Knowledge sharing in alliances and alliance portfolios*

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May 16, 2017

Abstract
We develop an analytical model of knowledge sharing in alliances and alliance portfolios. We show that, once the issue of encouraging effective collaboration is put center-stage, many standard intuitions of the “learning race” view and alliance portfolio literature are overturned or qualified. Partners engage in “learning races” in some cases, but exhibit “altruistic” behaviors in other cases. They may reduce their own absorptive capacity, or increase the transparency of their own operations, to facilitate their partner’s learning. Our work contributes towards putting the “learning race” literature on a more solid foundation, by explicitly recognizing the importance of encouraging knowledge sharing between partners. In alliance portfolios, we show that not all substitutability between alliance portfolio partners is bad. We distinguish between substitutability in implementation and substitutability in rival benefits, and show that the latter can be conducive to knowledge sharing.

Keywords: knowledge sharing, learning alliances, knowledge misappropriation, learning races, alliance portfolios.

JEL Classification: D21, D23, L24.

1 Introduction

Learning alliances, where an important objective of the partners is the acquisition of new skills and capabilities, are difficult to manage. On the one hand, the partnering firms (who may also be competitors) must share knowledge to create new knowledge, and cooperatively exploit this jointly created new knowledge (Hennart, 1988; Mitchell and Singh, 1993, 1996; Gulati, 1998). This gives them a common purpose. On the other hand, the partners must divide the gains from collaboration. The negotiations are affected by the relative bargaining positions after sharing, which depend upon how efficiently firms have learned

*We would like to thank participants in numerous seminars and in particular Nick Vikander for helpful discussions and remarks. All remaining errors are ours.
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from each other, and how well positioned they are to exploit that learning without the cooperation of the partner (Hamel, 1991; Yan and Gray, 1994; Lane and Lubatkin, 1998; Das and Teng, 2000; Panico, 2017).

In many cases, the new knowledge created cannot be accurately foreseen or adequately distinguished from what is already known by the partners. Thus, firms cannot contract or commit to jointly exploit it. Any existing contract or joint venture terms are subject to renegotiation under the threat that one partner or the other may walk away (Williamson, 1975; Grossman and Hart, 1986). We focus on the need to motivate partners to share knowledge, and study how alliances should be managed and partners selected.

Our focus on encouraging knowledge sharing yields predictions that are often very different, and sometimes diametrically opposed, from what some leading strategic management approaches would suggest. A key tenet of the learning race literature (Hamel, 1991; Yan and Gray, 1994; Inkpen and Beamish, 1997; Khanna et al., 1998) is that “participating firms [should] maximize their receptivity to the knowledge and skills of their partner while limiting the transparency of their own operations” (Mowery et al., 2002: 298). In our framework, firms can engage in “learning races” in some cases but exhibit “altruistic” behaviors in other cases. This may help explain some apparently puzzling behaviors, such as Toyota’s willingness to teach a competitor, GM, the “philosophy” and practice of lean manufacturing (Inkpen, 2005). It may also help explain why sometimes firms such as Cisco appear to deliberately reduce their own learning capability (Steinhilber, 2008), and why failure to do so may lead to disputes, such as in the case of Emisphere and Eli Lilly (Gibbons and Vogel, 2007; Gilson et al., 2009). Our focus on knowledge sharing also yields the counter-intuitive result that uncertainty about outcomes need not always hinder knowledge sharing. Instead, greater uncertainty, in the form of mean preserving spreads, may actually facilitate knowledge sharing.

Knowledge sharing may also be facilitated by adding new partners to a dyadic alliance. We examine alliance portfolios where a focal firm simultaneously manages multiple alliances (Gulati, 1998, 1999; Gulati et al., 2011; Vonortas and Zirulia, 2015). Existing research suggests that synergies between partners encourage collaboration, while partner substitutability hinders it by exacerbating competitive tensions (McEvily et al., 2000; Bae and Gargiulo, 2004; Lavie, 2007). However, empirical work on the effects of partner substitutability/similarity has yielded largely inconclusive results (Goerzen and Beamish, 2005; Swaminathan and Moorman, 2009; Vasudeva and Anand, 2011; Cui and O’Connor, 2012; Cui, 2013).

We provide a potential explanation for these mixed results by distinguishing between two types of
partner substitutability: substitutability in implementation and substitutability in rival benefits. Two firms (A and B) are substitutable (or replaceable) from the perspective of a focal firm F if they provide F with access to similar knowledge. This knowledge can be used to (i) implement existing projects or (ii) to undertake new ‘rival’ projects (yielding ‘rival benefits’) when alliances break down. We show that, while substitutability in implementation hinders knowledge sharing, substitutability in rival benefits facilitates it. Moreover, synergies in implementation tend to have a larger effect in sustaining knowledge sharing than substitutability in implementation has at hindering it. Overall, our findings suggest that substitutability is likely to have a less detrimental effect on knowledge sharing than generally thought.

Our theory has also implications for partner selection. We show that, from the focal firm’s perspective, there is often an inverted-U relationship between alliance value and partner substitutability. The reason is that substitutability has in general two conflicting effects: (i) on the focal firm’s payoff conditional on knowledge sharing and (ii) on the weak partners’ incentives to share knowledge. Because of these conflicting effects, F is better off if it chooses partners that are neither too similar nor too dissimilar to each other. Thus, the theory may help explain the non-linear, inverted-U relationships documented by Mowery et al. (1998), Swaminathan and Moorman (2009) and Vasudeva and Anand (2011).

This paper contributes toward putting the literature on competitive tensions in alliances on a more solid foundation. Scholars have noted that many of the learning race view’s recommendations suffer from a failure to recognize that the processes of value creation and value appropriation are inextricably linked (e.g., Zeng and Hennart, 2002). Scholars have also argued that the notion of a race to learn is “largely unrealistic,” for it is unclear what would motivate a likely loser to join the race (Inkpen, 2002: 272). This paper incorporates a knowledge sharing constraint into a model of learning in alliances, and shows that its inclusion has important consequences for how alliances should be managed. In particular, the model may help explain why, although learning is an important goal in many alliances, only few firms actually appear to have a racing intent (Mowery et al., 1996; Hennart et al., 1999; Inkpen, 2000).

A second contribution of the paper is to re-orient attention in strategy and economics from the problem of how weak firms can protect their intellectual assets in collaborations (e.g., Cohen et al., 2000; Katila et al., 2008; Hallen et al., 2014), to the problem of how leading firms can promote the health of their innovation ecosystems. Iansiti and Levien (2004) distinguish between “keystone organizations”, which share the benefits from asset orchestration with their partners, and “physical dominators”, which focus on value appropriation. This work examines different strategies—strategic investments in absorptive...
capacity, alliance portfolio management, and contractual solutions—that keystone organizations can use to create ecosystems conducive to knowledge sharing and innovation.

1.1 Related literature

The paper is related to several strands of the literature on organizations. Resource dependence theory (RDT) is a leading theoretical framework that emphasizes the importance of power in inter-firm relations. RDT contends that power in a relationship is held by the partner that controls the most critical resources (Pfeffer and Salancik, 1978). RDT scholars have distinguished between joint dependence—where both parties hold critical resources—and dependence asymmetry, where power is asymmetrically distributed (Casciaro and Piskorski, 2007; Gulati and Sylte, 2007). However, to the extent that control over resources is a fixed attribute of a firm, both notions are essentially static.

A number of papers have examined the dynamics of power in alliances. One critical resource which is hard to protect effectively and may spill over during collaboration is knowledge (Liebeskind, 1996). Information leakage is often cited as a major drawback of alliances (Arora and Merges, 2004; Oxley and Sampson, 2004; Sampson, 2007; Li et al., 2012). Indeed, some compare the experience of some young technology firms collaborating with more established incumbents to “swimming with sharks” (Katila et al., 2008; Diestre and Rajagopalan, 2012; Hallen et al., 2014; Colombo and Shafi, 2016). Knowledge spillovers may also shift the balance of power in favor of the partners that learn the fastest, giving rise to “learning races” and instabilities (Hamel, 1991; Yan and Gray, 1994; Inkpen and Beamish, 1997).

The literatures on “sharks” and “learning races” largely focus on how firms can protect their intellectual assets. For instance, Katila et al. (2008) find that new firms enter corporate investment relationships when their financial and managerial resource needs are high, and when they can defend themselves against misappropriation through defense mechanisms. One important safeguard is the choice of partners with limited opportunistic intent, as measured for instance by “relative scope” (Khanna et al., 1998; Baum et al., 2000) or by alliance type (Dussauge et al., 2000). Other important types of safeguards include patents, secrecy, timing, social defenses and organizational firewalls (Cohen et al., 2000; Katila et al., 2008; Hallen et al., 2014).

Our theory, while noting that “weak” firms may seek to protect their intellectual assets, emphasizes the actions that leading or “strong” firms may take to encourage knowledge sharing. These actions can include voluntarily reducing their own absorptive capacity through “Chinese walls” or other means, or increase the transparency of their own operations.
By examining alliance portfolios, the paper also contributes to a better understanding of how network structure influences knowledge sharing (Hansen, 1999, 2002; Argote et al., 2003; Reagans and McEvily, 2003; Hansen et al., 2005; Gulati et al., 2011). Structural factors that have been found to affect knowledge sharing in networks include social cohesion around a relationship (Hansen, 1999; Reagans and McEvily, 2003), the variety of knowledge sources within which a firm is embedded (Burt, 1992; Zaheer and McEvily, 1999; Baum et al., 2000; Reagans and McEvily, 2003) and competitive tensions among the members of a group (Gomes-Casseres, 1994; Baum et al., 2000; Dyer and Nobeoka, 2000). The similarity of knowledge sources within a network has typically been seen as an obstacle to effective knowledge sharing, both because it reduces knowledge variety and because it creates competitive tensions (e.g., Baum et al., 2000). However, empirical findings have been mixed (e.g., Goerzen and Beamish, 2005; Swaminathan and Moorman, 2009; Cui 2013). Our work may help reconcile these mixed findings by highlighting a type of knowledge redundancy (substitutability in rival benefits) that can actually foster knowledge sharing.

