b\,K_b^2)}{\partial\,\theta_i^b} & = & 0 \\ \frac{\partial}{\partial\,\phi_i}\left[\left(\frac{\phi_a\,\phi_b}{\omega_a\,\omega_b}\right)^{\frac{1}{2}}\right] & = & 0 \end{array}\right. \iff \left\{\begin{array}{lcl} 0 & = & \left[(1 - 2\,\phi_i)\,(\Theta_i - X) - 2\,\phi_i^2\,X\right]\,\Theta_i \\ 0 & = & [(1 - 2\,\phi_i)\,X - 2\,\Theta_i] \\ 0 & = & [(1 - 2\,\phi_i)\,X - 2\,\Theta_i] \\ 0 & = & (1 - 2\,\phi_i)\,, \end{array}\right. \tag{86}$$

where $\Theta_i = \left(\theta_i^a\,\Delta_a\,\pi_a(0) + \theta_i^b\,\Delta_b\,\pi_b(0)\right)\,\alpha\left(\frac{\hat{x}}{\hat{x}^{\xi} - 1}\right)$. That is, the contract must be such that $\phi_i = 1/2$ and $\theta_i^a\,\Delta_a\,\pi_a(0) + \theta_i^b\,\Delta_b\,\pi_b(0) = 0$. Now for such contracts, $h_a = h_b = h$. Also, denoting $K^2 \equiv (\bar{\kappa} + h)\,\left(\bar{\kappa} - \frac{h}{3}\right)$, they are such that $K_a^2 = K_b^2 = K^2$, and condition (69) gives the system of f.o.c.

$$\left\{\begin{array}{lcl} \xi\,\frac{3}{4}\,\frac{K^2}{4\,\sqrt{\omega_a\,\omega_b}} + \frac{1}{2}\,(\Delta_H - \xi)\,\pi_H(\hat{t}) & = & \xi\,\left[\lambda_i\,r + \theta_i^a\,\pi_a(\hat{t}) + \theta_i^b\,\pi_b(\hat{t})\right] \\ \xi\,\frac{3}{4}\,\frac{K^2}{4\,\sqrt{\omega_a\,\omega_b}} + \frac{1}{2}\,(\Delta_H - \xi)\,\pi_H(\hat{t}) & = & -\xi\,\left[\lambda_i\,r + \theta_i^a\,\pi_a(\hat{t}) + \theta_i^b\,\pi_b(\hat{t})\right]\,, \end{array}\right. \tag{87}$$

hence it is necessary that $\lambda_i\, r \;+\; \theta_i^a\, \pi_a(\hat{t}) \;+\; \theta_i^b\, \pi_b(\hat{t}) \;=\; 0$. In summary, a contract maximizing $W_J(x(t))$ and satisfying the renegotiation proof necessary condition is such that

$$\begin{cases} \phi_i = 1/2 & \\ \theta_i^a\, \Delta_a\, \pi_a(0) + \theta_i^b\, \Delta_b\, \pi_b(0) & = \;\; 0 \\ \lambda_i\, r \;+\; \theta_i^a\, \pi_a(\hat{t}) \;+\; \theta_i^b\, \pi_b(\hat{t}) & = \;\; 0 \;, \end{cases} \tag{88}$$

All solutions are equivalent to the simplest one, $(\phi_i, \lambda_i, \theta_i^a, \theta_i^b) = (1/2, 0, 0, 0)$, in that they all correspond to the same contract: one with a sharing rule $\phi_i = 1/2$ and an exit rule $V_i^*(\mathbf{k}(\hat{t})) = \pi_H(\hat{t})/(2r)$. We therefore write this second-best contract in its simplest form, $\phi_i = 1/2$ and $\left(\lambda_i, \psi_i^H, \psi_i^L\right) = (0, 1/2, 0)$. Note that under such contracts we also have

$$\frac{\partial\, R_J(\mathbf{e})}{\partial\, \phi_i} \;\;=\;\; \frac{\partial\, \left(C_a(e_a) + C_b(e_a)\right)}{\partial\, \phi_i} \;\;=\;\; 0\;. \tag{89}$$

