# Firm Boundaries in the New Economy: Theory and Evidence

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**Abstract**

The theory in this paper highlights the trade-offs that knowledge intensive firms confront when deciding among mergers/acquisitions, joint ventures, alliances, and arm's length contracts. I define a knowledge intensive firm as a collection of the knowledge assets that it *owns* and the agents who have *full access* to such assets. Therefore, boundary decisions between two firms are modeled using access to knowledge and ownership of knowledge. Modeling boundary choices using ownership cannot provide optimal incentives since ownership affects incentives asymmetrically, and ownership can encourage over-investment. In contrast, modeling the boundary choices using access and ownership can provide first best incentives since access and ownership complement each other in providing incentives: access affects incentives symmetrically while ownership affects them asymmetrically. The theory explains why some mergers/ acquisitions in knowledge intensive industries are successful while others fail and in what situations an alliance or a joint venture dominates a merger/ acquisition and vice-versa. Using a sample of alliances and joint ventures in the high technology industries, I provide empirical evidence to support the theory.

**Keywords**: Access, acquisitions, alliance, arms length contract, firm, hybrids, incentives, intellectual property, joint venture, knowledge, license, patent, mergers, ownership

**JEL Classifications**: D23, G34, L22

# 1 Introduction

This paper postulates and tests a theory of incomplete contracts that explains boundary decisions in knowledge intensive industries. Our starting point for the theory are the following observations. First, anecdotal and some systematic evidence[1] suggest that the success or failure of mergers and acquisitions in knowledge intensive industries is related to key employees staying on board after the deal is completed. For instance, contrast the acquisition of Netscape Communications by AOL with the acquisition of Level One by Intel. As the Business Week noted in its March (2003) issue, "After the AOL acquisition, Netscape's position in the internet browser market was undermined since the software engineers at Netscape fled *en masse*." In contrast, after Intel acquired Level One, all the important employees of Level One stayed on board which enabled Intel to extend its dominance in chips from personal computers to high speed connectivity.[2] Second, though firms in these industries frequently undertake alliances and joint ventures with other firms,[3] as Lerner and Rajan (2006) lament, "a relative paucity of attention has been paid to these exciting phenomena in the economics and finance literature." Examining these two observations collectively raises the following questions: What is a knowledge intensive firm? What are the costs and benefits of such a firm merging with or acquiring another firm compared to it undertaking an alliance or a joint venture with that firm? The theory in this paper aims to address these questions.

I view a knowledge intensive firm as a collection of the knowledge assets that it *owns* and the agents who have complete *access* to such assets. To understand the need to model knowledge intensive firms in this way, we have to review the existing theory. Consider first the Property Rights Theory (Grossman and Hart (1986), Hart and Moore (1990), Hart (1995), hereinafter GHM) that views a firm as a collection of assets that it *owns*, where ownership confers the right to make residual decisions about the asset. As Rajan and Zingales (2000) argue, employees cannot belong to a firm in this theory since they cannot be legally owned. Using this theory, we cannot distinguish between the AOL and Intel acquisitions since both AOL and Intel owned their respective target's knowledge assets after the acquisition. Second, consider Rajan and Zingales (1998, 2001)'s theory

[1] See evidence in the Management Strategy literature [Hambrick & Cannella (1993), Ranft and Lord (2000)].

[2] See the HBR article by Chaudhiri and Tabrizi (1999) for the Intel-Level One example.

[3] As the NSF Science and Technology Indicators (2006) avers, "Innovation involves a host of activities with external partners. . . Firms use, *inter alia*, alliances and joint venturtes to acquire knowledge. . . over seventy percent of these are in biotechnology and information technology."

which models a firm as a collection of agents who have access to a firm's assets, where access is defined as the ability to use or work with an asset. Their theory distinguishes between the AOL and Intel acquisitions based on the acquirer having access to the target's knowledge. However, they do not explicitly model how ownership of assets contributes to defining firm boundaries. To examine implications of the same, consider the research alliance between two biotechnology firms, MedImmune Inc and Ixsys Inc. As part of the alliance, MedImmune provided Ixsys a licence to its patented antibody technology. Thus Ixsys had access to this technology though it did not own it. Since MedImmune owned the patent, the alliance contract restricted Ixsys from using this license for any activity outside those detailed in the contract. Thus, which firm owned the patent had real implications for the activities that Ixsys could undertake using this antibody technology. However, in Rajan and Zingales' framework, we cannot delineate Ixsys' boundaries clearly since we cannot distinguish between Ixsys owning the patent versus MedImmune owning the same.

In essence, a knowledge intensive firm is a collection of the knowledge assets that it owns and the agents who have complete access to such assets *because* ownership of a knowledge asset confers a firm the legal right to make residual decisions about its use while access to knowledge provides the necessary expertise that lends substance to such a right. In keeping with this definition of a knowledge intensive firm, this paper models their boundary decisions using access to knowledge and ownership of knowledge.

Consider two firms whose knowledge/ technologies are complementary to each other. For concreteness, think of them as two biotechnology firms, John Inc. and Ram Inc. John specializes in discovering antibodies to cure diseases while Ram specializes in generating new drug delivery techniques. Given their complementary technologies, John and Ram benefit through a relationship with each other. In this setting, the central concern is how to encourage *both* firms to make investments that tailor their technology to that of their partner while discouraging them *simultaneously* from making investments aimed at stealing their partner's technology. As Anton and Yao (1994, 1995, 2002) and Rajan and Zingales (2001) show, investments to steal are an important concern with knowledge assets. Therefore, the theory models the twin problems of under- and over-investment by *both* firms.

The theory shows that the optimal boundary choice is an efficient response to these twin problems of under- and over-investment by both firms. The optimal choice reduces the distortion between the socially optimal and privately optimal investments of both firms, and *can provide the first best* incentives to both firms. In GHM, boundary choices cannot achieve this outcome since mergers/ acquisitions and arms-length contracts are modeled using ownership of assets. I show in the text that there are two reasons why ownership cannot provide optimal incentives to both firms. First, giving one firm ownership of an additional asset enhances its incentives but reduces that of the firm losing ownership. Second, ownership can have the *adverse effect* of encouraging over-investment.

In contrast, first best incentives can be provided to both firms when the boundary choices are modeled using *access* and ownership. Access is modeled to be reciprocal: John provides Ram the same degree of access as it receives from Ram. The mapping from access and ownership to the boundary choices is as follows. In a merger/acquisition, the acquirer owns the rights to use its knowledge and the target's knowledge while in joint ventures, strategic alliances and arms length contracts, each firm own the rights to use its knowledge. In a fully integrated merger/acquisition, access provided to knowledge is full while access between the two firms is high in joint ventures, moderate in alliances and minimal in arms length contracts. See Section 2 for the modeling of boundary choices using access and ownership.

After deciding access and ownership through an incomplete contract, the two firms make investments that are specific to the relationship. Investments that are made to tailor each firm's technology to that of the partner enhance the joint surplus and are *socially beneficial*. In contrast, investments that either firm makes to replicate the partner's technology is *socially wasteful*.[4] As in other incomplete contract settings, neither these investments nor the surplus generated thereof are contractible. See Section 3 for the setup of the theory.