From a modelling perspective, our model builds on the modern property-rights theory of the firm (Grossman and Hart, 1986; Hart and Moore, 1990; de Fontenay and Gans, 2005). However, while most of the property-rights literature explains inefficiencies and underinvestment as the outcomes of a public good problem—the unwillingness of transaction partners to privately contribute to joint value creation—we highlight shifts in outside options. In so doing, we establish a formal connection between the mutual dependency and learning races literatures in strategy, and the property-rights literature in economics. Panico (2017) also shows in a property-rights setting that alliance partners can engage in tactics to enhance their bargaining positions. However, unlike Panico, we focus on knowledge sharing, and show that partners may strategically weaken their own bargaining positions. We also examine the effects of uncertainty, and analyze alliance portfolios.

The remainder of the paper is organized as follows. The basic model is presented in Section 2. There we show how shifts in bargaining positions can destabilize alliances, and how different types of uncertainty affect knowledge sharing. Subsequent sections examine solutions to the problem of suboptimal knowledge sharing. The solutions we consider are: strategic choice of learning capabilities (Section 3), alliance portfolios (Section 4), and contracts (Section 5). Section 6 concludes. All omitted proofs are in Appendix A.
2 Model

There are two firms, $F$ and $A$, that can collaborate. We will sometimes refer to firm $F$ as the ‘focal’ firm, because it may be involved in more than one collaboration.

Collaboration involves two stages. In the first stage, $F$ and $A$ can share knowledge about their technology and markets. In the second stage, they must decide whether to continue to work together and implement a project. An example would be Technip and Schlumberger sharing information to jointly develop subsea integrity and surveillance solutions for flexible pipes used in deep offshore oil and gas production.\footnote{For more information on Technip and Schlumberger' cooperation agreement, see Technip's press release at http://www.technip.com/en/press/technip-and-schlumberger-announce-joint-development-agreement (accessed 01/05/2017).} Implementation consists of bringing the new product to market.

The key assumptions we make are that (i) it is impossible to contract on knowledge sharing, and that (ii) the firms cannot commit ex ante (before knowledge sharing) to implement the project together ex post. These assumptions imply that the firms cannot be forced to collaborate, neither in the initial phase of knowledge sharing nor the subsequent implementation phase. This could be because it is impossible for a court to verify, for instance, that a firm has done its best to transmit its knowledge, or that a partner is performing in a consummate rather than perfunctory fashion during co-development. In countries with less developed institutions, these assumptions may also reflect very high costs of using the legal and judicial system.

To determine whether it is privately profitable for a firm to share knowledge with a partner, we need to specify the payoffs associated with different strategies. If $F$ and $A$ do not share their knowledge, then the collaboration does not get started and we assume that $F$ and $A$ obtain their “baseline” payoffs, which we normalize to zero.

A second possibility is that $F$ and $A$ share their knowledge. The payoff they get from knowledge sharing depends on whether they implement their project together or terminate their collaboration prematurely. If the firms implement the project together, the joint value they create is $V$. If they terminate their collaboration prematurely (before implementation), each firm applies the knowledge it has gained in its existing markets. Thus, $F$ gets $\pi_F$ and $A$ gets $\pi_A$. For instance, consider the collaboration between Mobil, which developed new zeolite-based catalyst for petroleum refining, and Badger, which had expertise in the design and engineering of these processes. The collaboration involved Badger developing a new refining process using Mobil’s zeolite catalyst, and drawing upon the internal data and know-how that Mobil
had developed around the performance of the catalyst. The collaboration envisaged that the new process would be used by Mobil internally and offered commercially by Badger to other oil companies, as a part of its engineering and design business, with Mobil getting a share of the licensing royalty income.\(^2\) In terms of our model, the value of the collaboration, if implemented jointly, is \(V\). If, however, the collaboration were terminated prematurely, Mobil would likely be able to use some of what it learned from Badger to design a process using its zeolite catalyst to use in its own refineries. Mobil would also probably try to license this catalyst technology through other engineering and design firms. Combined, these efforts would yield Mobil \(\pi_F\). Badger, on the other hand, would not be able to use Mobil’s catalyst. However, the knowledge Badger gained would be useful with other zeolite-based catalytic refining systems, earning it \(\pi_A\).

Note that these alternatives are possible only if the collaboration is terminated. Indeed, to the extent that firm \(A\) can use the knowledge it gains from the alliance without jeopardizing the alliance itself, these payoffs would simply be added to both \(V\) and \(\pi_A\), making the collaboration more attractive to \(A\) without making it less attractive to \(F\). Our interest, on the other hand, is in “rival benefits” which can potentially jeopardize the collaboration by making it less attractive to the other partner. In terms of the example, if Badger were to offer zeolite-catalyst based technologies from other innovators to oil refiners, it would likely cause Mobil to withdraw from the collaboration. Thus, Badger can earn \(\pi_A\) only by forgoing its share of \(V\).

Clearly, \(\pi_F\) and \(\pi_A\) may both be positive since \(F\) and \(A\) may both learn something useful from their interaction that they can use to improve their existing products, though of course one partner may learn more than the other (e.g., \(\pi_F > \pi_A\)). However, we also allow for situations where one partner is “expropriated” by the other (e.g., \(\pi_F > 0, \pi_A < 0\)). This is the “swimming with sharks” or “information leakage” scenario highlighted by a number of scholars.

We posit \(V \geq \pi_F + \pi_A\). Thus, after knowledge sharing, it is efficient for the two firms to implement the project together. This could be because the partners have complementary capabilities in developing and commercializing the new product, or because litigation or competition following a break-up dissipate rents.

Sharing knowledge is costly both in terms of time and effort. For simplicity, \(F\) and \(A\) are assumed to incur the same cost of knowledge sharing: \(\frac{1}{2}I\).\(^3\) Thus, \(I > 0\) denotes the total cost of this activity.

\(^2\)See http://www.badgerlicensing.com/AboutUs_OurHistory.html (accessed 15/05/2017).
\(^3\)The assumption that knowledge sharing costs are the same for \(F\) and \(A\) is just for simplicity. The assumption can easily
Knowledge sharing is efficient if $V - I \geq 0$.\footnote{For completeness, we should also specify what happens in case of unilateral knowledge sharing. We assume that, if $F$ shares knowledge with $A$ but $A$ does not, then $F$ pays the knowledge sharing cost $\frac{1}{2}f$ and $A$ enjoys a benefit $\pi_A^u \geq 0$ (the superscript $u$ stands for unilateral knowledge sharing). If $A$ shares knowledge but $F$ does not, then $A$ pays the cost $\frac{1}{2}I$ and $F$ enjoys a benefit $\pi_F^u \geq 0$. Given that contracts on knowledge sharing are not enforceable, it should be clear that neither $F$ nor $A$ have any incentive to unilaterally share their knowledge. A firm that did that would incur a cost $\frac{1}{2}f$ without enjoying any benefit. In short, unilateral knowledge sharing cannot be an equilibrium of the game.}

If the firms decide to implement the project together, they must bargain over how to divide the resulting surplus $V - \pi_F - \pi_A$. We assume bargaining is efficient and determined according to the Nash solution with equal weights. Thus, the partners’ payoff are given by

$$
\Pi_i = \pi_i + \frac{1}{2} [V - \pi_F - \pi_A] - \frac{1}{2} I, \quad i = F, A.
$$

That is, each firm gets its new (after knowledge sharing) outside option $\pi_i$, plus half of the surplus from implementation, minus the costs of knowledge sharing $\frac{1}{2}I$.

Knowledge sharing will occur only if each firm $i = F, A$ obtains more if both firms share their knowledge than if both firms do not share their knowledge:

$$
\Pi_i \geq 0.
$$

We refer to (2) as $i$’s knowledge sharing constraint. If this constraint holds, we say that knowledge sharing is privately profitable for firm $i$ (assuming that the other firm also shares knowledge). After some manipulations, $A$ and $B$’s knowledge sharing constraints can be rewritten as:

$$
V - I \geq \pi_A - \pi_F
$$

$$
V - I \geq \pi_F - \pi_A.
$$

Unsurprisingly, $F$ and $A$ are more likely to collaborate if knowledge sharing creates substantial value ($V - I$ large). However, partners also care about their relative bargaining positions. If $\pi_A > \pi_F$, then knowledge sharing shifts bargaining power in favor of $A$ (that is, outside options shift from $(0, 0)$ to $(\pi_F, \pi_A)$, with $\pi_A > \pi_F$), which makes $F$ less likely to share its knowledge (i.e., condition (3) is less likely to hold). Conversely, if $\pi_F > \pi_A$, then bargaining power shifts in favor of $F$, and $A$ is less likely to share knowledge with $F$.

Note that the shifts in bargaining positions as measured by $|\pi_F - \pi_A|$ only influence how the surplus generated by the alliance is divided between $F$ and $A$. The condition for the efficiency of knowledge sharing, $V \geq I$, does not depend on the relative magnitudes of $\pi_F$ and $\pi_A$ (assuming $\pi_F + \pi_A \leq V$).

\footnote{be relaxed (for instance by assuming that $F$ incurs a fraction $\alpha$ of the total knowledge sharing costs) without qualitatively changing any of the main results of the paper.}
We can summarize the discussion above as follows.\footnote{Because knowledge sharing only benefits a firm if the other firm also shares its knowledge and firms choose their actions simultaneously and non-cooperatively, there is always the possibility of coordination failure. That is, even when condition (5) holds, partners may fail to share knowledge because they hold beliefs (correct in equilibrium) that the other partner will not share. We rule out this Pareto-inferior equilibrium on the grounds that alliance partners should be able to coordinate on a mutually beneficial outcome.}

**Proposition 1.** Knowledge sharing is efficient when $V \geq I$. However, it is privately profitable for both firms only when

$$V - I \geq |\pi_F - \pi_A|.$$  \hspace{1cm} (5)

Thus, in equilibrium there is an inefficiently low level of knowledge sharing.