Proof of Proposition 3: Having established that the second-best sharing rule, ϕ_i, and the optimal exit rule, $\left(\lambda_i, \psi_i^H, \psi_i^L\right)$ satisfy (88), we reiterate the first two steps in the previous proof: We first examine the partners' non-cooperative optimal dissolution time. We then examine each partner's optimal effort level. For such a contract, $\frac{\partial\, V_i^*(\mathbf{k}(\hat{t}))}{\partial\, \hat{x}} = \Delta_H \frac{V_i^*(\mathbf{k}(\hat{t}))}{\hat{x}}$, hence the f.o.c. (68) for $\hat{x}$ simplifies to

$$\frac{\partial\, V_{i,J}(x(t))}{\partial\, \hat{x}} = \frac{1}{\hat{x}} \left(\frac{x(t)}{\hat{x}}\right)^{\xi} \left[\xi \frac{P_{i,J}(\mathbf{e})}{r} \;+\; (\Delta_H - \xi)\, V_i^*(\mathbf{k}(\hat{t}))\right] \;\;=\;\; 0\,, \tag{90}$$

where $V_i^*(\mathbf{k}(\hat{t})) = k_H^2(\hat{t})/(8\, \omega_H\, r)$. Let $\hat{t}^{Full}$ be the time partner H completes its knowhow. From (33), $\hat{t}^{Full}$ is the first time $x(t)$ reaches the threshold state $\hat{x}^{Full}$ such $k_H^2(0)\, \alpha\, s(\mathbf{e})\, \hat{x}^{Full} \;=\; \bar{\kappa}^2$.

<u>Case 1:</u> $\xi\, P_{i,J}(\mathbf{e}) \,+\, (1-\xi)\, \bar{\kappa}^2/(8\, \omega_H) \;<\; 0$. Then there exists $\hat{t}^{Part} < \hat{t}^{Full}$ such that $\xi \frac{P_{i,J}(\mathbf{e})}{r} \,+\, (1 - \xi)\, \frac{k_H^2(\hat{t}^{Part})}{8\, \omega_H\, r} = 0$ and $k_H(\hat{t}^{Part}) < \bar{\kappa}$. H *partially* completes its knowhow (so $\Delta_H = 1$) and the joint venture is *temporary* (it is eventually dissolved). Using (90), (64) can be written

$$V_{i,J}(x(t)) = \max_{e_i} \left\{ P_{i,J}(\mathbf{e}) \left[1 \,+\, \frac{1}{\xi - 1} \left(\frac{x(t)}{\hat{x}}\right)^{\xi}\right] \, \frac{1}{r} \right\}\,. \tag{91}$$

<u>Case 2:</u> $\xi\, P_{i,J}(\mathbf{e}) \,+\, (1-\xi)\, \bar{\kappa}^2/(8\, \omega_H) \;\geq\; 0$ and $P_{i,J}(\mathbf{e}) \;-\; \bar{\kappa}^2/(8\, \omega_H) \;\leq\; 0$. Here $\frac{\partial\, V_{i,J}(x(t))}{\partial\, \hat{x}} \geq 0$ for all $\hat{x} \leq \hat{x}^{Full}$, and $\frac{\partial\, V_{i,J}(x(t))}{\partial\, \hat{x}} \,<\, 0$ for all $\hat{x} \,>\, \hat{x}^{Full}$. Hence $\hat{x} \,=\, \hat{x}^{Full}$. H *fully* completes its knowhow (so $\Delta_H = 0$) but the joint venture is *temporary*. Here (64) becomes

$$V_{i,J}(x(t)) = \max_{e_i} \left\{ P_{i,J}(\mathbf{e}) \left[1 \,-\, \left(\frac{x(t)}{\hat{x}}\right)^{\xi}\right] \, \frac{1}{r} \,+\, \frac{\bar{\kappa}^2}{8\, \omega_H} \left(\frac{x(t)}{\hat{x}}\right)^{\xi} \right\}\,. \tag{92}$$

Case 3: $P_{i,J}(\mathbf{e}) - \bar{\kappa}^2/(8\,\omega_H) > 0$. Here $\frac{\partial V_{i,J}(x(t))}{\partial \hat{x}} > 0$ for all $\hat{x}$. Then $\hat{x} \to +\infty$ and it is never optimal for either partner to dissolve. Both partners *fully* complete their knowhow (so $\Delta_H = 0$) and the joint venture is *permanent* (it is never dissolved). Here (64) becomes

$$V_{i,J}(x(t)) = \max_{e_i} \left\{ \frac{P_{i,J}(\mathbf{e})}{r} \right\} . \tag{93}$$

In all 3 cases the f.o.c. (70) for e_i then simplifies to

$$\frac{1}{2}\,\bar{\kappa}\, e_i^{-\frac{1}{2}}\, e_j^{\frac{1}{2}} - 2\,\omega_i\, e_i = 0\,, \tag{94}$$

hence the equilibrium effort level in (73) simplifies to

$$e_i \;=\; \frac{\bar{\kappa}}{4\,\left(\omega_i^3\,\omega_j\right)^{\frac{1}{4}}} . \tag{95}$$

With (95) we can express the following: First

$$P_{i,J}(\mathbf{e}) \;=\; \frac{3\,\bar{\kappa}^2}{16\,(\omega_a\,\omega_b)^{\frac{1}{2}}} . \tag{96}$$