Given this setup, modeling the boundary choices using access and ownership can provide improved incentives to both firms for the following reason. When John and Ram provide each other more (respectively less) access, both of them have stronger (respectively weaker) incentives to make socially beneficial and socially wasteful investments. Thus, access affects their incentives symmetrically. In contrast, if John transfers ownership of its technology to Ram, John's incentives to make socially beneficial and socially wasteful investments get weakened while that of Ram get

[4]Note that, in other settings, investments to replicate knowledge may be ex-post socially beneficial (though ex-ante inefficient). Here, such investment is wasteful ex-post since it duplicates what another agent already knows.

strengthened. Thus, ownership affects their incentives asymmetrically. Therefore, when both firms under-invest (respectively over-invest), increasing (respectively decreasing) access brings their investments closer to the first best. In contrast, when John over-invests and Ram under-invests, transferring ownership of John's technology to Ram brings their investments closer to the first best. Because of this complementarity in access and ownership, modeling the boundary choices using access and ownership provides better incentives to both firms. See Section 4 for an example illustrating this complementarity and Section 5 for the general results on the same.

This difference in the incentive effects of access and ownership has important consequences for the outcome of mergers/ acquisitions in knowledge intensive industries. Given the asymmetric effect of ownership on incentives, the incentives of the acquired firm get dampened in an acquisition. This is particularly the case when big established firms such as AOL acquire startups such as Netscape Communications. Incentives in startup firms are high-powered; employees working in these startups exhibit a revealed preference for such high-powered incentives. However, big established incumbents cannot replicate such high-powered incentives when the startup becomes a division of the large firm [Gertner, Scharfstein, Stein (1994), Amador and Landier (2003)]. When such employees face the likelihood of working in an environment where their incentives are not high powered, they may leave as happened in the case of the AOL-Netscape acquisition. *Without the important employees of the acquired firm, the acquirer is left without access to the crucial knowledge.* Such acquisitions may be doomed to fail because, as the theory shows, both access to knowledge and ownership over knowledge are required to provide optimal incentives for investment in knowledge assets. Therefore, when potential acquirers cannot alleviate the reduction in incentives of the target's employees due to transfer of ownership, it is optimal for the two firms to provide access to each other's knowledge through an alliance or joint venture. This is because access through an alliance or a joint venture has a symmetric effect on the firms' incentives while a change in ownership due to a merger/ acquisition has an asymmetric effect on incentives. In contrast, when the acquirer can retain the key employees of the acquired firm by providing them strong incentives, and thus mitigate the asymmetric effect of ownership, then a merger/ acquisition dominates other alternatives since maximum access can be achieved through a merger/ acquisition. This was the case when Intel acquiring Level-One.

The theory generates comparative statics predictions about how the optimal boundary choice varies with how easy or difficult it is to replicate each firm's knowledge.[5] To understand these predictions, note that Ram over-invests (respectively under-invests) when John's knowledge is easy (respectively difficult) to replicate. Similarly, John over-invests (respectively under-invests) when Ram's knowledge is easy (respectively difficult) to replicate. Therefore, when knowledge of both firms is very easy to replicate, firms will choose an arms length contract to provide minimal access to each other. As knowledge of both firms becomes more difficult to replicate, firms choose to provide more access to each other through a strategic alliance at first and then a joint venture. In contrast, the firm whose knowledge is easy to replicate would acquire the firm whose knowledge is difficult to replicate in order to prevent wasteful investment by the latter.

I test the prediction that access has a symmetric effect on the incentives while ownership has an asymmetric effect. I use strategic alliances in high technology industries to construct a proxy for access. An alliance in which a license is provided to some technology indicates greater access than an alliance where no such license is provided. To construct a proxy for ownership, I combine strategic alliances with joint ventures. Those joint ventures in which one partner has a majority ownership in the JV firm corresponds closely to Grossman and Hart's definition of ownership since the majority owner would get to exercise the residual rights of control. The breadth of a firm's patent portfolio, measured across all industry categories using citations to the patents, is employed as a proxy for ease of replicating knowledge. This is because a broad patent portfolio indicates a broad base of technological know-how and so a greater ability to replicate other's knowledge. As support for the symmetric effect of access, I find that a license is likelier in a strategic alliance when patent portfolio of both the firms is narrow. As support for the asymmetric effect of ownership, I find that a joint venture is more likely when the patent portfolio of one firm is narrow while that of the other firm is broader. See Section 6 for this empirical test of the theory.

This paper makes two contributions. First, by highlighting the trade-offs involved in mergers/ acquisitions, arms length contracts and hybrids like alliances and joint ventures, this paper brings theory proximate to the choices that firms in knowledge intensive industries confront in reality. By doing so, the theory highlights situations when a merger/ acquisition would be sub-optimal compared to an alliance or a joint venture and vice-versa; this helps throw light on why some mergers/

[5] Cohen, Nelson and Walsh (2000) note in their survey evidence across 140 industries that the use of patents and secrecy to prevent knowledge from being stolen are key mechanisms that firms use to appropriate returns from their knowledge.

acquisitions succeed while others fail. Second, in the limited context of knowledge intensive firms, the theory models the *separation between ownership and control*: access to knowledge represents control that is distinct from possessing the ownership rights to the knowledge. In the Property Rights framework of GHM, ownership has been identified with control since ownership is defined as the right to make those decisions that are not laid down in a contract. However, this paper shows that ownership of the knowledge asset need not necessarily imply control over it; both the legal right to make decisions, which is conferred by ownership, and the expertise to make such decisions, which is gained through access, are necessary to have effective control. In this respect, this paper resembles Aghion and Tirole (1996) who model the distinction between formal and real authority based on the information that an agent has to make the necessary decisions.

The paper differs from the existing literature in other ways. The theory highlights that an adverse effect of transferring ownership of a knowledge asset could be over-investment in replicating that knowledge. Rajan and Zingales (1998) also show that ownership can have an adverse effect on incentives. In their analysis, an owner under-invests more than an agent without ownership since the owner has a larger opportunity set and by specializing he forgoes his outside options. They make this case with physical assets since specialization renders physical assets less useful outside the relationship. However, they note that if only the human capital of an agent is specialized but the physical asset is not specialized, then this effect may not result. Thus, the adverse effect of ownership in the context of knowledge assets is a novel result. Due to this adverse effect of ownership, one agent owning two complementary assets may not be optimal. This is in contrast to the general GHM prediction that complementary assets must be owned by the same agent. Furthermore, in the GHM setup, ownership of an asset is determined by either a difference in marginal productivity or a difference in the bargaining powers of two agents (Aghion and Tirole (1994)). In contrast, the theory here shows that since ownership has an asymmetric effect on incentives, the allocation of ownership matters even in situations where there is no difference in either the bargaining power or the marginal product of the two agents.

## 2 Boundary decisions

Following the case made in the Introduction for modeling boundary decisions using access to knoweldge and ownership of knowledge, this section details the mapping from access and ownership to the boundary decisions. Before describing this mapping, it is useful to highlight the similarities and differences between strategic alliances and joint ventures and compare them to a merger/ acquisition on the one hand and an arms length contract on the other.

Joint ventures (JV) involve the partners *creating a new legal and organizational entity* in which they share equity. This feature of JVs is distinctive and it separates them from simple contracts and strategic alliances. While this feature of JVs resembles mergers/acquisitions, JVs do not involve the establishment of a single hierarchy as would happen in a merger/ acquisition. Thus while joint ventures represent more integration than a strategic alliance or an arms-length contract, they are less integrated compared to mergers/ acquisitions.