Proposition 1 captures the idea that some value-creating alliances may not be formed when knowledge sharing creates large shifts in bargaining positions. Value creation is important, as highly valuable alliances ($V - I$ high) tend to be formed, but asymmetries in the evolution of outside options create a wedge between efficient and inefficient knowledge sharing. Preserving the balance of power within the partnership (a low $|\pi_F - \pi_A|$ in absolute value) helps reduce the risk of suboptimal knowledge sharing and collaboration.

One application of the model is to knowledge (mis)appropriation in alliances. A common concern is that one partner may learn information that belongs to the other partner and use it on alternative projects. For instance, a large pharmaceutical firm may acquire valuable scientific information while collaborating with a biotech company. Then, the ex post outside option of the pharmaceutical firm (say $\pi_B$) would increase, while the ex post outside option of the biotech company ($\pi_A$) would not change or may even decrease. The appropriating firm would then become less dependent on its partner, and may even lose interest in the collaboration (Arora and Merges, 2004; Oxley and Sampson, 2004; Katila et al., 2008; Diestre and Rajagopalan, 2012; Hallen et al., 2014).

2.1 Uncertainty

Strategic alliances, especially when the goal of the alliance is to develop new knowledge and products, are characterized by large uncertainty. Here we explore how different types of uncertainty affect firms’ incentives to share knowledge. We find that, contrary to conventional wisdom, uncertainty often promotes knowledge sharing in our setting.

We begin with the case where there is uncertainty about the value of the synergies between $F$ and $A$. Uncertainty is resolved after knowledge sharing but before implementation. Specifically, we assume
that $V$ is a random variable distributed with cumulative distribution function $G$ over the support $[\underline{V}, \overline{V}]$. As before, following knowledge sharing, the partners’ outside options also change, from $(0, 0)$ to $(\pi_F, \pi_A)$. We assume $\overline{V} > \pi_F + \pi_A > \underline{V}$, so that, if synergies $V$ are low, it is efficient to terminate the alliance after knowledge sharing. Firms are risk neutral.

In this setting, it is optimal for $F$ to share knowledge (conditional on $A$ sharing knowledge) if

$$
\pi_F + \frac{1}{2} \int_{\pi_F + \pi_A}^{\overline{V}} (V - \pi_F - \pi_A) dG \geq \frac{1}{2} I. \tag{6}
$$

Similarly, it is optimal for $A$ to share knowledge (conditional on $F$ sharing knowledge) if

$$
\pi_A + \frac{1}{2} \int_{\pi_F + \pi_A}^{\overline{V}} (V - \pi_F - \pi_A) dG \geq \frac{1}{2} I. \tag{7}
$$

Intuitively, if firms share their knowledge, they appropriate their outside options ($\pi_F$ or $\pi_A$) plus half of the surplus, which accrues only when synergies are sufficiently high ($V \geq \pi_F + \pi_A$). By contrast, the condition for efficient knowledge sharing is

$$
\pi_F + \pi_A + \int_{\pi_F + \pi_A}^{\overline{V}} (V - \pi_F - \pi_A) dG \geq I. \tag{8}
$$

Proposition 2 characterizes the equilibrium under synergy uncertainty and shows how greater uncertainty (modelled as a mean preserving spread of the original distribution $G$) affects knowledge sharing.

**Proposition 2.**

(i). In equilibrium there is an inefficiently low level of knowledge sharing.

(ii). Early termination of an alliance (before implementation) occurs with positive probability. Early termination, when it occurs, is always efficient.

(iii). An increase in uncertainty about synergies makes knowledge sharing becomes more likely.

As in the model without uncertainty, the non-cooperative equilibrium exhibits an inefficiently low level of knowledge sharing. However, unlike the baseline model, now an alliance can be terminated early—after knowledge sharing but before implementation—if synergies turn out to be low. Proposition 2 also shows that the incentives for knowledge sharing are greater if there is more uncertainty about the value of synergies. Intuitively, a mean preserving spread of the distribution of $V$ increases the likelihood of extreme (very low and very high) realizations of $V$. If $V$ is very low, after knowledge sharing the partners
can always obtain \( \pi_F \) and \( \pi_A \). The downside is therefore limited. On the other hand, if \( V \) is very high, the partners can share this large value. This upside of knowledge sharing grows in importance as more extreme realizations of \( V \) become possible. In short, we find that there is an option value associated with knowledge sharing, and the value of that option increases with the level of uncertainty over synergies.

A similar intuition holds for other types of uncertainty. For instance, consider the case where there is uncertainty is about the strength of a partner’s bargaining position after knowledge sharing (i.e., the uncertainty is about \( \pi_F \) or \( \pi_A \)). More specifically, suppose \( V \) and \( \pi_A \) are known, while \( \pi_F \) is distributed over \([\pi_F, \pi_F]\) with cumulative distribution \( K \). Thus, there is initially uncertainty about the value of \( F \)’s outside option. \( \pi_F \) is realized after knowledge sharing but before implementation. We assume that \( \pi_F \geq \pi_A = 0 \). \( \pi_F \geq \pi_A \) implies that knowledge sharing will occur if and only if the “weak” partner \( A \)’s knowledge sharing constraint is satisfied. Finally, we assume \( \pi_F < V < \pi_F \), so that it is possible that the alliance is terminated after knowledge sharing but before implementation.

Perhaps surprisingly, we find that greater uncertainty about a partner’s bargaining position can increase the incentives of the other partner to share knowledge.

**Proposition 3.** Suppose \( \pi_F \) is a random variable distributed over \([\pi_F, \pi_F]\). Also, assume \( \pi_F \geq \pi_A = 0 \). Then, if uncertainty about \( \pi_F \) increases, in equilibrium knowledge sharing becomes more likely.

Proposition 3 shows that greater uncertainty about the outside option of the “strong” partner tends to increase the “weak” partner’s incentives to share knowledge and hence the likelihood of knowledge sharing. The intuition for the result builds again on real-options logic. If the partners share knowledge and \( \pi_F \) turns out to be very high, \( A \)’s losses are limited because \( A \) can always obtain \( \pi_A (= 0) \). By contrast, if \( \pi_F \) turns out to be very low, the partners will implement the project together and share the surplus \( V - \pi_F \). Clearly, \( A \) benefits if very small realizations of \( \pi_F \) become more likely. Because of this asymmetry in how \( A \)’s payoff is affected by more extreme realizations of \( \pi_F \), greater uncertainty tends to increase \( A \)’s incentives to share knowledge and hence knowledge sharing.\(^6\)

### 3 Encouraging knowledge sharing in alliances

So far we have shown that competitive tensions can lead to suboptimal levels of knowledge sharing. In the next three sections, we consider strategies that prospective partners can use to encourage knowledge sharing.

\(^6\)Finally, the model can also be extended to allow for multiple rounds of knowledge sharing. In Appendix B, we develop a multi-stage, optimal stopping game of knowledge sharing, and show that our key qualitative results are robust. Large shifts in bargaining positions lead to inefficiently premature termination of knowledge sharing.
sharing when competitive tensions are strong. These strategies include: (i) strategic investments in absorptive capacity, (ii) alliance portfolio management, and (iii) contractual solutions. Throughout, we will assume with no essential loss of generality that $F$ is the “strong” partner, in the sense that $\pi_F > \pi_A$. Thus, the binding knowledge sharing constraint will generally be that of the “weak” partner $A$.\footnote{In the alliance portfolio case, identifying whose knowledge sharing constraint is binding is less straightforward.}

### 3.1 Strategic investments in absorptive capacity

An influential literature in strategy stresses that attempts to appropriate the returns from collaboration may generate learning races, where partners try to absorb their partners’ knowledge while attempting to protect their own (e.g., Hamel, 1991; Khanna et al., 1998). Our model suggests that, while appropriability concerns are important (the payoffs $\Pi_i$ of both partners increase in their bargaining positions $\pi_i$), an excessive focus on strengthening one own’s bargaining position may be counterproductive because it may discourage knowledge sharing and collaboration ($\pi_F$ may be so large that (5) does not hold).

In this section we develop a simple extension of the model where firms can invest in their ability to absorb external knowledge, which in turn improves their bargaining position vis-à-vis their partner. We show that, when the need of encouraging knowledge sharing is taken into account, firms do not always want to maximize their receptivity to their partners’ knowledge. Instead, they may sometimes intentionally limit their own learning capability to encourage participation. Thus, the model can potentially explain why in reality firms seldom appear to exhibit a racing intent (Mowery et al., 1996; Hennart et al., 1999; Inkpen, 2000) and instead their behavior is more often best described as cooperative (Inkpen, 2005).

We assume that, prior to the knowledge sharing phase, firms can invest in their absorptive capacity. These investments increase the payoff the payoff that firm $i = F, A$ can obtain after termination from $\pi_i^L$ to $\pi_i^H$, where $\pi_i^H \geq \pi_i^L$. Thus, the first stage of our game (where players invest in absorptive capacity) can be viewed as one where firm $F$ selects bargaining position $\pi_F = \{\pi_F^L, \pi_F^H\}$ and firm $A$ selects bargaining position $\pi_A = \{\pi_A^L, \pi_A^H\}$.

The learning race literature suggests that in an alliance, the “participating firms [should] maximize their receptivity to the knowledge and skills of their partner while limiting the transparency of their own operations” (Mowery et al., 2002: 298). Thus, this literature suggests that $F$ should select $\pi_F^H$ and $A$ should select $\pi_A^H$. To bias the results in this direction, we assume that investments in absorptive capacity are costless: $\pi_i^H$ and $\pi_i^L$ are equally costly. Thus, any deviation from the outcome $(\pi_F^H, \pi_A^H)$ will emerge not because of cost considerations but for purely strategic reasons.
Finally, to reduce the number of the cases to consider, we assume that $\pi_F^L \geq \pi_A^H$. This implies that the focal firm $F$ is always the “stronger” (faster learning) partner, while $A$ is always the “weaker” (slower learning) partner. All other features of the model in Section 2 remain the same.