Second, from (39), the threshold state $\hat{x}^{Full}$ is such that

$$k_H^2(0)\,\frac{\alpha\,\hat{x}^{Full}\,\bar{\kappa}}{2\,\sqrt{\omega_a\,\omega_b}} \;=\; \bar{\kappa}^2\,, \tag{97}$$

hence

$$\hat{x}^{Full} \;=\; \frac{2\,\bar{\kappa}\,\sqrt{\omega_a\,\omega_b}}{\alpha\,k_H^2(0)} . \tag{98}$$

Third, the threshold state $\hat{x}^{Part} \equiv x(\hat{t}^{Part})$, solves $\xi\,\frac{P_{i,J}(\mathbf{e})}{r} + (1-\xi)\,\frac{k_H^2(\hat{t}^{Part})}{8\,\omega_H\,r} = 0$, hence

$$\hat{x}^{Part} = \frac{\xi}{\xi\,-\,1}\,\frac{3\,\bar{\kappa}\,\omega_H}{\alpha\;k_H^2(0)} . \tag{99}$$

Finally, the conditions defining the different cases can be written:

Case 1: $\sqrt{\frac{\omega_L}{\omega_H}} > \frac{3\,\xi}{2\,(\xi-1)}$;

Case 2: $\sqrt{\frac{\omega_L}{\omega_H}} \in \left(\frac{3}{2}\,,\,\frac{3\,\xi}{2\,(\xi-1)}\right)$;

Case 3: $\sqrt{\frac{\omega_L}{\omega_H}} < \frac{3}{2}$.

Importantly (noting that $\xi > 1$), when the joint venture is *temporary* (Cases 1 and 2), the partner that buys out the other at dissolution, H, is always the low cost partner, i.e. H is such that $\omega_H = \omega_a \wedge \omega_b$ $\square$.

The payoffs from the CCM: Under the CCM, partner j chooses an exit price $W^*(\mathbf{k}(\hat{t}))$ at the time of dissolution. Partner i can then either (i) buy out partner j for $\phi_j\,W^*(\mathbf{k}(\hat{t}))$ or (ii) sell out to partner j for $\phi_i\, W^*(\mathbf{k}(\hat{t}))$. The values to partner i are then $\frac{\pi_i(t)}{r} - \phi_j\, W^*(\mathbf{k}(\hat{t}))$ when buying out partner j and $\phi_i\, W^*(\mathbf{k}(\hat{t}))$ when selling out to partner j.

– If $\pi_i(t) \geq \pi_j(t)$, partner j best chooses an exit price

$$W^*\left(\mathbf{k}(\hat{t})\right) \;=\; \frac{\pi_i(t)}{r} \;-\; \epsilon\;, \tag{100}$$

where $\epsilon \in \mathbf{R}^+$ and set as small as possible. In this case, partner i chooses to buy out partner j and

$$V_i^*(\mathbf{k}(t)) \;=\; \phi_i\, W^*(\mathbf{k}(\hat{t})) \;+\; \phi_j\, \epsilon\;, \tag{101}$$

$$V_j^*(\mathbf{k}(t)) \;=\; \phi_j\, W^*(\mathbf{k}(\hat{t})) \;-\; \phi_j\, \epsilon\;. \tag{102}$$

– If $\pi_i(t) < \pi_j(t)$, partner j chooses an exit price

$$W^*(\mathbf{k}(\hat{t})) \;=\; \frac{\pi_i(t)}{r} \;+\; \epsilon\;, \tag{103}$$

In this case, partner i chooses to sell out to partner j and

$$V_i^*(\mathbf{k}(t)) \;=\; \phi_i\, W^*(\mathbf{k}(\hat{t})) \;+\; \phi_i\, \epsilon\;, \tag{104}$$

$$V_j^*(\mathbf{k}(t)) \;=\; \frac{\pi_j(t)}{r} - \phi_i\, W^*(\mathbf{k}(\hat{t})) \;-\; \phi_i\, \epsilon\;. \tag{105}$$

– Partner j's best choice is therefore to always choose an exit price

$$W^*(\mathbf{k}(\hat{t})) \;=\; \frac{\pi_i(t)}{r} \;\pm\; \epsilon \;=\; V_{i,S}(k_i(\hat{t})) \;\pm\; \epsilon\;. \tag{106}$$