Compared to JVs, strategic alliances (SA) have *few hierarchical controls* built into them. An alliance is commonly a voluntarily initiated cooperative agreement among firms that involves exchange, sharing or co-development of assets. Partners in an alliance often contribute capital, technology and firm-specific assets. The governance structure of the alliance is the formal contract that partners use to formalize it. Thus a strategic alliance resembles an arms length contract more than it resembles mergers/ acquisitions.

### 2.1 Defining the Boundary decisions

As argued in the Introduction, I view a knowledge intensive firm as a collection of the knowledge assets that it *owns* and the agents who have *full access* to such assets. Thus, in a merger/ acquisition, the surviving entity owns its knowledge assets and that of the target. Also, the access that the two firms provide to each other is maximum if the two of them undertake a merger/ acquisition. In contrast, if the two firms transact through an arms length contract, then each firm owns its respective knowledge asset. Further, the access that each firm provides to its knowledge is minimal in this case. The rationale behind this classification is the following. When the two firms operate idependently, there is little knowledge sharing between the employees of the two firms. On the other hand, as business units in a single firm following a merger/ acquisition, the employees of the two business units can interact closely with each other. When employees in a firm work together, knowledge flows easier through the social networks that get created between them (Kogut and Zander (1992)). Thus, greater interaction between employees in a firm results in greater access to each other's knowledge while minimal interaction in an arms-length contract results in minimal access.

Hybrids such as strategic alliances and joint ventures lie in between these two extremes. Joint ventures are characterized by higher level of access than strategic alliances. Joint ventures involve creation of a separate organizational and legal entity where employees from the partner organizations interact together. This interaction between the employees of the partner firms leads to more sharing of knowledge in joint ventures than in strategic alliances where the interactions are more sporadic. The joint venture between GM and Suzuki (CAMI Automotive Inc.) illustrates this feature of joint ventures. GM rotated its managers between the parent organization and CAMI to ensure that its employees across the board where able to learn about Suzuki's manufacturing systems and JIT processes.

Consistent with this mapping, Gomes-Casseres, et. al. note that "Knowledge flows will be the smallest between firms that have only arm's length relationships... At the other extreme, a multinational corporation will align interests of its distinct units so as to maximize knowledge sharing within the firm... Knowledge sharing in alliances should be intermediate." In joint ventures and strategic alliances, each firm owns its knowledge assets as in an arms length contract.[6]

Figure 1 depicts pictorially this continuum of boundary choices using access and ownership.

# 3 Model

This section lays out the framework for the theory and presents the steps involved in solving the model.

[6] To be sure, in a joint venture the assets are owned by the joint venture entity rather than by either firm. Joint ownership means that when trade negotiations between the two partners break down, neither partner firm has the right to operate the asset independently. Thus, joint ownership of assets has no effect on the marginal incentives of the two partner firms. Hence, from an incentive point of view, treating a joint venture as each firm owns its assets is similar to joint ownership.

### 3.1 Setup

Consider two firms, A and B, possessing knowledge assets, P and Q, respectively. For concreteness, think of P as technology required for developing antibodies to various diseases while Q represents technology to deliver such antibodies to humans. A and B have a motivation to enter into an economic exchange since P and Q are complementary assets that are worth more together than separate. I assume that both agents are risk-neutral and neither is liquidity constrained so that ex-ante transfers from A to B or vice-versa are possible.

A and B make investments, $e^A$ and $e^B$ respectively, that are specific to the relationship. The cost of investment is equal to the level of investment. These investments are observable but not verifiable.

In order to make these investments, A and B have to provide access mutually to P and Q. I assume that *access is reciprocal*: A provides B access to P and gets the same degree of access to Q from B. Let this level of access be denoted by $\alpha$, $\alpha \in [0, 1]$ where $\alpha = 0$ represents minimal access while $\alpha = 1$ represents full access. Note that the assumption about the access being reciprocal does not affect the main result in this paper (see Section **??** for a discussion of this assumption).

A and B own P and Q respectively to start with. However, they may decide to change this pattern of ownership. Let $\delta = 0$ if A and B own P and Q respectively while $\delta = 1$ if, without loss of generality, A owns both P and Q. Thus $\delta \in \{0, 1\}$.

Let the output that A and B produce together be $R$. This joint output is a function of the specific investments, $e^A$ and $e^B$. Let $r^j$ for $j \in \{A, B\}$ denote the outside options of A and B. These are the outputs that A and B, respectively, can produce alone if their relationship gets terminated. The outside option of A(B) is a function of the specific investment made by A(B)[7]. The outside options are also functions of the degree of access, $\alpha$, and ownership of assets, $\delta$.

Finally, A's (B's) outside option is a function of A's (B's) ability to replicate Q(P). The degree of replicability is a function of the nature of the asset (patented knowledge is difficult to replicate for example) and the characteristics of the agent itself (more knowledgeable agents would have greater ability to replicate other's knowledge). I use $\theta^A$ $\left(\theta^B\right)$, $\theta^A, \theta^B \in \mathbb{R}^+$, to denote A's (B's) ability to replicate Q(P): a higher $\theta$ denotes a greater ability to replicate.

[7]The assumption that A's outside option is a function of only $e^A$, and not $e^B$, is not critical to any of the results.

### 3.2 Notation

Superscripts denote the function for the respective agent. Thus $r^A$ and $r^B$ denote the outside options for A and B respectively, $e^A$ and $e^B$ denote the investments made by A and B respectively, and $\theta^A$ $\left(\theta^B\right)$ denotes A's (B's) ability to replicate the knowledge that he gets access to. Subscripts, on the other hand, are used for denoting partial derivatives. Thus,

$$R_i \equiv \frac{\partial R}{\partial e^i}, R_{ii} \equiv \frac{\partial^2 R}{\partial \left(e^i\right)^2}, r_i^i \equiv \frac{\partial r^i}{\partial e^i}, r_{ii}^i \equiv \frac{\partial^2 r^i}{\partial \left(e^i\right)^2}, r_{i\alpha}^i \equiv \frac{\partial^2 r^i}{\partial e^i \partial \alpha}, r_{i\theta}^i \equiv \frac{\partial^2 r^i}{\partial e^i \partial \theta^i}, i \in \{A, B\}$$

### 3.3 Technology

The functional dependencies of $R, r^A$ and $r^B$ are shown mathematically below

$$R = R\left(e^A, e^B, \alpha\right), \qquad r^A = r^A\left(e^A, \alpha, \delta; \theta^A\right), \qquad r^B = r^B\left(e^B, \alpha, \delta; \theta^B\right) \tag{T1}$$

The joint output, $R$, is an increasing, concave function of the specific investments $e^A, e^B$ and $\alpha$.

$$\begin{aligned} R_i &> 0, R_{ii} < 0 \quad, i \in \{A, B\} \\ R_\alpha &> 0, R_{\alpha\alpha} < 0 \end{aligned} \tag{T2}$$

As in Grossman and Hart (1986) and Hart (1995), I assume that there are no strategic interactions between the investments made by A and B

$$R_{AB} = 0 \tag{T3}$$

While this assumption is not critical to the results[8], it simplifies the analysis. Furthermore, no additional intuition is gained from having $R_{AB} \neq 0$.

The outside option of each agent is an increasing, concave function of the investment of that agent[9]

$$r_i^i > 0, r_{ii}^i < 0 \quad, i \in \{A, B\} \tag{T4}$$

[8] When $R_{AB} \geq 0$ or $R_{AB} < 0$, all the results hold with one additional assumption about the relative magnitudes of $R_{AB}$ and $R_{ii}, i \in A, B$. The proofs for the same are available from the author on request.