Proposition 4 below shows that the learning race intuition is in general incorrect. Partners do sometimes engage in learning races and maximize their learning capability (case (iii) below). However, in some circumstances they purposefully limit their absorptive capacity and increase their partner’s payoff (case (ii)).

Proposition 4. Suppose knowledge sharing is efficient ($V \geq I$), firm $F$ is always the faster learner ($\pi_F^L \geq \pi_A^H$), and investments in absorptive capacity are costless ($\pi_i^H$ and $\pi_i^L$ are equally costly, $i = A, B$). In equilibrium:

(i) If $\pi_F^L - \pi_A^H > V - I$, then the firms do not share knowledge. The outcome is inefficient and the choice of absorptive capacity is inconsequential.

(ii) If $\pi_F^L - \pi_A^H \leq V - I < \pi_F^H - \pi_A^H$, then partner $F$ selects $\pi_F^L$ and partner $A$ selects $\pi_A^H$. Knowledge sharing occurs.

(iii) If $\pi_F^H - \pi_A^H \geq V - I$, then partner $F$ selects learning capability $\pi_F^H$ and partner $A$ selects learning capability $\pi_A^H$. Knowledge sharing occurs.

Proposition 4 shows that, when firms are very asymmetric in terms of their learning potential (case (i)), knowledge sharing does not occur. Asymmetries between firms are so strong that they lead to a breakdown of cooperation. The resulting outcome is inefficient.

By contrast, when the firms are sufficiently symmetric in terms of their learning potential (case (iii)), a learning race takes place. Both firms maximally invest in learning, but this still leads to a fairly symmetric outcome. Thus, they still find it privately profitable to share their knowledge.

The most interesting case arises when learning potential is asymmetric but not excessively so (case (ii)). A strategy of maximizing learning capability becomes self-defeating for the stronger partner $F$. By maximizing its learning capability, firm $F$ discourages the potential partner $A$ from entering the alliance and sharing its knowledge. $F$ is better off by limiting its learning capability to just $\pi_F^L$, thus acting in an apparently altruistic fashion.

There are many examples of firms that appear to deliberately reduce their own absorptive capacity to mitigate the risk of conflicts with their partners. Cisco, for instance, is a firm that has successfully
managed a large number of alliances in a variety of sectors, geographies and technological areas. Cisco recognizes that conflicts can arise when partners are exposed to each other’s knowledge. For instance, Steve Steinhilber, Vice President of strategic alliances at Cisco, notes that:

One of the most contentious issues in negotiating the confidentiality terms of an alliance agreement is the treatment of residuals – that is, general knowledge, know-how, and the skills that each partner’s employees will gain by being exposed to the other party’s confidential information (2008: 101). [...] you face considerable risk [...]. You could open your doors to a company that could hurt you in your own market over time, gain competitive advantages, or acquire unique knowledge or skills that it could not have obtained otherwise (2008: 114).

Steinhilber recommends that partners establish ground rules to manage information security and intellectual property rights. These rules should be designed not simply to protect one own’s resources, but also to ensure that all the partners are treated fairly and nobody’s knowledge is mishandled. In particular, Steinhilber suggests that firewalls may also be created to prevent Cisco from learning too much from its partners. Specifically, he recommends:

Setting clear parameters in your agreements that identify the information to be shared and the permitted use of such information. In certain instances, it may be necessary to restrict information to some employees and to set up firewalls to prevent tainting other groups within the company that are developing similar technology independently. [...] Setting up training and procedures to protect your partner’s confidential information and watching for actions by your partner that may signal an improper use of your own information (2008: 119; emphasis added).

The model could easily be modified to examine the partners’ incentives to limit the transparency of their own operations. The learning race literature suggests that firms should minimize the transparency of their operations, thus reducing their partners’ absorptive capacity. This suggests that $F$ should take actions to minimize $\pi_A$, while $A$ should take actions to minimize $\pi_F$. Arguments analogous to the ones presented above make clear that there are situations when a strong partner will find it beneficial to “altruistically” increase the transparency of its own operations. An example would be Toyota’s willingness to teach General Motors valuable lean manufacturing practices (Inkpen, 2005).
Note that, in both the case of Cisco and Toyota, it is the large or fast-learning firm that appears to behave altruistically. Thus, “strong” partners do not always have to behave like “sharks”. Instead, they can adopt calculative altruistic behaviors, motivated by the need of encouraging collaboration and knowledge sharing ex ante.

4 Knowledge sharing in alliance portfolios

A recent literature focuses on alliance portfolios and interdependencies among a focal firm’s alliance partners. At the risk of simplifying a complex subject, this literature argues that overlaps among the alliance partners reduces value: overlaps reduce the potential for synergies and increase the potential for conflict among the partners. The result, according to this logic, is lower stability of alliances and lower value to the focal firm (e.g., Vasudeva and Anand, 2011; Wassmer and Dussauge, 2011).\(^8\)

We examine the issue of substitutability through the lenses of our model. The key contribution of this section will be to distinguish between two different types of substitutability and show that there is a type of substitutability that facilitates, not hinder, knowledge sharing. We will also characterize how the payoff of a focal firm varies with the similarity of its partners and show that, regardless of which type of substitutability is more important, the focal firm frequently benefits from choosing partners that are neither too similar nor too dissimilar from each other.

We focus on a simple setting where a focal partner \(F\) can collaborate with two firms, \(A\) and \(B\). We say that \(A\) and \(B\) are substitutes if they allow \(F\) to access similar pools of knowledge. We distinguish between two types of substitutability: substitutability in implementation and substitutability in rival benefits.

**Substitutability in implementation.** Substitutability in implementation refers to situations where the contribution of a *former* partner, which may have been useful to implement a project, can partly be substituted by the contribution of a *current* partner. For instance, suppose \(F\) and \(A\) share knowledge to develop new artificial intelligence (AI) algorithms. If their alliance is prematurely terminated (after knowledge sharing but before implementation), \(F\) may be able to use some of the knowledge acquired from

---

\(^8\)On the other hand, as Lavie (2007) notes, greater overlap among alliance partners increases the relative bargaining power of the focal firm. Cui (2013) argues that similarity or redundancy of resources among alliance partners may benefit the focal firm by securing access to resources in uncertain environments.
A to develop its own algorithms, to use in its own operations (a “rival” project). Importantly, the rival project can only be started if the alliance with A is terminated. This could be because F’s researchers, who were working with A, must be redeployed to work in-house on the rival project.

We posit that, if F terminates its collaboration with A and implements the rival project alone, it earns $\pi_{FA}$. Alternatively, F could ask one of its current partners to help. We assume that, if B helps with the implementation of the rival project, the value that F and B can create together is $\pi_{FA} + s^{Imp}$. Thus, $s^{Imp} \geq 0$ measures the value of B’s contribution to the implementation of the rival project. Since the rival project arises from interactions between F and A, it is reasonable to assume that the more similar A and B are, the larger $s^{Imp}$ will be. For instance, if B is also an AI firm, $s^{Imp}$ may be large. By contrast, if B is a more traditional software development firm, $s^{Imp}$ is likely to be small. We assume that, if the collaboration between F and B on their own project was prematurely terminated, B would not be willing to help F with the rival project.

Substitutability in rival benefits. Substitutability in rival benefits refers to situations where the knowledge gained by former partners is partly overlapping. For instance, suppose F and A share knowledge but their alliance is prematurely terminated. Then F may be able to use some of the knowledge acquired from A in its existing operations (a “rival” project), thus obtaining “rival” benefits $\pi_{FA}$. Similarly, if F and B share knowledge but their alliance is prematurely terminated, F may use some knowledge acquired from B to earn “rival” benefits $\pi_{FB}$.

Importantly, if both alliances are prematurely terminated, the rival benefits that accrue to F may not be $\pi_{FA} + \pi_{FB}$, but $\pi_{FA} + \pi_{FB} - s^{RB}$, where $s^{RB} \geq 0$ measures substitutability in rival benefits. Substitutability in rival benefits reflects the fact that A and B may give F access to similar, partly overlapping information. For instance, F may benefit from additional expertise in developing semi-supervised machine learning methods in areas such as image classification. Redeploying in-house computer scientists previously working with either A or B may be very valuable, but redeploying internally both teams may yield diminishing returns, because some of what is learned from B has already been learned from A.  

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9This example implicitly assumes that there is only one rival project—developing algorithms for image classification—
To simplify the analysis, for the rest of this section we will assume that $A$ and $B$’s outside options following knowledge sharing are $\pi_A = \pi_B = 0$, and $\pi_{FA} = \pi_{FB} = \pi_F$. These assumptions are just for simplicity and can easily be dropped without affecting the qualitative results of the paper.

We begin with the case when $F$ and $A$ and $F$ and $B$ do not share knowledge. Then, $F$, $A$ and $B$ all obtain their baseline payoffs, which are normalized to 0.

Next, suppose knowledge sharing occurs in one and only one alliance. For instance, suppose $F$ and $A$ share knowledge. Because $B$ would not be part of any interaction, effectively it would be as if $B$ did not exist. The analysis would follow the same steps as in Section 2. We would have that knowledge sharing is efficient if $V \geq I$; however, it is privately profitable for both $F$ and $A$ only if $V - I \geq \pi_F$. Thus, in a noncooperative equilibrium knowledge sharing occurs less often than socially optimal.

The final possibility is that knowledge sharing occurs in both alliances. We want to describe how much value is created by the firms depending on implementation decisions. To do so, let $v(S)$ be the value created by coalition $S$, where $S \in \{F, A, B, FA, FB, AB, FAB\}$. Thus, for instance, $v(FAB)$ denotes the value created by $F$, $A$ and $B$ working together; that is, when both $F$ and $A$ and $F$ and $B$ implement their projects together (no alliance is prematurely terminated). Similarly, $v(FA)$ denotes the value created by $F$ and $A$ working together, and the alliance between $F$ and $B$ was prematurely terminated. The value or ‘worth’ of the empty coalition $\emptyset$ is always zero: $v(\emptyset) = 0$. All these values are gross of knowledge sharing costs.