The payoffs to partners i and j are therefore

$$V_i^*(\mathbf{k}(\hat{t})) \;=\; \phi_i\; V_{i,S}(k_i(\hat{t}))\;, \tag{107}$$

$$V_j^*(\mathbf{k}(\hat{t})) \;=\; \begin{cases} \phi_j\; V_{i,S}(k_i(\hat{t})) \quad \text{if } \pi_i(\hat{t}) \geq \pi_j(\hat{t})\;, \\ \qquad\qquad \text{and partner i buys out partner j;} \\ V_{j,S}(k_j(\hat{t})) - \phi_i\, V_{i,S}(k_i(\hat{t})) \quad \text{if } \pi_i(\hat{t}) < \pi_j(\hat{t})\;, \\ \qquad\qquad \text{and partner i sells out to partner j.} \end{cases} \tag{108}$$

Note that it is always the superior user of the asset at dissolution, whom we have referred to as partner H, who buys out its counterpart. From (107) and (108), the CCM amounts to an exit rule

$$\left(\lambda_i, \psi_i^H, \psi_i^L\right)\;,\; \left(\lambda_j, \psi_j^H, \psi_j^L\right) = \begin{cases} (0, \phi_i, 0)\;,\; (0, \phi_j, 0) & \text{if } (i,j) = (H,L)\;, \\ (0, 0, \phi_i)\;,\; (0, 1, -\phi_i) & \text{if } (i,j) = (L,H)\;. \end{cases} \quad \square \tag{109}$$

Proof of Lemma 1: The derivatives of $E_0\left[\hat{t}\right]$ and $V_0\left[\hat{t}\right]$ with respect to $\chi \in \{\bar{\kappa}; k_H(0); k_L(0); \omega_H; \omega_L; \alpha\}$ clearly have the same sign as the derivative of $\hat{x}_J$ w.r.t. χ.

– When H partially completes its knowhow (Case 1, $k_H(\hat{t}) < \bar{\kappa}$), we have $\hat{x}_J = \hat{x}^{Part}$ given in (**??**). The comparative statics are then $\partial\, \hat{x}^{Part} / \partial\, \bar{\kappa} > 0$; $\partial\, \hat{x}^{Part} / \partial\, k_H(0) < 0$; $\partial\, \hat{x}^{Part} / \partial\, k_L(0) = 0$; $\partial\, \hat{x}^{Part} / \partial\, \omega_H > 0$; $\partial\, \hat{x}^{Part} / \partial\, \omega_L = 0$; $\partial\, \hat{x}^{Part} / \partial\, \alpha < 0$.

– When H fully completes its knowhow (Case 2, $k_H(\hat{t}) = \bar{\kappa}$), we have $\hat{x}_J = \hat{x}^{Full}$ given in (**??**). The comparative statics are then $\partial \hat{x}^{Full}/\partial \bar{\kappa} > 0$; $\partial \hat{x}^{Full}/\partial k_H(0) < 0$; $\partial \hat{x}^{Full}/\partial k_L(0) = 0$; $\partial \hat{x}^{Full}/\partial \omega_H > 0$; $\partial \hat{x}^{Full}/\partial \omega_L > 0$; $\partial \hat{x}^{Full}/\partial \alpha < 0$. □

Proof of Proposition 5: Write $W_J^{(1)}(x(t))$ as

$$W_J^{(1)}(x(t)) = \max_{\mathbf{e},\hat{x}} \left\{ \frac{(P_{a,J}(\mathbf{e}) + P_{b,J}(\mathbf{e}))}{r} \left[1 - \left(\frac{x(t)}{\hat{x}} \right)^{\xi} \right] + \left(V_a^*(\mathbf{k}(\hat{t})) + V_b^*(\mathbf{k}(\hat{t})) \right) \left(\frac{x(t)}{\hat{x}} \right)^{\xi} \right\} , \tag{110}$$

$$\text{with } \; P_{a,J}(\mathbf{e}) + P_{b,J}(\mathbf{e}) = 2\,\bar{\kappa}\,\sqrt{e_a\; e_b} - \omega_a\, e_i^2 - \omega_i\, e_b^2\,, \tag{111}$$

$$\text{and } \; V_a^*(\mathbf{k}(\hat{t})) + V_b^*(\mathbf{k}(\hat{t})) = \frac{k_H^2(\hat{t})}{4\,\omega_H\, r}\,. \tag{112}$$

Then reiterate the same steps as in the proof of Proposition 3. □

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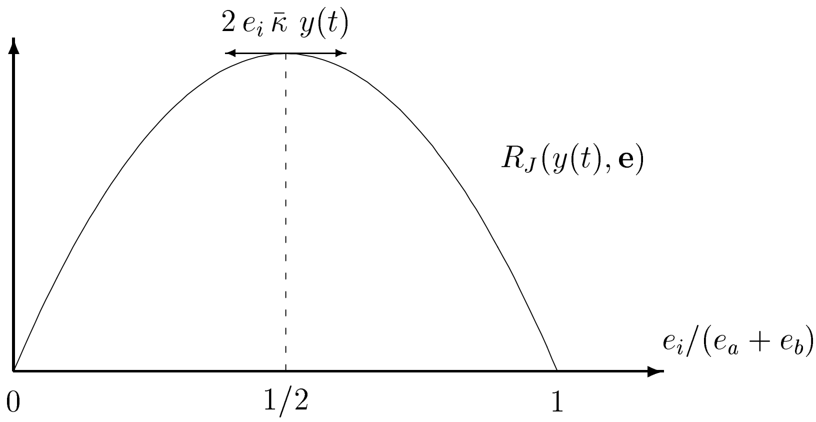


Figure 1: Revenues from Joint Operations, $R_J(\mathbf{e})$.