[9] S's outside option is not a function of F's investment and vice-versa. Similar to the assumption that $R_{SF} = 0$, this assumption is neither critical to the results nor is any additional intuition gained by relaxing it.

When access $\alpha$ is higher, investment by each agent is more productive. Mathematically,

$$R_{i\alpha} > 0, r^i_{i\alpha} > 0 \quad , i \in \{A, B\} \tag{T5}$$

Consider the following example to illustrate the above technological assumption. When a student learns a new subject, the instructor and the teaching assistant are the assets that he needs access to. The time that the student gets to spend with the instructor and the teaching assistant represents access to these assets. When the instructor or the teaching assistant provide more access (spend more time), the student would be more productive in learning the subject. Thus increasing access enhances the productivity of investment.

Following Grossman and Hart (1986), ownership of an additional asset increases the marginal value of the owner's outside option. Since $\delta = 1$ corresponds to A owning both P and Q,

$$r^A_A(\delta = 1) > r^A_A(\delta = 0), r^B_B(\delta = 1) < r^B_B(\delta = 0) \tag{T6}$$

Note that Rajan and Zingales (1998) consider the case where ownership reduces the marginal value of outside options. However, they make this case with physical assets since specialization renders physical assets less useful outside the relationship. However, they note that if only the human capital of an agent is specialized but the physical asset is not specialized, then it is not obvious that owner's outside option with the asset falls with specialization. Since, my analysis is concerned with the ownership of knowledge, it is more plausible that ownership of knowledge enhances the value of the outside options rather than diminishing them.

Since the theory analyzes situations where A's and B's knowledge are equally important, I assume a symmetric technology.

$$\begin{aligned} R_A &= R_B = R_e; R_{AA} = R_{BB} = R_{ee}; r^A_{AA} = r^B_{BB} = r_{ee} \\ R_{A\alpha} &= R_{B\alpha} = R_{e\alpha}; r^A_{A\alpha} = r^B_{B\alpha} = r_{e\alpha} \end{aligned} \tag{T7}$$

Furthermore, unlike GHM, this allows me to focus on situations where the boundary choice matters even when there is no difference between the marginal productivity of the two firms.

As knowledge becomes easier to replicate, the outside option becomes more productive at the margin. Hence

$$r^i_{i\theta} > 0 \quad , i \in \{A, B\} \tag{T8}$$

Note that, to simplify the analysis, the functions here are assumed to be smooth and twice differentiable. However, all the results can be proved using the framework provided by Milgrom and Shannon (1994) for more generic functions that may not share these nice properties.

### 3.4 Timing and Events

The model is set in two periods spanning the times $t = 0, 1$ and 2. The timing of events in the model (which is pictorially depicted in Figure 2) is as follows.

At $t = 0$, the firms choose the level of access $\alpha$ to provide to each other, and the pattern of ownership of knowledge assets P and Q, $\delta$. At $t = 1$, specific investments $e^A$ and $e^B$ are chosen by A and B respectively. At $t = 2$, A and B bargain over the split of the surplus that is realized in their relationship. I assume that the bargaining approach used is 50:50 Nash bargaining. Note that the 50:50 split is employed only for convenience. A generalized Nash bargaining solution where A and B split the surplus in a different proportion would not alter the analysis or the results.

To make sure that the results in this paper are robust to alternative bargaining solutions[10], I show in Appendix xxx that the analysis in this paper remains relevant when the alternating-offers bargaining model *a la* Rubinstein (1982) is used instead of the Axiomatic Nash bargaining solution.

Note that the level of access provided or the ownership chosen at $t = 0$ does not affect the bargaining outcomes at $t = 2$. While this is a standard assumption made in the Property Rights literature, it may strike readers as strong. However, as argued in Hart (footnote 17, Chapter 2, 1995), assuming that the choice of the institution at $t = 0$ does not affect bargaining outcomes is weak, since it would be too easy to obtain a theory of costs and benefits of the different institutional choices by making the bargaining outcomes a function of these institutional choices.

Furthermore, note that even though uncertainty is not modeled explicitly here, the following analysis is not affected if we replace the payoffs at $t = 2$ by their expectations [see Hart and Moore( footnote 5, 1990)].

[10] De Meza and Lockwood (1998) show that the GHM results do not generalize when the alternative-offers bargaining protocol of Rubinstein (1982) is used.

### 3.5 Nature of contracts

Contracts are assumed to be incomplete as in GHM. Explicitly, two important assumptions characterize the incomplete contracts environment. First, the investments at $t = 1$ are observable but not verifiable. Second, the payoffs $R$ and $r^j$ ,$j \in A, B$ are assumed to be non-contractible at $t = 0$, though they are contractible at $t = 2$. These assumptions are justified by invoking two more primitive assumptions. First, the contract at $t = 0$ cannot specify in detail all the different contingencies that may arise – a situation that Tirole (1999) labels "indescribable contingencies." Secondly, neither party can commit at $t = 0$ to not resort to ex post renegotiation at $t = 2$ after threatening to exercise its outside option.

The assumption of "indescribable contingencies" is natural to the setting being studied since it is unlikely that the two firms will be able to write a contract describing precisely the specific details that are entailed in developing a product using their respective technologies. However, as Tirole (1999) explains, indescribability would not limit the menu of contracts that can be written at $t = 0$ if the two parties can commit to a contract that would not be renegotiated at $t = 2$. Indescribability matters more for the contract to be incomplete when renegotiation is possible "because the constraints imposed by renegotiation make it harder to make up for the information garbling that is implied by the indescribability of contingencies." Tirole (pp. 761, 1999).

Note that given indescribability and renegotiation, revenue-sharing rules contracted at $t = 0$, incentive contracts, contracts that explicitly specify performance at $t = 2$, or mechanisms that involve messaging between the two parties or to third parties become impotent in solving the incentive problem that is analyzed in this paper [see Hart (Chapter 4, 1995) for details].

### 3.6 Additional Assumptions

To ensure the existence of unique solutions for the first best and second best levels of investment, I assume that

$$\begin{aligned} \lim_{e_i \to \infty} \left[R_i(e_i, e_j)\right] &= 0, \lim_{e_i \to 0} \left[R_i(e_i, e_j)\right] = \infty, \ i \in \{A, B\} \ \ j = \{A, B\} \backslash i \\ \lim_{e_i \to \infty} \left[r_i^i(e_i)\right] &= 0, \lim_{e_i \to 0} \left[r_i^i(e_i)\right] = \infty, \ i \in \{A, B\} \end{aligned} \tag{A1}$$

Further, to ensure the existence of a unique interior solution for access, I assume that

$$\frac{R_{e\alpha}}{r_{e\alpha}} > \frac{R_{ee}}{R_{ee} + 2r_{ee}} \tag{A2}$$

I assume that there are some quasi-rents to be realized in the relationship, i.e.,

$$R\left(e^A, e^B\right) > r^A\left(e^A, \alpha, \delta; \theta^A\right) + r^B\left(e^B, \alpha, \delta; \theta^B\right) \quad \forall e^A, e^B, \alpha, \delta, \theta^A, \theta^B \tag{A3}$$

Hence, neither A nor B would rationally want to leave the relationship at $t = 2$. The outside options thus serve as threat points in the bargaining and are never exercised in equilibrium; thus there are no ex-post inefficiencies in the model. Thus assumption is quite standard in the property rights literature.