We assume that the value that coalition $FAB$ can create is $v(FAB) = 2V + b$. $2V$ is the ‘baseline’ value of the projects that $F$ and $A$ and $F$ and $B$ implement. In addition, the coalition also obtains the synergistic benefit $b \geq 0$. $b$ captures complementarities or synergies between $A$ and $B$ in implementation. By combining $A$ and $B$’s capabilities during the implementation stage, the coalition $FAB$ creates $b$ more value than if $A$ and $B$ were involved in two completely unrelated alliances.

---

where the help of scientists previously working with $A$ or $B$ is useful. But the basic idea of decreasing marginal returns to redeployment applies also when there are multiple projects. To see that, suppose for instance that $F$ can use expertise in AI to develop algorithms for image classification and speech recognition. Such expertise is worth rival benefits $\bar{\pi}$ if scientists are working on image classification, and $\bar{\pi}$ if scientists are working on speech recognition, with $\bar{\pi} > \bar{\pi}$. Assuming that the expertise from $A$ or $B$ is equally valuable in either project, prematurely terminating either alliance and redeploying the scientists internally will yield rival benefits $\bar{\pi}$. However, terminating the second alliance as well will only yield $\bar{\pi}$. Internal redeployment exhibits decreasing marginal returns.
If instead the alliance between $F$ and $B$ is terminated before implementation, by working together $F$ and $A$ can create $v(FA) = V + \pi_F + s^{Imp}$. The value created by $B$ working alone is instead $v(B) = 0$. Again, $V$ is the value created by $F$ and $A$ implementing their project together. $\pi_F + s^{Imp}$ is the additional value created by $F$ and $A$ implementing $F$’s rival project together. We assume $s^{Imp} \in [0, V - \pi_F]$, which implies that prematurely terminating an alliance before implementation is not efficient. Similarly, we assume that the worth of coalition $FB$ is $v(FB) = V + \pi_F + s^{Imp}$ and the worth of coalition $A$ is $v(A) = 0$.

Lastly, if both alliances are terminated before implementation, the values created by coalitions $F$, $A$ and $B$ are, respectively $v(F) = 2\pi_F - s^{RB}$, $v(A) = 0$ and $v(B) = 0$. Non-focal partners always get a payoff of 0 if they do not implement projects with $F$. The focal partner $F$, by contrast, can work on rival projects, earning $2\pi_F - s^{RB}$. As mentioned above, $s^{RB}$ measures substitutability in rival benefits. We assume $s^{RB} \in [0, \pi_F]$. $s^{RB} = \pi_F$ would capture a situation where the knowledge that flows from $A$ and $B$ is perfectly overlapping, from $F$’s perspective.\footnote{We could also examine complementarities in rival benefits by simply letting $s^{RB} < 0$. Such complementarities would arise, for instance, if a large, critical mass of AI scientists is necessary to successfully implement a rival project.}

Table 1 summarizes the values created by all the possible non-empty coalitions following knowledge sharing. Two completely unrelated alliances would have $b = s^{Imp} = s^{RB} = 0$.

**TABLE 1: Coalitional values after knowledge sharing**

<table>
<thead>
<tr>
<th>Neither collaboration is terminated prematurely</th>
<th>$v(FAB) = 2V + b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>One and only one collaboration is terminated prematurely</td>
<td>$v(FA) = v(FB) = V + \pi_F + s^{Imp}$</td>
</tr>
<tr>
<td>$v(AB) = 0$</td>
<td></td>
</tr>
<tr>
<td>Both collaborations are terminated prematurely</td>
<td>$v(F) = 2\pi_F - s^{RB}$</td>
</tr>
<tr>
<td>$v(A) = v(B) = 0$</td>
<td></td>
</tr>
</tbody>
</table>

Following Hart and Moore (1990), we use the Shapley value to assign payoffs to individual firms. If knowledge sharing occurs, then the “grand coalition” $FAB$ will emerge because it creates the greatest
total value\textsuperscript{11}. The Shapley value assigns each firm its expected marginal contribution assuming that the order in which they join the grand coalition is random. Formally, for \(i = F, A, B\) and any subset of firms \(S \subseteq N = \{F, A, B\}\), the value assigned to firm \(i\) is:

\[
\phi_i = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|!(|N| - |S| - 1)!}{|N|!} (v(S \cup \{i\}) - v(S))
\]

where \(|S|\) denotes the number of firms in \(S\) and, for any positive integer \(r\), \(r! = 1 \times 2 \times \ldots \times r\), and \(0! = 1\).

The Shapley value yields the expressions for the firms’ (gross) payoffs:\textsuperscript{12}

\[
\phi_F = V + \pi_F + \frac{1}{3}b + \frac{1}{3}(s^{\text{Imp}} - s^{RB})
\]

\[
\phi_A = \phi_B = \frac{1}{2}(V - \pi_F) + \frac{1}{3}b - \frac{1}{6}(s^{\text{Imp}} - s^{RB}).
\]

Note that \(\phi_F + \phi_A + \phi_B = v(FAB)\). This follows from the efficiency property of the Shapley value.

As the single alliance case, the fact that \(F\) can use the knowledge learnt from its partners on rival projects shifts the balance of power in its favor—\(F\) gets an additional \(\frac{1}{2}\pi_F\) from each partner, and \(A\) and \(B\) lose the same amount. The synergistic value \(b\) is created only if all the firms work together; hence \(b\) is split equally among them. Substitutability in implementation has both costs and benefits for \(A\) and \(B\). On the one hand, \(A\) can be replaced by \(B\), which lowers \(A\)’s bargaining power vis-à-vis \(F\). On the other hand, \(A\) may replace \(B\). In this case, \(A\) will share the benefits of substitutability in implementation with \(F\). The cost of lower bargaining power for \(A\) (and similarly for \(B\)) is \(\frac{1}{2}s^{\text{Imp}}\), while the benefit of replacing \(B\) is just \(\frac{1}{6}s^{\text{Imp}}\). The benefit is half the cost because the gains from replacing \(B\) does not just accrue to \(A\), but must be split between \(A\) and \(F\). Thus, \(A\) and \(B\) on average lose as a result of implementation substitutability, and \(F\) gains. Finally, substitutability in rival benefits \(s^{RB}\) lowers the outside option of the focal firm \(F\) in case both alliances are terminated and therefore weakens \(F\)’s bargaining position

\textsuperscript{11}Indeed, \(s^{\text{Imp}} \in [0, V - \pi_F]\) implies that coalitional values \(v\) satisfy superadditivity: \(v(S \cup T) \geq v(S) + v(T)\) for any two disjoint set of firms \(S\) and \(T\).

\textsuperscript{12}To compute \(\phi_F\), one can proceed as follows. There are six possible ways in which firms \(F, A\) and \(B\) can be ordered: \(FAB, FBA, AFB, BFA, ABF\) and \(BAF\). The marginal contribution of \(F\) when \(F\) is the first firm to join the grand coalition (orderings \(FAB\) and \(FBA\)) is \(v(F) - v(\emptyset) = 2\pi_F - s^{RB}\). The marginal contribution of \(F\) when \(F\) is the second firm to join the grand coalition (orderings \(AFB\) and \(BFA\)) is \(v(AF) - v(A) = v(BF) - v(B) = V + \pi_F + s^{Imp}\). The marginal contribution of \(F\) when \(F\) is the third firm to join the grand coalition (orderings \(ABF\) and \(BAF\)) is \(v(ABF) - v(AB) = v(BAF) - v(BA) = 2V + b\). Because all orderings are equiprobable, we obtain equation (9). \(\phi_A\) and \(\phi_B\) are computed similarly.
vis-à-vis A and B. Thus, $s^{RB}$ appears with a negative sign in equation (9), and with a positive sign in equation (10).

Because of the knowledge sharing costs, net payoffs are given by $\Pi_F = \phi_F - I$, $\Pi_A = \phi_A - \frac{1}{2}I$ and $\Pi_B = \phi_B - \frac{1}{2}I$. Knowledge sharing with both partners is efficient if $V + \frac{1}{2}b \geq I$. Knowledge sharing is privately profitable for all firms if $\Pi_F, \Pi_A$ and $\Pi_B$ are all greater than or equal to zero.

Proposition 5 shows that, unlike in the single alliance scenario, in the alliance portfolio case inefficiently low levels of knowledge sharing can arise not only because the “weak” partners A and B are adversely affected by shifts in bargaining positions, but also because the “strong” partner $F$ has too little incentive to collaborate.

**Proposition 5.** In the alliance portfolio case, knowledge sharing can be inefficiently low because (i) the non-focal firms A and B are adversely affected by shifts in bargaining positions, or because (ii) $F$ appropriates too small a fraction (1/3) of the synergistic value $b$.

The “strong” partner $F$ might inefficiently choose not to share knowledge with its partners when the gains from collaboration mostly come from the synergistic value $b$. Because agreement of all three partners is needed for $b$ to be achieved, $F$ can only appropriate one third of this value. However, $F$ must incur half of all knowledge sharing costs. Because benefits and costs are not equally shared, inefficiencies can result.

To simplify the exposition and facilitate the comparison between the single and the portfolio alliance cases, in the following we will assume that $V \geq I$. This implies that inefficiencies in the portfolio case can only originate from shifts in bargaining positions, as in the single alliance case. That is, the knowledge sharing condition $\Pi_F \geq 0$ always holds, and the only knowledge sharing constraints that may not hold are those of the “weak” partners (i.e., the condition $\phi_A = \phi_B \geq \frac{1}{2}I$).

We have the following.

**Proposition 6.** Suppose $V \geq I$. In alliance portfolios:

(i). *Substitutability in rival benefits facilitates knowledge sharing, while substitutability in implementation*
hinders it. Synergies in implementation also facilitate knowledge sharing.