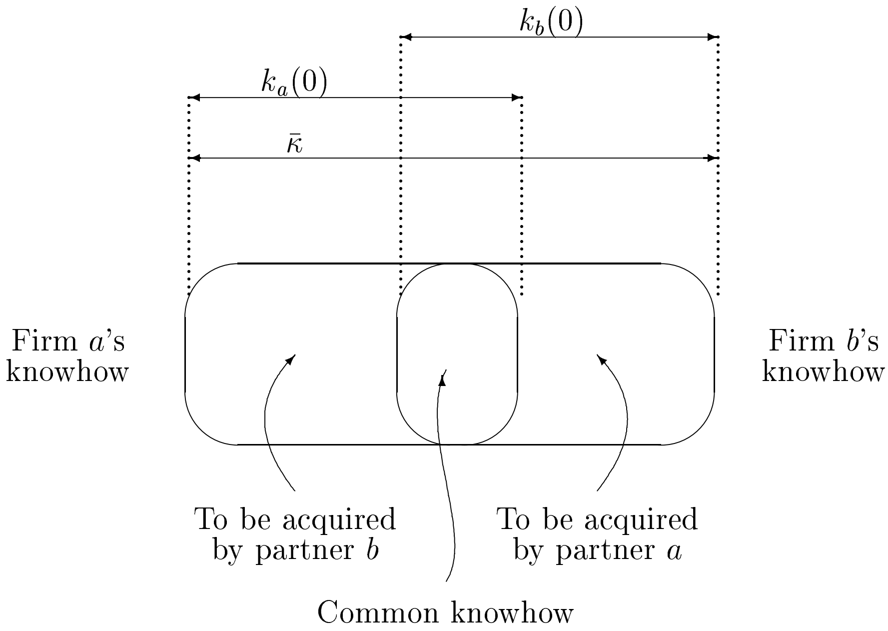


Figure 2: Firms Initial Knowhow, $(k_a(0), k_b(0))$, Combined Knowhow, $\bar{\kappa}$, and Knowhow to be Acquired.

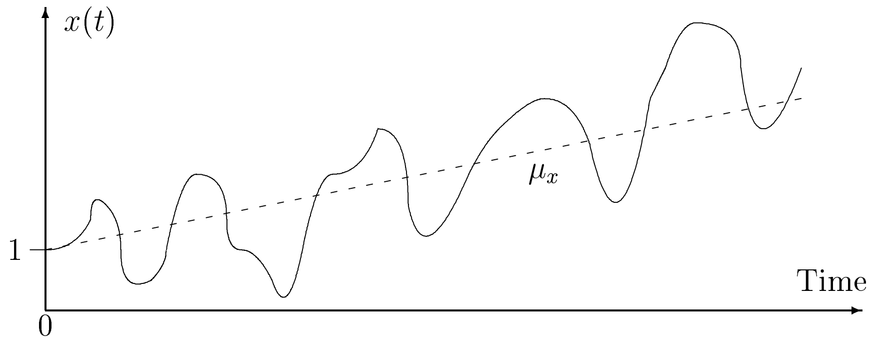


Figure 3: Learning Uncertainty Factor, $x(t)$

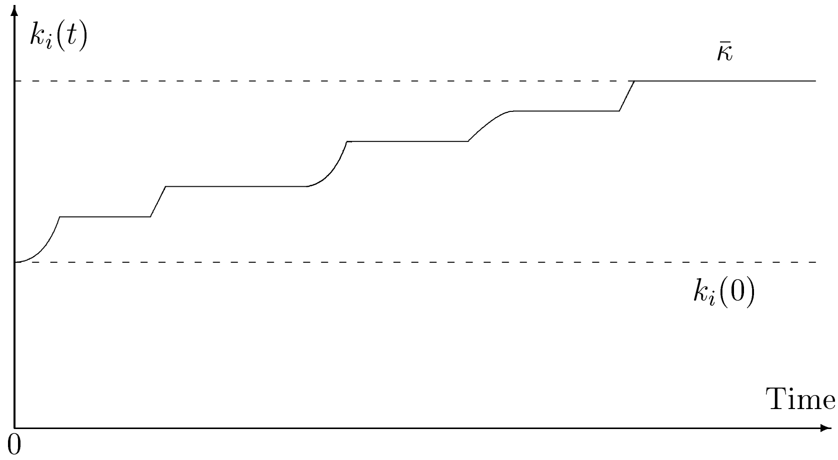


Figure 4: Evolution of Firm i's Knowhow, $k_i(t)$.