To allow for both over-investment and under-investment by the scientist and the financier, I assume

$$\lim_{\theta^i \to 0} r_i^i\left(\ldots; \theta^i\right) = 2, \lim_{\theta^i \to \infty} r_i^i\left(\ldots; \theta^i\right) = 0, i \in A, B \tag{A4}$$

These boundary conditions provide necessary variation in $R_e$ and $r_e$ to ensure $R_e > r_e$ and $R_e < r_e$.

## 3.7 Solving the model

I solve the framework presented through backward induction starting at $t = 2$. At $t = 2$, bargaining takes place between A and B (assumed to be 50:50 Nash bargaining) and the split of the output between them is decided. At $t = 1$, each agent decides the Nash equilibrium level of investment by maximizing his share of the joint output less the cost of his investment. These equilibrium levels of investment are used to compute the expected joint surplus at $t = 0$. Access and ownership are then chosen to maximize this joint surplus. Since A and B are assumed not to be liquidity constrained, they can effect private transfers to each other at $t = 0$ to ensure that access and ownership are chosen to maximize the joint surplus.

### 3.7.1 Split of output

A and B split the output produced in the relationship at $t = 1$ using 50:50 Nash bargaining. The joint surplus produced in the relationship is

$$TS\left(e^A, e^B\right) = R\left(e^A, e^B\right) - e^A - e^B \tag{1}$$

while the individual surpluses of A and B are given by

$$TS^A\left(e^A, e^B, \alpha, \delta; \theta^A, \theta^B\right) = \frac{R\left(e^A, e^B\right) + r^A\left(e^A, \alpha, \delta; \theta^A\right) - r^B\left(e^B, \alpha, \delta; \theta^B\right)}{2} - e^A \tag{2}$$

$$TS^B\left(e^A, e^B, \alpha, \delta; \theta^A, \theta^B\right) = \frac{R\left(e^A, e^B\right) - r^A\left(e^A, \alpha, \delta; \theta^A\right) + r^B\left(e^B, \alpha, \delta; \theta^B\right)}{2} - e^B \tag{3}$$

### 3.7.2 Specific Investments

If complete contracts could be written, the investments chosen by A and B would maximize the joint surplus TS (see equation (1)). Denote these first-best investments by $e^{iF}$ ,$i \in \{A, B\}$. The first order conditions for the Nash equilibrium first best investments $\left(e^{AF}, e^{BF}\right)$ are

$$\begin{aligned} R_A\left(e^{AF}, e^{BF}\right) &= 1 \\ R_B\left(e^{AF}, e^{BF}\right) &= 1 \end{aligned} \tag{4}$$

. Concavity of $R\left(e^A, e^B\right)$ and the boundary conditions $(A1)$ ensure the existence and uniqueness of $\left(e^{AF}, e^{BF}\right)$.

Since contracts are not complete, A and B would choose investments to maximize their individual surpluses $TS^A$ (see equation (2)) and $TS^B$ (see equation (3)). Denote these second-best investments by $e^{i*}$ ,$i \in \{A, B\}$. The first order conditions for the Nash equilibrium $\left(e^{A*}, e^{B*}\right)$ are

$$\begin{aligned} \frac{1}{2}R_A\left(e^{A*}, e^{B*}, \alpha\right) + \frac{1}{2}r_A^A\left(e^{A*}, \alpha, \delta; \theta^A\right) &= 1 \\ \frac{1}{2}R_B\left(e^{A*}, e^{B*}, \alpha\right) + \frac{1}{2}r_B^B\left(e^{A*}, \alpha, \delta; \theta^A\right) &= 1 \end{aligned} \tag{5}$$

. Concavity of $R\left(e^A, e^B\right)$, $r^A\left(e^A\right)$, and $r^B\left(e^B\right)$ along with the boundary conditions $(A1)$ ensure that $\left(e^{A*}, e^{B*}\right)$ exists and is unique.

### 3.7.3 Access and ownership

Given the equilibrium second best investments, $e^{A*}$ and $e^{B*}$, the joint surplus produced in the relationship is

$$TS^*\left(\alpha, \delta; \theta^A, \theta^B\right) = R\left(e^{A*}(.), e^{B*}(.)\right) - e^{A*}\left(\alpha, \delta; \theta^A\right) - e^{B*}\left(\alpha, \delta; \theta^B\right) \tag{6}$$

Since I assume that neither party is liquidity constrained, ex-ante private transfers at $t = 0$ are possible. Thus, the optimal choice of access and ownership[11] are given by

$$\left(\alpha^*, \delta^*\right) \equiv \arg\max_{(\alpha,\delta)} \left[TS^*\left(\alpha, \delta; \theta^A, \theta^B\right)\right] \tag{7}$$

# 4 A simple example

Before analyzing the model in detail, it is useful to consider an example. Consider the following functional forms for the joint output $R$ and the outside options $r^A$ and $r^B$.

$$\begin{aligned} R\left(e^A, e^B\right) &= 8e^A - \frac{1}{2}\left(e^A\right)^2 + 8e^B - \frac{1}{2}\left(e^B\right)^2 \text{ where } e^A, e^B \in \mathbb{R}^+ \\ r^A\left(e^A, \alpha, \delta; \theta^A\right) &= \left(2 + 4\alpha + 2\delta + 6\theta^A\right)e^A - \frac{1}{2}\left(e^A\right)^2 \text{ where } \theta^A \in [0,1] \\ r^B\left(e^B, \alpha, \delta; \theta^B\right) &= \left(2 + 4\alpha - 4\delta + 6\theta^B\right)e^B - \frac{1}{2}\left(e^B\right)^2 \text{ where } \theta^B \in [0,1] \end{aligned}$$

The first best investments derived using the first order conditions (4) are

$$e^{AF} = e^{BF} = 7 \tag{8}$$

[11] If contracts were complete, then the first best investments can be implemented. In this case, the choice of access and ownership is irrelevant since there are no distortions in investment which need to be mitigated by choosing access and ownership.

while the second best investments, derived using the first order conditions (5) , are

$$\begin{aligned} e^{A*} &= 4 + 2\alpha + \delta + 3\theta^{A} \\ e^{B*} &= 4 + 2\alpha - 2\delta + 3\theta^{B} \end{aligned} \tag{9}$$

Note in (9) that as access increases (decreases), both A's and B's investments increase (decrease) $\left[\frac{de^{A*}}{d\alpha} = \frac{de^{B*}}{d\alpha} > 0\right]$. In contrast, when the ownership of Q is transferred from B to A, A's investment increases while that B decreases $[e^{A*}(\delta = 1) > e^{A*}(\delta = 0)$ while $e^{B*}(\delta = 1) < e^{B*}(\delta = 0)]$. Thus changing *access has a symmetric effect* on A's and B's incentives while transferring *ownership has an asymmetric effect.* Lemma 2 in Section 5 generalizes this result.

Now, I consider four cases to show how each of the four boundary choices provides first-best incentives to both A and B. Refer Figures 3, 4, 5, and **??** respectively for the plot of the first-best and second-best investments. In each of these figures, the solid, dotted and dash-dot lines respectively depict first-best, second-best when A and B own their respective assets $(\delta = 0)$ , and second-best when A owns both assets P and Q $(\delta = 1)$.