(ii). Synergies in implementation have a larger effect in facilitating knowledge sharing than substitutability in implementation has in hindering it. More precisely, suppose \( b = k_1 + \lambda \) and \( s^{\text{Imp}} = k_2 + \lambda \).

Then knowledge sharing in alliance portfolios becomes more likely as \( \lambda \) grows.

All these comparative statics results follow from the knowledge sharing constraints of the “weak” partners:

\[
V - I \geq \pi_F - \frac{2}{3}b + \frac{1}{3}(s^{\text{Imp}} - s^{\text{RB}}). \tag{11}
\]

The analysis suggests two reasons why substitutability may not be as bad at discouraging knowledge sharing as generally thought. First, we identify a type of substitutability, substitutability in rival benefits, which facilitates rather than hinder knowledge sharing. Second, we show that synergies in implementation \( b \) have a larger effect in facilitating knowledge sharing than substitutability in implementation \( s^{\text{Imp}} \) has in hindering it. The reason, as mentioned above, is that substitutability in implementation has some beneficial effects for non-focal partners. A non-focal partner may lose a lot when it is replaced, but it may also gain a little when it is instrumental in replacing another non-focal partner.

A second straightforward implication of our analysis is that knowledge sharing in a portfolio may be sustainable, while knowledge sharing in a single alliance may be not.

**Proposition 7.** Suppose \( V \geq I \). If \( V - I < \pi_F \) but \( V - I \geq \pi_F - \frac{2}{3}b + \frac{1}{3}(s^{\text{Imp}} - s^{\text{RB}}) \), then knowledge sharing in a portfolio is sustainable, while knowledge sharing in a single alliance is not.

What is interesting about this result is that it remains true even if there are no synergies between partners \( (b = 0) \), because substitutability in rival benefits also facilitates knowledge sharing. Proposition 7 suggests that a way to encourage knowledge sharing in a dyadic alliance where competitive tensions are present may be introduce a third partner. This strategy may be beneficial not only when there are synergies in implementation between the non-focal partners, but also when the knowledge that the focal firm can absorb from its non-focal partners and use in other rival projects is largely overlapping.
Besides selecting the “right” number of partners, a focal firm must also select partners with suitable characteristics. The question we ask is the following: Should the focal firm $F$ choose non-focal partners that are similar to each other (i.e., with a large degree of substitutability), or partners that are different from each other (with a low degree of substitutability)?

To answer this question, let $s^{\text{Imp}} = \alpha\Psi$ and $s^{\text{Rb}} = (1 - \alpha)\Psi$. The parameter $\Psi \geq 0$ measures the degree of similarity between $A$ and $B$. A high degree of similarity between $A$ and $B$ increases both substitutability in implementation and substitutability in rival benefits. $\alpha \in [0, 1]$ is a parameter capturing to what extent substitutability in implementation is more important than substitutability in rival benefit. If $\alpha = 1$, then only substitutability in implementation matters. If $\alpha = 0$, then only substitutability in rival benefit is important. By varying $\alpha$, we can examine how our results depend on the type of substitutability.

Proposition 8 below shows that, regardless of which type of substitutability is more important, $F$ should often choose partners that are neither too similar or too dissimilar from each other.

**Proposition 8.** Suppose $s^{\text{Imp}} = \alpha\Psi$ and $s^{\text{Rb}} = (1 - \alpha)\Psi$, where $\Psi \geq 0$ and $\alpha \in [0, 1]$.

(i). If $\alpha < \frac{1}{2}$ and $V - I - \pi_F + \frac{2}{3}b \leq 0$, then $F$’s equilibrium payoff first rises then declines with $\Psi$.

The optimum level of similarity from $F$’s viewpoint is intermediate ($\Psi^* = \frac{3(V-I-\pi_F)+2b}{2\alpha-1}$).

(ii). If $\alpha < \frac{1}{2}$ and $V - I - \pi_F + \frac{2}{3}b > 0$, then $F$’s equilibrium payoff monotonically declines with $\Psi$. The optimum level of similarity from $F$’s viewpoint is zero.

(iii). If $\alpha > \frac{1}{2}$ and $V - I - \pi_F + \frac{2}{3}b \leq 0$, then $F$’s equilibrium payoff is independent of $\Psi$ and always equal to 0.

(iv). If $\alpha > \frac{1}{2}$ and $V - I - \pi_F + \frac{2}{3}b > 0$, then $F$’s equilibrium payoff first rises then declines with $\Psi$.

The optimum level of similarity from $F$’s viewpoint is intermediate ($\Psi^* = \frac{3(V-I-\pi_F)+2b}{2\alpha-1}$).\(^\text{13}\)

Proposition 8 suggests that the relationship between the value that $F$ can appropriate and the degree of similarity of its alliance partners is typically non-monotonic. The reason is that there are in general...

\(^{13}\text{For completeness, we also have that, if } \alpha = \frac{1}{2}, \text{ then } F\text{’s equilibrium payoff is independent of } \Psi \text{ and equal to } V-I+v+\frac{1}{4}b.\)
two conflicting effects at play: (i) on the focal firm’s payoff conditional on knowledge sharing and (ii) on the weak partners’ incentives to share knowledge.

Consider substitutability in implementation first. A high degree of similarity $\Psi$ between non-focal partners benefits $F$ conditional on knowledge sharing because it strengthens $F$’s bargaining power. However, too much similarity reduces the non-focal partners’ incentives to share knowledge, with detrimental effects on $F$ as well. Thus, the optimum level of similarity between non-focal partners from $F$’s viewpoint is intermediate (Proposition 8, case (iv)).

When substitutability is in rival benefits, these effects are reversed. Partner similarity harms $F$ conditional on knowledge sharing, but also induces the non-focal partners to share knowledge. Initially (for low levels of similarity), knowledge sharing in an alliance portfolio is not sustainable, and $F$’s payoff is low. However, when $\Psi$ crosses $\Psi^*$, knowledge sharing becomes sustainable, so $F$’s payoff suddenly rises. As $\Psi$ grows further, substitutability in rival benefits monotonically reduces $F$’s payoff (Proposition 8, case (i)).

Thus, regardless of which type of substitutability is more important, $F$ is often better off by choosing partners that are neither too similar nor too dissimilar to each other. The relationship between $F$’s payoff and non-focal partner similarity $\Psi$ has often an inverted-U shape (cases (i) and (iv)).

This basic intuition is complicated by the fact that initial conditions also matter. Depending on the initial propensity of its alliance partners to share knowledge (whether $V - I - \pi_F + \frac{3}{2} b \leq 0$), only part of the inverted-U curve may be observed. Case (ii) describes a situation where, because substitutability is mostly in rival benefits ($\alpha < \frac{1}{7}$) and knowledge sharing can always be sustained, partner similarity is always detrimental to $F$. Hence the optimal value of partner similarity from $F$’s viewpoint is zero. Case (iii) describes a situation where knowledge sharing can never be sustained. In that case, because there is no knowledge sharing, the degree of partner similarity is inconsequential.

The complexity of these predictions may help explain the variety of often conflicting empirical findings. Consistent with prediction of an inverted-U relationship between the value appropriated by the focal partner and the similarity of the non-focal partners, Swaminathan and Moorman (2009) find that alliance announcements create value (i.e., abnormal stock returns) especially when the degree to which
the firm’s network of alliances involves firms that possess nonredundant knowledge, skills, and capabilities is moderate. Vasudeva and Anand (2011) find an inverted U-shaped relationship between the technological diversity in a focal firm’s alliance portfolio and the likelihood that the focal firm cites its partner’s patents. However, Cui and O’Connor (2012) find no statistically significant relationship between alliance portfolio resource diversity and innovation, although several interaction effects are significant (consistent with (iii)), while Goerzen and Beamish (2005) and Cui (2013) find monotonic relationships (consistent with (ii), or with only a portion of an inverted-U shape being observed). Evidence inconsistent with our theory would find a U-shaped relationship between a focal partner’s value appropriation and the similarity of its partners. We are not aware of any empirical work documenting such relationship.

5 Contractual solutions

In this section, we briefly discuss why contractual solutions are of limited use.

Payments to share knowledge. Payments provided by the “strong” partner to the “weak” partner to encourage the weak partner to enter an alliance and share knowledge do not solve the problems associated with shifting bargaining positions. The reason is that knowledge sharing is not observable by a court. Thus, the weak partner would sign the contract, accept the payment, and then would not share knowledge if that was not in its own interest. This logic is similar to the problem with termination fee contracts.

Termination fee contracts. Termination fee contracts may appear to be a potential solution to the problems highlighted in this paper. However, they will work only under very stringent assumptions. To see this, recall from Section 2 that firms F and A share knowledge only if both their knowledge sharing constrains are met:

\[
\frac{1}{2} (V + \pi_F - \pi_A) \geq \frac{1}{2} I \\
\frac{1}{2} (V - \pi_F + \pi_A) \geq \frac{1}{2} I.
\]

\(^{14}\text{In the context of dyadic alliances, Mowery et al. (1998) and Vonortas and Okamura (2009) find evidence of an inverted-U relationship between partners’ technological overlap and the probability of alliance formation.}\)
Suppose collaboration is efficient \((V \geq I)\) and \(F\) is the strong partner \((\pi_F > \pi_A)\). Furthermore, for the problem to be interesting suppose that, in the absence of contracts, collaboration cannot be sustained because it is not sufficiently profitable for the weak partner \((V - \pi_F + \pi_A \geq I\) fails).