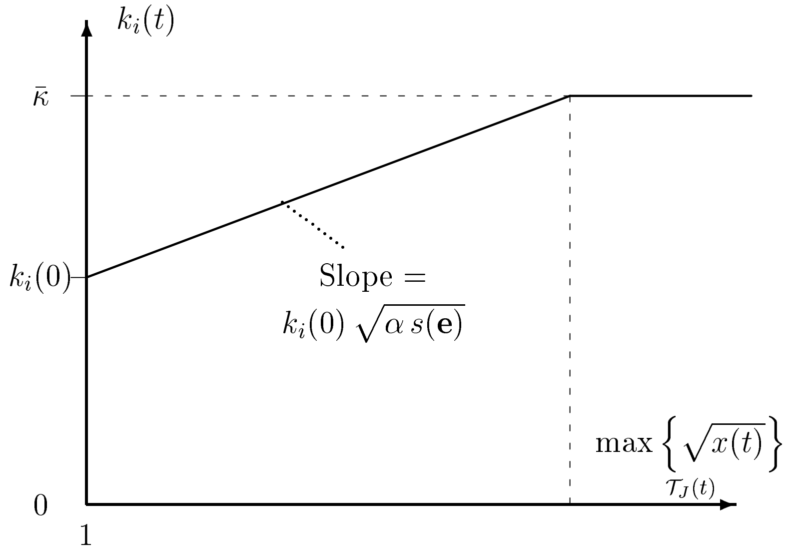
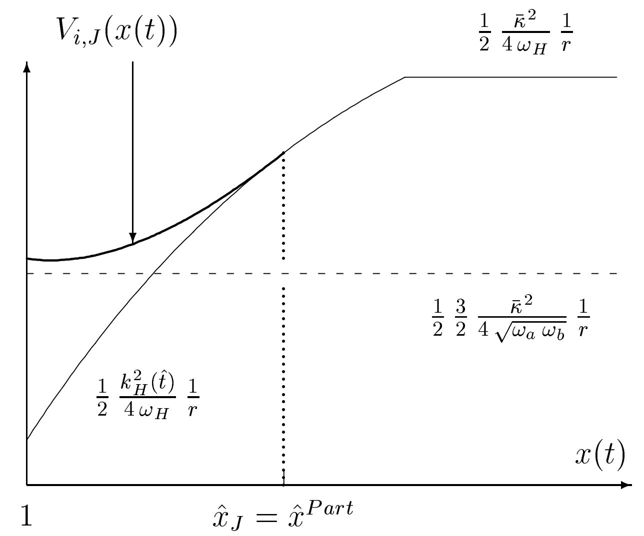
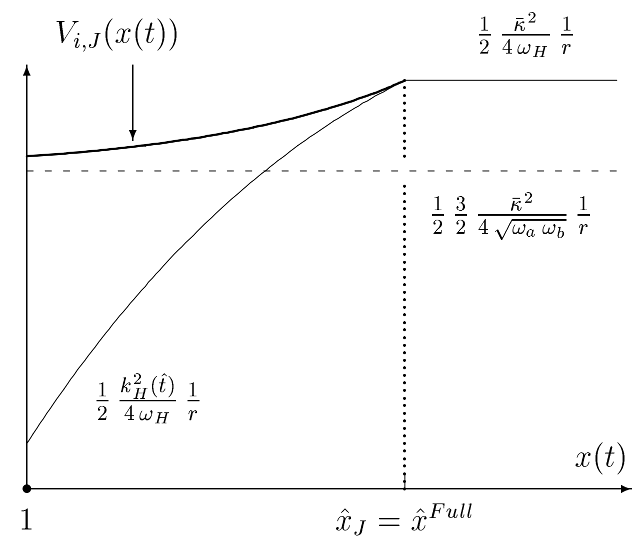


Figure 5: Influence of Initial Knowhow, $k_i(0)$, Effort Levels, $\mathbf{e}$, and Ease of Knowhow Acquisition, α, on Firm i's Knowhow, $k_i(t)$.



(a) - Case 1: Partially completed knowhow



(b) - Case 2: Fully completed knowhow

Figure 6: Value of Joint Operations to Partner i.