**Case 1 (Arms length contract optimal):** Consider first the case where P and Q are extremely easy to replicate $(\theta^{A} = \theta^{B} = 1)$. Figure 3 shows that in this case, $e^{A*}(\delta = 0) \geq e^{AF}\ \forall\alpha$ and $e^{B*}(\delta = 0) \geq e^{BF}\ \forall\alpha$. Therefore, *both A and B over-invest* in this case. It can be verified that, in this case, $R_{B} \leq r_{B}^{B}(\delta = 0)\ \forall e^{B}$ and $R_{A} \leq r_{A}^{A}(\delta = 0)\ \forall e^{A}$ which leads to the over-investment.

Transferring ownership of B's asset to does not achieve the objective of providing first best incentives to *both* A and B. When $\delta = 1$, A over-invests at all values of access $\left[e^{A*}(\delta = 1) > e^{AF}\ \ \forall\alpha\right]$. Thus, *ownership has the adverse effect of encouraging over-investment* by the owner. In contrast, decreasing access *simultaneously* decreases the incentives of both A and B and when access is minimal $(\alpha = 0)$ , their investments equal the first best. This is because access affects A's and B's incentives symmetrically. In essence, when both A and B over-invest, changing access (to minimal) *can* provide first best incentives to both A and B while transferring ownership *will* not.

Therefore, minimal access and each firm owning its asset, which corresponds to arms length contracts, is optimal.

**Case 2 (Alliance optimal):** Now consider the case where P and Q are moderately easy to replicate $(\theta^{A} = \theta^{B} = \frac{2}{3})$. Figure 4 shows that $\alpha \lesseqgtr 0.5 \Leftrightarrow e^{A*}(\delta = 0) \lesseqgtr e^{AF}$ and $e^{B*}(\delta = 0) \lesseqgtr e^{BF}$.

It can be verified that, in this case, $\alpha \lesseqgtr 0.5 \Leftrightarrow R_B \lesseqgtr r_B^B(\delta = 0)\ \forall e^B$ and $R_A \lesseqgtr r_A^A(\delta = 0)\ \forall e^A$ which leads to the under- and over-investment.

Transferring ownership of B's asset to A cannot achieve the objective of providing first best incentives to *both* A and B since changing ownership leads to under-investment by B at all levels of access $\left[e^{B*}(\delta = 1) < e^{BF}\ \ \forall \alpha\right]$. In contrast, changing access can provide first best incentives to both A and B. When access is lower (respectively higher) than the optimal $\alpha^* = 0.5$, both agents underinvest (respectively over-invest). Due to this *symmetric effect of access* on incentives, decreasing (respectively increasing) access is optimal when both agents over-invest (respectively under-invest).

Therefore, moderate access and each firm owning the asset, which corresponds to a strategic alliance, is optimal.

**Case 3 (Joint Venture optimal):** Consider now the case where P and Q are moderately difficult to replicate ($\theta^A = \theta^B = \frac{1}{3}$). Figure 5 shows that $\alpha \lesseqgtr 0.75 \Leftrightarrow e^{A*}(\delta = 0) \lesseqgtr e^{AF}$ and $e^{B*}(\delta = 0) \lesseqgtr e^{BF}$. As in the previous case, changing access enhances the surplus while changing ownership does not. In this case $\alpha^* = 0.75$ provides first best incentives to both A and B.

Thus, high access and each firm owning its respective asset, which corresponds to a joint venture, is optimal.

**Case 4 (Merger/ Acquisition optimal):** Finally, consider the case where Q is difficult to replicate ($\theta^A = 0$) but P is easy to replicate ($\theta^B = 1$). Figure **??** shows that in this case, $e^{A*}(\delta = 0) < e^{AF}\ \forall \alpha$ while $e^{B*}(\delta = 0) \geq e^{BF}\ \forall \alpha$. Thus, in this case, *A under-invests while B over-invests*. It can be verified that, in this case, $R_A > r_A^A(\delta = 0)\ \forall e^A$ and $R_B < r_B^B(\delta = 0)$ $\forall e^B$ which leads to the under-investment by A and over-investment by B. When $\delta = 0$, changing access cannot provide first best incentives to both A and B. This is because, in this case, one agent under-invests while another over-invests. In contrast, transferring ownership of Q to A is effective since this reduces over-investment by B and simultaneously mitigates under-investment by A too. Transferring ownership of Q to A reduces B's incentives but enhances A's. Since both agents under-invest when $\delta = 1$, increasing access to $\alpha = 1$ leads to first-best investments by both A and B.

Thus, full access and A owning both P and Q, which corresponds to a merger/ acquisition is optimal.

By comparing across these four cases, we can infer that

a. A and B under-invest (respectively over-invest) when their investment enhances the marginal value of joint output more (respectively less) than the marginal value of outside option. This result is illustrated graphically in Figure 7. Lemma 1 in Section 5 generalizes it.

b. A under-invests (respectively over-invests) when B's knowledge is difficult (respectively easy) to replicate. A similar result applies for B. This result, which is the basis of the comparative statics predictions, is illustrated graphically in Figure **??**. Lemma 3 in Section 5 generalizes it.

c. Ownership can have the adverse effect of encouraging over-investment. See Lemma 2 for the generalization of this result.

d. Increasing (respectively decreasing) access is optimal when A and B under-invest (respectively over-invest). In contrast, transferring ownership of B's asset to A is optimal when B over-invests while A under-invests. Thus, access and ownership are complementary mechanisms for providing optimal incentives to A and B. Proposition 1 applies this result to generate the comparative statics predictions.

e. The optimal boundary choice can provide first-best incentives to both A and B. Modeling boundary choices using solely access or ownership cannot achieve the first-best in these different scenarios.

# 5 Results

Having described the important features of the model using an example, I now analyze the general model and prove the main results.

## 5.1 Complementarity between Access and Ownership

LEMMA 1 Given $\alpha, \delta$, (a) $r_i^i \leq R_i \; \forall e^i \Rightarrow e^{i*} \leq e^{iF}$ and $r_i^i > R_i \; \forall e^i \Rightarrow e^{i*} > e^{iF}$,$i \in \{A, B\}$ .

Given the access and ownership chosen at $t = 0$, A under-invests when the marginal effect of A's investment on the joint output is more than its effect on A's outside option. On the other hand, A *over-invests* when the marginal effect of A's investment on the joint output is less than its effect on A's outside option. A similar result holds for B's investment too.

*Why is over-investment more likely to be caused with knowledge assets but not in tangible assets*? In contrast to tangible assets, knowledge can be stolen more easily from the owner. Furthermore, in order to be able to steal knowledge, the agent getting access has to make investments to replicate the knowledge. Such investments are socially inefficient since they are duplicative. While such over-investment is an important concern with intangible assets, it is less concerning with physical assets since the likelihood of successful stealing is very low when rights over physical property are well enforced. Since GHM concerns investment relating to physical assets, they ignore over-investment even though their model allowed the possibility of the same.

Thus, with knowledge assets, (a) under-investment in tailoring complementary pieces of knowledge and (b) over-investment in stealing knowledge are both material concerns.

LEMMA 2

$$
\begin{aligned}
(a)\, \frac{de^{A*}}{d\alpha} &= \frac{de^{B*}}{d\alpha} > 0 \\
(b)\ e^{A*}(\delta = 1) &> e^{A*}(\delta = 0)\, ; e^{B*}(\delta = 1) < e^{B*}(\delta = 0)
\end{aligned}
$$

Increasing access increases the incentives of both A and B to make specific investments while transferring ownership enhances the incentives of the agent getting ownership but dampens that of the agent losing it.