To avoid this problem, suppose \(F\) offers a contract to \(A\) that pays \(x\) to \(A\) if \(F\) terminates the contract. In this case, once knowledge sharing has occurred, \(F\)'s outside option is \(\pi_F - x\), and \(A\)'s outside option is \(\pi_A + x\).\(^{15}\) The new gross payoffs that accrue to \(F\) and \(A\) after negotiations are thus, respectively,

\[
\frac{1}{2}(V + \pi_F - \pi_A) - x \quad \text{and} \quad \frac{1}{2}(V - \pi_F + \pi_A) + x.
\]

For knowledge sharing to occur, we need it to be profitable for the weak partner: \(\frac{1}{2}(V - \pi_F + \pi_A) + x \geq \frac{1}{2}I\). This condition can be rewritten as

\[
x \geq (\pi_F - \pi_A) - (V - I).
\]

By setting \(x^* = \frac{\pi_F - \pi_A - (V - I)}{2}\), firm \(F\) can induce firm \(A\) to share knowledge.

The ability of termination fees to induce knowledge sharing, however, is limited. One important reason is that the contract may induce the weak partner \(A\) to behave opportunistically. Specifically, \(A\) may not share knowledge, which may force \(F\) to terminate the collaboration, resulting in a payment of \(x\) to \(A\). Note that this payment is less than \(A\)'s payoff from not reneging and sharing knowledge, \(\frac{1}{2}(V - \pi_F + \pi_A) + x - \frac{1}{2}I\), only if \((\pi_F - \pi_A) - (V - I) > 0\), which cannot true (because we assumed \(V - \pi_F + \pi_A \geq I\) fails). That is, a contract that encourages knowledge sharing also tends to encourage opportunistic behavior by \(A\). Thus, termination fees will not help unless the courts can indemnify \(F\) against reneging by \(A\).

Another issue with termination-fee contracts relates to their enforceability. In practice, U.S. courts have refused to enforce breach damages that are deemed to be excessive (Chung, 1998). This suggests that, if \(x^*\) is ‘too high’ to be enforceable by courts, then \(F\) will not be able to induce \(A\) to share knowledge. Moreover, \(x^*\) will be high precisely in situations with particularly large shifts in bargaining positions that threaten collaboration incentives.

\(^{15}\)Here we assume that \(F\) is the only firm that has an incentive to terminate the alliance. It is easy to check that, given the contract, firm \(A\) has no incentive to prematurely terminate the alliance.
Firms enter into alliances for a variety of reasons: to facilitate collusion and increase market power (Porter and Fuller, 1986; Hagedoorn, 1993; Nakamura et al., 1996), to share risks and take advantage of new opportunities (Kogut, 1991; Gulati et al., 2000), to pool resources with other firms (Williamson, 1985; Hennart, 1988) and to acquire new skills and capabilities (Hamel, 1991; Mowery et al., 1996; Khanna et al., 1998; Lane and Lubatkin, 1998).

In this paper, we have focused on alliances where an important objective is the acquisition of new skills and capabilities (“learning alliances”), but where contracts are incomplete and firms cannot commit to exploit the newly created knowledge jointly. Firms share knowledge to create value (e.g., new products). However, knowledge sharing also creates agency hazards. For instance, a firm may steal a partner’s trade secrets, or asymmetric learning may occur. In the latter case, the faster learner may over time be able to reduce its dependency on the partner and appropriate a greater share of the collaborative pie. All these risks, if foreseen, can discourage knowledge sharing, unless contractual or other types of safeguards exist.

This paper contributes to the literature on learning in alliances, and provides a different perspective on learning races. Many if not most of the learning race view’s recommendations suffer from a failure to recognize that the processes of value creation and value appropriation are inextricably linked. Indeed, as Zeng and Hennart (2002: 193) argue, “[e]fforts at increasing one’s value extraction from a joint venture often damage cooperation and negatively impact value creation.” Scholars also argue that the notion of a race to learn may be “largely unrealistic,” for it is unclear what motivates a likely loser to join a race (Inkpen, 2002: 272). In this paper we incorporate a knowledge sharing constraint into a model of learning in alliances, and show that its inclusion has important consequences for both how alliances should be managed and how partner should be selected.

This perspective yields nuanced predictions. In some cases, the stronger partner may limit its own ability to learn, as Cisco does, or help enhance the learning ability of its partners. Indeed, in some cases, firms appear to go to great lengths to facilitate their partner’s learning efforts, even when these partners are competitors in the product market. In a study of American-Japanese joint ventures in the automo-
tive industry, Inkpen (1998) reports many instances of Japanese firms facilitating technology transfer to American partners through training of American engineers, temporary redeployment of personnel and transfer of equipment designs. We also find nuanced results regarding alliance portfolios. The simple intuition that alliance portfolios should be constructed to minimize overlap in technology among partners is potentially misleading when we consider learning alliances and incomplete contracts.

A distinguishing feature of our work is that we focus on the strategies that leading firms can use to encourage knowledge sharing ex ante, rather than on the better understood issue of how weak partner can protect their knowledge in alliances. In that respect, our analysis shares a flavour with contributions emphasizing the role of “keystone” firms in sharing the benefits from collaboration with partners, rather than appropriating the benefits (Iansiti and Levien, 2004).

Alliances are by definition not zero-sum games. Instead, they have the potential to create value. Value capture strategies must be balanced against the need to ensure value creation. Our focus on the need to induce knowledge sharing by the weaker partner is, at the most abstract level, an attempt put the emphasis back on value creation.

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Appendix A: Omitted proofs

The proofs of Propositions 1, 6 and 7 follow directly from the discussion in the main body of the paper. Below, we prove Propositions 2 to 5 and 8.

**Proof of Proposition 2.** (i) By adding (6) and (7), we obtain (8). Thus, if the firms share knowledge, it must be efficient. The converse is obviously not true.

(ii) Early termination of an alliance (after knowledge sharing but before implementation) occurs when $V < \pi_F + \pi_A$; that is, with probability $G(\pi_F + \pi_A)$.

(iii). Let $V$ and $V'$ be random variables with cumulative distributions $G$ and $H$, respectively. Let $H$ be a mean preserving spread of $G$. Thus, $V'$ is more “risky” than $V$. We wish to show that incentives for knowledge sharing are greater under distribution $H$ than under distribution $G$. To do so, define

$$
\Phi_F(V) = \begin{cases} 
\pi_F & \text{if } V < \pi_F + \pi_A \\
\pi_F + \frac{1}{2}(V - \pi_F - \pi_A) & \text{if } V \geq \pi_F + \pi_A 
\end{cases}
$$

By construction

$$
\pi_F + \frac{1}{2} \int_{\pi_F + \pi_A}^{V} (V - \pi_F - \pi_A) dG = \int_{V}^{V} \Phi_F(V) dG.
$$

Because $\Phi_F$ is convex in $V$ and $H$ is a mean preserving spread of $G$, Theorem 2 in Rothschild and Stiglitz (1970) implies that

$$
\int_{V}^{V} \Phi_F(V) dG \leq \int_{V}^{V} \Phi_F(V) dH.
$$

Thus firm $F$ has a greater incentive to share knowledge (conditional on A’s sharing knowledge) under distribution $H$ than under distribution $G$ (that is, $\int_{V}^{V} \Phi_F(V) dG \geq I/2$ implies $\int_{V}^{V} \Phi_F(V) dH \geq I/2$). A completely analogous argument proves that $A$ has a greater incentive to share knowledge (conditional on $F$’s sharing knowledge) under $H$ than under $G$. This proves the result. ■

**Proof of Proposition 3.** Let $\pi_F$ and $\pi_F'$ be random variables distributed over $[\underline{\pi}_F, \overline{\pi}_F]$ with cumulative distribution functions $K$ and $Q$, respectively. Let $Q$ be a mean preserving spread of $K$. Thus, $\pi_F'$ is more “risky” than $\pi_F$. Suppose $\overline{\pi}_F \geq \pi_A = 0$ and $\underline{\pi}_F < V < \overline{\pi}_F$. We wish to show that incentives for knowledge sharing are greater under distribution $Q$ than under distribution $K$.

We have that it is optimal for $F$ to share knowledge (conditional on $A$ sharing knowledge) if

$$
\int_{\underline{\pi}_F}^{\overline{\pi}_F} \pi_F dK + \frac{1}{2} \int_{\underline{\pi}_F}^{V} (V - \pi_F) dK \geq \frac{1}{2} I. \tag{12}
$$
Also, it is optimal for $A$ to share knowledge (conditional on $F$ sharing knowledge) if

\[
\frac{1}{2} \int_{\pi_F}^{V} (V - \pi_F) dK \geq \frac{1}{2} I. \tag{13}
\]

Clearly if (13) holds, then also (12) holds. Thus, in the non-cooperative equilibrium knowledge sharing will occur if and only if $A$’s knowledge sharing constraint is satisfied.

Define

\[
\Omega_A(\pi_F) = \begin{cases} 
0 & \text{if } V < \pi_F \\
\frac{1}{2}(V - \pi_F) & \text{if } V \geq \pi_F
\end{cases}
\]

By construction

\[
\frac{1}{2} \int_{\pi_F}^{V} (V - \pi_F) dK = \frac{1}{2} \int_{\pi_F}^{\pi_F} \Omega_A(\pi_F) dK.
\]

Because $\Omega_A$ is convex in $\pi_F$ and $Q$ is a mean preserving spread of $K$, Theorem 2 in Rothschild and Stiglitz (1970) implies that

\[
\int_{\pi_F}^{\pi_F} \Omega_A(\pi_F) dK \leq \int_{\pi_F}^{\pi_F} \Omega_A(\pi_F) dQ.
\]

Thus $A$ has a greater incentive to share knowledge under distribution $Q$ than under distribution $K$. This proves the result. ■

**Proof of Proposition 4.** Assumptions $V \geq I$ and $\pi_F^L \geq \pi_A^H$ imply that $F$’s knowledge sharing constraint is always satisfied. The only knowledge sharing constraint that may not be satisfied is $A$’s. From (??), it is clear that, by selecting $\pi_A = \pi_A^H$, firm $A$ will maximize both the probability of knowledge sharing and its share of the alliance returns. Thus, if knowledge sharing takes place, firm $A$ will select $\pi_A = \pi_A^H$.