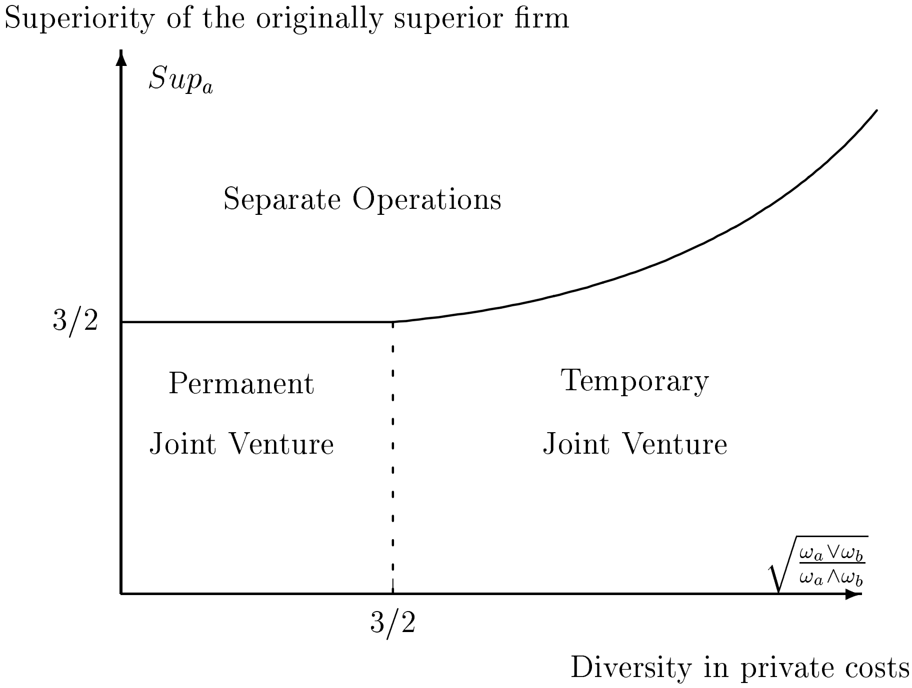


Figure 7: Initial Organizational Form in the Presence of Moral Hazard.

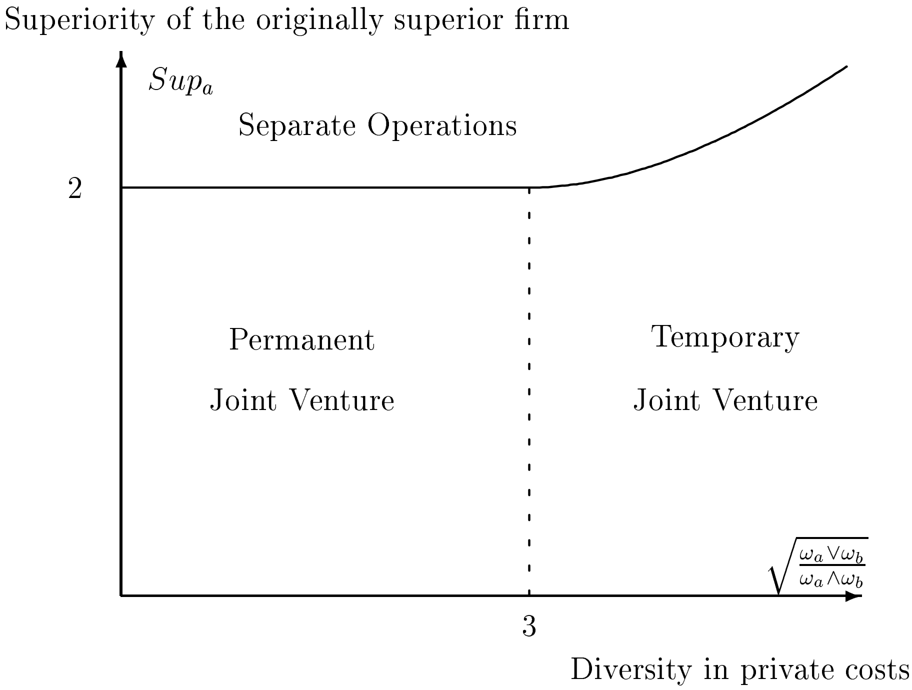
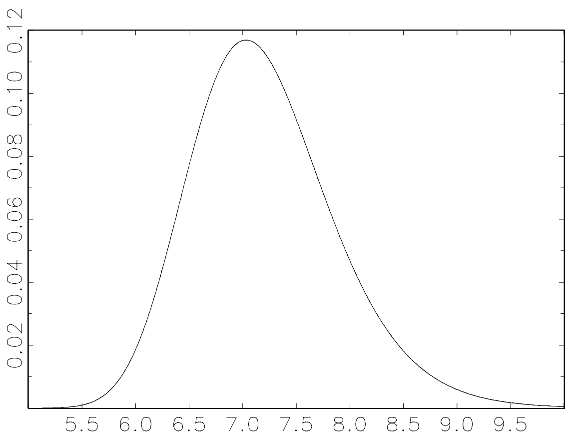
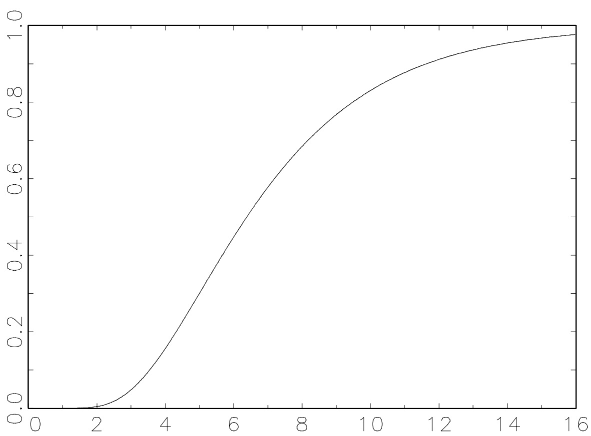