The intuition for the result is as follows. Increasing access increases the investments made by A and B since increased access makes investment more productive (refer to technological assumption ($T5$)). In contrast, on transferring ownership of B's asset to A, A's outside option becomes more productive, while B's becomes less productive.

The adverse effect of ownership can be seen by juxtaposing part (b) of Lemma 1 with part (b) of the above Lemma. Think of investments by A to replicate B's knowledge. Such investments only A's outside option at the margin but not the joint output. Therefore, $R_A > r_A^A \ \forall e^A, \delta$. Therefore, providing ownership of B's asset to A increases his overinvestment. This represents an *adverse effect of transferring ownership* of an additional asset. The intuition for this result is as follows. If ownership of B's asset is transferred to A, A's bargaining power is enhanced at the margin since he can threaten to develop products without B's cooperation. Such a threat was less credible when B owned his asset. Also, A can't effect his threat of dispensing with B unless he invests to replicate B's knowledge. Therefore, on getting ownership of B's asset, A overinvests more.

Rajan and Zingales (1998) also show that ownership can have an adverse effect on incentives. In their analysis, an owner under-invests more than an agent without ownership since the owner has a larger opportunity set and by specializing he forgoes his outside options. They make this case with physical assets since specialization renders physical assets less useful outside the relationship. However, they note that if only the human capital of an agent is specialized but the physical asset is not specialized, then this effect may not result. Thus, the adverse effect of ownership in the context of knowledge assets is a novel result. Due to this adverse effect of ownership, one agent owning two complementary assets may not be optimal. This is in contrast to the general GHM prediction that complementary assets must be owned by the same agent.

## 5.2 Comparative Statics Predictions

Lemma 3 Given $\alpha, \delta$, there exist $\widehat{\theta^i}$ such that (a) $\theta^i \leq \widehat{\theta^i} \Rightarrow e^{i*} \leq e^{iF}$ and $\theta^i > \widehat{\theta^i} \Rightarrow e^{*i} > e^{iF}$

This lemma is a generalization of point (b) in the example shown in Section 4 above.

Proposition 1 Consider $\left(\theta_A^1, \theta_B^1\right) \neq \left(\theta_A^2, \theta_B^2\right)$.

(a)

$$\theta_A^1 > \theta_A^2 \text{ and } \theta_B^1 > \theta_B^2 \Rightarrow \alpha^* \left(\theta_A^1, \theta_B^1\right) \leq \alpha^* \left(\theta_A^2, \theta_B^2\right)$$

(b)

$$\theta_A^1 > \theta_A^2 \text{ and } \theta_B^1 < \theta_B^2 \Rightarrow \delta^* \left(\theta_A^1, \theta_B^1\right) \leq \delta^* \left(\theta_A^2, \theta_B^2\right)$$

As *both* A's and B's knowledge become easier to replicate, the optimal level of access decreases (part (a)). In contrast, when A's knowledge becomes easier to replicate while B's knowledge becomes more difficult to replicate, it is optimal to transfer ownership of B's knowledge to A (part (b)).

Corollary 1 There exist $\widehat{\theta^A}$ and $\widehat{\theta^B}$ such that if

$$\begin{aligned}
(a)\ (i)\ \theta^A &> \widehat{\theta^A} \text{ and } \theta^B > \widehat{\theta^B} \Rightarrow \alpha^* = 0 \\
(ii)\ \theta^A &\leq \widehat{\theta^A} \text{ and } \theta^B \leq \widehat{\theta^B} \Rightarrow \alpha^* = 1 \\
(b)\ (i)\ \theta^A &\leq \widehat{\theta^A} \text{ and } \theta^B > \widehat{\theta^B} \Rightarrow \delta^* = 1 \\
(ii)\ \theta^A &\geq \widehat{\theta^A} \text{ and } \theta^B < \widehat{\theta^B} \Rightarrow \delta^* = 0
\end{aligned}$$

When *both* A's and B's knowledge are easy to replicate, minimal access is optimal while full access is optimal when *both* A's and B's knowledge are difficult to replicate (part (a)). In contrast, when A's knowledge is easy to replicate while B's is difficult to replicate, ownership of B's knowledge must be transferred to A (part (b)).

The intuition behind Proposition 1 and the above corollary are as follows. Changing access has a symmetric effect on incentives of A and B while transferring ownership has an asymmetric effect – the incentives of the agent getting ownership is enhanced while that of the agent losing ownership is dampened. Therefore, regulating access is optimal when both agent's incentives need to be simultaneously increased or decreased. In contrast, ownership must be taken from the over-investing agent and given to the under-investing agent.

The results then follow by noting that incentives of A and B increase as the knowledge they get access to becomes easier to replicate.

Proposition 1 highlights the complementarity of access and ownership in generating optimal incentives for specific investment. Given the contrasting effects of access and ownership on incentives, they are both required in aligning incentives of agents to socially optimal levels. As the example in Section 4 shows, choosing access and ownership simultaneously can provide first-best incentives to A and B. This is because choosing access and ownership together solves simultaneously the problems of (a) under-investment in tailoring complementary pieces of knowledge, and (b) over-investment in stealing knowledge.

Thus, when knowledge of both firms is easy (difficult) to replicate, they will choose to restrict (provide full) access to each other by choosing less (more) integrated organizational forms. In contrast, when knowledge of one firm is easier to replicate and another's difficult to replicate, the firm whose knowledge is easy to replicate must acquire the other firm.

# 6 Empirical Evidence

I test the prediction in proposition 5.2. To proxy for access, I use licensing in strategic alliances as a proxy for access and patent based measures to proxy how easy knowledge is to replicate.

## 6.1 Construction of the Dataset

The dataset is constructed by merging strategic alliance and joint venture deals from the Securities Data Company (SDC)'s Platinum database with the NBER patent database compiled by Hall, Jaffe and Trajtenberg (2001). The complete list of divisions and subsidiaries of each firm drawn from the S&P Directory of Corporate Affiliations are also used. The SDC module on Joint Ventures and Alliances primarily includes joint ventures and strategic alliances for both US and non-US firms.[12]

Although the strategic alliances database dates back to 1986, SDC initiated systematic data collection procedures for tracking such deals only in 1989. Hence my sample includes alliances over the period 1990–2002. Due to inadequate corporate reporting requirements on alliances, the SDC data does not include all deals consummated by US firms over this period. However, since this database is the most comprehensive source of information on such deals, it is ideal for empirical analysis.

The sample includes strategic alliances and joint ventures involving two US firms in four hi-tech industries: Drugs (SIC 2833-2836), Telecom Equipment (SIC 3663-3669), Semi-conductors (SIC 3671-3679) and Surgical Equipment (3841-3845). Since the coverage for US firms is more comprehensive than non-US firms, I restrict my analysis to US based alliances only. Among the strategic alliances, only those deals which involved two partners are used. This is to ensure that the empirical tests were close to the setup studied in the theory.

Furthermore, the sample includes only those strategic alliances and joint ventures for which both partner firms are found in the NBER patent database. This is because the explanatory variables

[12] Refer Anand and Khanna (2000) for a detailed description of alliance and joint venture deals in the SDC Platinum database.

are constructed from the NBER patents data for both the firms.

### 6.2 Proxy for Access

I use licenses to technologies in strategic alliances and other additional features in licenses such as worldwide or exclusive license to construct proxies for access.[13] To construct a proxy for access which does not involve change in ownership, I include strategic alliances but exclude joint ventures.