Consider the problem firm $F$ faces. The objective of firm $A$ is to maximize its own payoff with respect to $\theta_A$,

\[
\max_{\pi_A \in \{\pi_F^L, \pi_A^H\}} \frac{1}{2} [V + \pi_F - \pi_A - I], \tag{14}
\]

subject to $A$’s knowledge sharing constraint being met

\[
V - \pi_F + \pi_A - I \geq 0 \tag{15}
\]

and firm $A$ choosing $\pi_A = \pi_A^H$. (If $A$’s knowledge sharing constraint is not met, then $F$’s payoff is 0. This is clearly worse than what $F$ can obtain with knowledge sharing.)

From (14), it is clear that $F$ will choose the highest value of $\pi_F$ compatible with (15) being met when $\pi_A = \pi_A^H$. If

\[
V - \pi_F^L + \pi_A^H - I < 0 \iff \pi_F^L - \pi_A^H > V - I,
\]

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then there is no value of $\pi_F$ that can induce $A$ to share knowledge sharing. Thus, knowledge sharing does not occur.

If

$$V - \pi_F^L + \pi_A^H - I \geq 0 \Rightarrow V - \pi_F^L + \pi_A^H - I \Leftrightarrow \pi_F^L - \pi_A^H \leq V - I < \pi_F^H - \pi_A^H,$$

then $\pi_F = \pi_F^L$ and knowledge sharing occurs.

If

$$V - \pi_F^H + \pi_A^H - I \geq 0 \Leftrightarrow \pi_F^H - \pi_A^H \leq V - I,$$

then $\pi_F = \pi_F^H$ and knowledge sharing occurs. This proves Proposition 4. ☐

**Proof of Proposition 5.** We can write the conditions for knowledge sharing to be privately profitable for all partners as

$$\Pi_F = 2(V - I) + b + 2M \geq 0$$

$$\Pi_A = \Pi_B = V - I + \frac{1}{2}b - M \geq 0$$

where

$$M = -\frac{1}{3}b + \left[\pi_F + \frac{1}{3}(s^{Imp} - s^{RB})\right].$$

Proposition 4 follows from the fact that $M$ can be positive or negative, and large enough as to outweigh the value creation component $V - I + \frac{1}{2}b$. For instance, (i) if shifts in bargaining power are small ($\pi_F + \frac{1}{3}(s^{Imp} - s^{RB}) \approx 0$), (ii) value creation $V - I + \frac{1}{2}b$ is positive but small, (iii) and synergies $b$ are sufficiently large, then knowledge sharing would be efficient but it would not be in $F$’s private interest ($\Pi_F < 0$). ☐

**Proof of Proposition 8.** Plugging $s^{Imp} = \alpha\Psi$ and $s^{RB} = (1 - \alpha)\Psi$ into $F$’s gross payoff (9) and the non-focal partners’ knowledge sharing constrain (11) yields

$$V + \pi_F + \frac{1}{3}b + \frac{1}{3}(2\alpha - 1)\Psi \tag{16}$$

and

$$V - I - \pi_F + \frac{2}{3}b \geq \frac{1}{3}(2\alpha - 1)\Psi. \tag{17}$$

$F$ maximizes (16) with respect to $\Psi \geq 0$ subject to (17). Proposition 7 follows immediately from inspection of equations (16)-(17). ☐
Appendix B: A dynamic model of knowledge sharing

In the basic model in Section 2, there is only one round of knowledge sharing. Here we develop a multi-stage, optimal stopping game of knowledge sharing, and show that our key qualitative results are robust.

Consider a collaboration between two infinitely-lived firms (or partners). Time is discrete. In each period $t = 1, 2, \ldots + \infty$, the firms decide whether or not they want to continue their collaboration. If the partnership is terminated at time $t$, then each partner $i = A, B$ receives a payoff $\Pi_{i,t}$. This payoff depends on whether the partners reach an agreement at time $t$ concerning the division of the joint value. If they reach an agreement, then they split a joint payoff of $R_t$. If not, each party obtains its outside option $\pi_{i,t}$. As standard in the incomplete contract literature, $R_t$ is assumed to be observable but not verifiable. Moreover, bargaining is assumed to be efficient and determined according to the Nash solution with equal weights. Thus, if the partnership is terminated at time $t$, $i$’s payoff is given by

$$\Pi_{i,t} = \begin{cases} \pi_{i,t} + \frac{1}{2} [R_t - \pi_{A,t} - \pi_{B,t}] & \text{if } R_t \geq \pi_{A,t} + \pi_{B,t} \\ \pi_{i,t} & \text{otherwise} \end{cases}$$

This implies that when the agreement is efficient ($R_t \geq \pi_{A,t} + \pi_{B,t}$), the parties receive their outside options plus and equal fraction of the surplus. To focus on inefficient termination, we will typically assume unless otherwise specified that $R_t \geq \pi_{A,t} + \pi_{B,t}$ for all $t$.

Effective collaboration requires investment by both partners to create joint value. Specifically, effective collaboration requires each partner to exert unobservable effort at private cost $\frac{1}{2}I$, $I > 0$. If both parties exert effort (i.e., collaborate, invest), then in period $t+1$ the joint payoff and outside options are $(R_{t+1}, \pi_{A,t+1}, \pi_{B,t+1})$. We assume $R_1 < \infty$ and decreasing marginal returns to investment: $\Delta R_{t+1} \leq \Delta R_t$ for all $t$, where $\Delta R_t \equiv R_{t+1} - R_t$. If at $t$ at least one party does not invest, then the partnership is terminated with payoffs $(R_t, \pi_{A,t}, \pi_{B,t})$.

Note that the assumptions that investment is unobservable and $R_t$ is non-verifiable imply that partners cannot contract on effort.

To characterize the solution to this stopping game, some notation must be introduced. A policy is a rule for choosing when to stop. Let $V_{i,t}$ denote the $i$’s maximum expected return at time $t$, conditional on $j \neq i$ never stopping. An optimal policy for $i$ for this auxiliary problem exists and can be found by solving the optimality equation

$$V_{i,t} = \max \left[ \Pi_{i,t}, -\frac{1}{2}I + V_{i,t+1} \right]$$

(see, e.g., Ross, 1983). Let

$$Z_i = \left\{ t : \Pi_{it} \geq -\frac{1}{2}I + \Pi_{i,t+1} \right\}$$

be the set of periods $t$ for which $i$ finds that stopping is at least as good as investing for exactly one period and then stopping. The one-stage look-ahead policy for $i$ is defined as the policy that stops the first time the process enters a state in $Z_i$. The following result is standard (see Ross, 1983: 54-55).

**Result (*).** Suppose $Z_i$ is a closed sets of states. Then the one-stage look-ahead policy for the auxiliary problem is optimal for $i = A, B$.

---

16Note that, in equilibrium, if one party stops investing, then the other party will also stop investing since otherwise it would waste $I/2$. Our framework also rules out equilibria where both parties stop investing at some period $t$ and then both restart at time $t + s$, $s \geq 1$. These equilibria do not exist if there is some small discounting.
Result (*) states that, provided that $B$ (respectively, $A$) keeps investing, then for $A$ (respectively, $B$) it is optimal to stop whenever stopping now is better than stopping the next period. Result (*) applies for instance, when $\Pi_{it}$ is ‘concave’ in $t$ (i.e., $\Delta \Pi_{it}$ is decreasing). Then in fact, if $\Delta \Pi_{it} \leq \frac{1}{2} I$ holds for some $t'$, it must also hold for all $t'' > t'$ ($Z_i$ is a closed sets of states). Obviously if $\Delta \Pi_{it}$ is decreasing, then as soon as $\Delta \Pi_{it} \leq \frac{1}{2} I$ partner $i$ should stop investing.

Focusing on partner $A$ and assuming that partner $B$ always invests, Result (*) implies that $A$ will stop at time $T_A$, where $T_A$ is the smallest $t$ such that

$$\Pi_{i;T_A} \geq \Pi_{i;T_A+1} - \frac{1}{2} I.$$ (18)

Let $\Delta R_t \equiv R_{t+1} - R_t$ and $\Delta \pi_{i,t} \equiv \pi_{i,t+1} - \pi_{i,t}$. Since $R_t \geq \pi_{At} + \pi_{Bt}$ for all $t$, (18) can be rewritten as

$$\Delta R_{T_A} - I \leq \Delta \pi_{B,T_A} - \Delta \pi_{A,T_A}.$$ (19)

Thus, $A$ stops investing when the partnership is no longer very productive ($\Delta R_{T_A} - I$ is small) and bargaining power is shifting in favor of $B$ ($\Delta \pi_{B,T_A} - \Delta \pi_{A,T_A}$ is large).

$B$’s problem is symmetric. If $A$ always invests, then $B$ must stop at time $T_B$, where $T_B$ is the smallest $t$ such that

$$\Delta R_{T_B} - I \leq \Delta \pi_{A,T_B} - \Delta \pi_{B,T_B}.$$ (18)

Thus $B$ stops earlier if the partnership is no longer very productive (as before) and its relative bargaining power starts to decline. Since the partnership terminates when either party stops investing, the actual stopping time is given by

$$T^* = \min[T_A, T_B]$$

or equivalently

$$\Delta R_{T^*} - I \leq |\Delta \pi_{A,T^*} - \Delta \pi_{B,T^*}|.$$ (19)

Note that if investment could be contracted upon, then the relationship would be terminated as soon as

$$\Delta R_T \leq I.$$ (19)

Proposition A summarizes our findings.

**Proposition A.** Suppose that an agreement is always efficient and $Z_A$ and $Z_B$ are closed sets of states. Then the collaboration is terminated at time $T^*$, where $T^*$ is the smallest $t$ satisfying

$$\Delta R_{T^*} - I \leq |\Delta \pi_{A,T^*} - \Delta \pi_{B,T^*}|.$$ (19)

Thus, compared to an efficient solution, in the non-cooperative equilibrium the collaboration terminates inefficiently early.

This proposition is very similar to Proposition 1 in the main body of the paper. It shows that collaboration is more likely to be terminated inefficiently early if continuation creates large shifts in bargaining power.