Figure 8: Initial Organizational Form in the Absence of Moral Hazard

Figure 9: Uncertainty of the Joint Venture Duration, in the Baseline Case.



(a) Probability Density Function of the Joint Venture Duration, $f_0(t)$.



(b) Expected Dissolution Frequency, $EDF(t)$
(Probability that Dissolution occurs before date t).

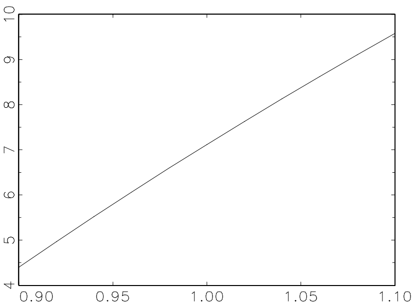
The horizontal axis shows time t in years. The analytical expressions of $f_0(t)$ and $EDF(t)$ are

$$\begin{aligned} f_0(t) &= \frac{\ln[\hat{x}_J]}{\sigma_x \sqrt{2\,\pi\, t^3}} \exp\left[- \left(\frac{\ln[\hat{x}_J] - (\mu_x - \sigma_x^2/2)t}{2\,\sigma_x^2\, t} \right)^2 \right] , \\ EDF(t) &= N\left[\frac{-\ln[\hat{x}_J] + (\mu_x - \sigma_x^2/2)t}{\sigma_x \sqrt{t}} \right] + \exp\left(\frac{2\, \ln[\hat{x}_J]\,(\mu_x - \sigma_x^2/2)}{\sigma_x^2} \right) N\left[\frac{-\ln[\hat{x}_J] - (\mu_x - \sigma_x^2/2)t}{\sigma_x \sqrt{t}} \right] . \end{aligned}$$

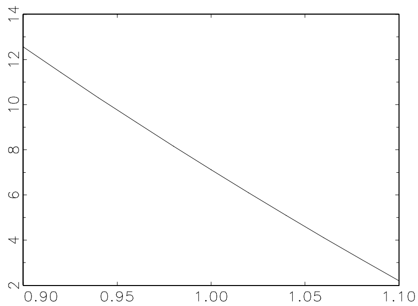
where $N(.)$ denotes the cumulative normal distribution.

Figure 10: Comparative Statics of the Expected Duration, $E_0\left[\hat{t}\right]$.

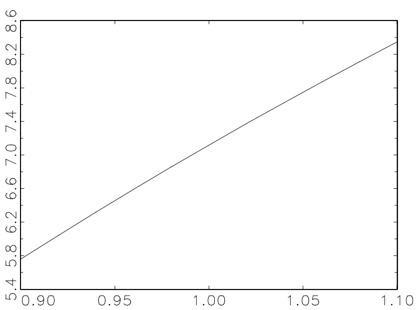
-10% to +10% change in $\bar{\kappa}$



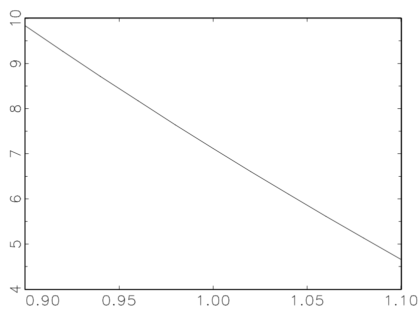
-10% to +10% change in $k_H(0)$



-10% to +10% change in ω_H



-10% to +10% change in α



The vertical axis shows $E_0[\hat{t}]$ in years. The horizontal axis shows the factor by which the baseline value is multiplied.