An alliance in which a license is provided to any technology indicates greater access than an alliance where no such license is provided. A license to a technology is a good proxy for access since such a license is always accompanied by a transfer of knowledge from the licensor to the licensee. Take for example, MedImmune Inc.'s strategic alliance with Ixsys Inc[14]. In return for funding from MedImmune, Ixsys was required to perform research in optimizing specific antibodies (provided by MedImmune) using its proprietary expertise in optimizing protein therapeutic candidates. In order for Ixsys to undertake the research, MedImmune granted a license to Ixsys to the antibody technology. The alliance agreement required MedImmune to provide access to the antibody and other knowledge as illustrated by the following section from the licensing agreement:

> "2.4 ... MEDIMMUNE shall provide IXSYS any information and data which the parties mutually agree is reasonably necessary for IXSYS to conduct the [research] PROGRAM. Additionally ... MEDIMMUNE shall provide IXSYS, at MEDIMMUNE's sole cost, with such technical assistance as IXSYS reasonably requests regarding the use of such assay under the PROGRAM."

The SDC data also provides information about whether the license in a strategic alliance is an exclusive license or a non-exclusive one, and whether the licence is a worldwide license or not. I supplemented this information with the information provided in the alliance synopsis. This is because the SDC fields on exclusive/ worldwide licenses often understated these features.

Table 3 shows the distribution of strategic alliances involving a license and those not involving licenses for the original SDC Platinum dataset and the merged SDC-NBER dataset. This table

[13] While the theory presented above assumes reciprocal access, a license is a proxy for one-way access from the licensor to the licensee. This, however, is not a concern since the assumption of reciprocal access is innocuous and so the result in Proposition 5.2 also holds for one way access.

[14] MedImmune Inc is a large biotechnology company with nearly $1 billion revenues in the year 2002. Ixsys Inc. is now Applied Molecular Evolution Inc. and had revenue of $5.5 billion in 2002. Ixsys and MedImmune undertook this alliance in February 1999.

shows that in the original SDC data, the percentage of licenses is 45% while it is 43% in the merged dataset. However, there is substantial variation in the percentage of licenses across different years and across industries. Hence, to test the hypotheses, I control for biases resulting from this merged sample by including calendar year and industry fixed effects.

Table 4 presents the distribution of licenses based on their exclusivity and on the geographical restrictions on these licenses.

### 6.3 Proxy for ownership

I use strategic alliances and joint ventures together to construct a proxy for ownership. To ensure that the test for ownership is unaffected by changes in access, I use only those joint ventures and strategic alliances in which no license is involved.[15]

I only include those joint ventures where one partner owns more than 50% equity in the joint venture company. Thus, 50:50 joint ventures are excluded from the analysis. Since a majority owner would be expected to exercise the residual rights of control, including only those JVs involving a majority owner ensures that the empirical analysis corresponds closely to Grossman and Hart (1986)'s definition of ownership.

### 6.4 Measures for ease of replicating knowledge

I use the breadth of patent portfolios as the main proxy for ease of replicating knowledge. The reasoning behind this proxy is as follows. If a firm has broad technological knowledge, then it would be able to steal its partner's knowledge more easily. This breadth of technological knowledge would be reflected in the breadth of its patent portfolio. Since more patents indicate a larger base of knowledge and hence a greater ability to replicate, the number of patents is also employed as a proxy.

These patent based measures were constructed for each deal. For both firm in a deal, the first task was to match the firm name in the SDC database with the names of all subsidiaries/divisions belonging to the same Corporate family in the NBER patent database. For each firm in the SDC database, the corporate family was constructed by referring to the 1990 issue of S&P's Directory of

[15] I could have used those alliances and joint ventures involving a license being provided. However, the SDC data includes very few joint ventures involving a license.

Corporate Affiliations. After matching the firms, the patent portfolio was computed by including the patents of all the subsidiaries/ divisions in the Corporate Family of the firm. This was to take account of the fact that firms record patents under various subsidiaries and divisions.

### 6.4.1 Breadth of patent portfolios

The patent portfolios for the partner firms are drawn from the NBER Patent Database [Hall, Jaffe and Trajtenberg(2001)]. Since patents are an output of R&D and are a good representation of the stock of technological knowledge in firms, they are a suitable way to measure characteristics of the knowledge. Patent data include citations which can be used to construct breadth measures for these patent portfolios.[16]

As in Trajtenberg, Jaffe and Henderson (1997), I measure the breadth of a patent as a Herfendahl Index measure using patent citations. If a patent represents a broad body of knowledge, then citations to that patent would span many industry classes. On the other hand, if a patent represents a narrow body of knowledge, then its citations would be restricted to a specific industry. Thus breadth of a patent $i$, $bp_i$, is measured as

$$bp_i = 1 - \sum_{j}^{36} s_{ij}^2 \tag{10}$$

where $s_{ij}$ denotes the percentage of citations received by patent $i$ that belong to industry category $j$. The breadth of a firm's portfolio of patents, $Pat\_Breadth_1$, is the sum of the breadth measure of its individual patents. Thus if the firm has N patents

$$Pat\_Breadth_1 = \sum_{i=1}^{N} bp_i = \sum_{i=1}^{N} \left( 1 - \sum_{j}^{36} s_{ij}^2 \right) \tag{11}$$

The breadth of patent portfolio is also calculated using the number of patents across different

[16] One of the problems with patent data is that not all innovations are patentable. Also, other mechanisms like secrecy and lead time may be relied upon rather than patenting to capture returns from innovation. Hence, patent portfolios of firms are likely to be an underestimate of their technological knowledge. However, this under-estimation of the stock of knowledge is unlikely to lead to any systematic bias in the breadth measures across different firms.

industry categories. This measure, $Pat\_Breadth_2$, is defined as

$$Pat\_Breadth_2 = 1 - \sum_{j}^{36} \left(\frac{n_j}{N}\right)^2$$

#### 6.4.2 Number of patents

I also use log of the number of patents of the licensee as a proxy for ease of replicating knowledge. This is because more patents indicates a larger base of knowledge and hence a greater ability to replicate other's knowledge.

Panel B in Table 2 shows the correlation between patent protection, patent breadth as measured using citations on patents (Pat_Breadth1), patent breadth as measured using the number of patents across different industries (Pat_Breadth2), and the logarithm of the number of patents (Log Patents). While the three measures of patent breadth are positively correlated, their correlation is not perfect and can, thus, be employed as separate explanatory variables.

### 6.5 Test for Access

Part (a) of proposition 5.2 predicts that access decreases as knowledge of both firms becomes easier to replicate. The basic formulation to test this hypothesis is

$$Prob\left(License_k = 1\right) = b_0 + b_1 \cdot \theta_i + b_2 \cdot \theta_j + BX + \in_k \tag{12}$$

where $k = 1, \ldots, N$ are strategic alliances in hi-tech industries from 1990-2002. $License_k = 1$ if a license was provided by a partner in the alliance while $License_k = 0$ if there was no license provided. $\theta_i$ and $\theta_j$ are proxies for replicability of firms $i$ and $j$ in alliance $k$ while $X$ is a set of control variables.

Part (a) of proposition 5.2 states that

$$Hypothesis : b_1 < 0, b_2 < 0 \tag{13}$$

To ensure robustness of the results to different specifications of access, I also examine the likelihood of an exclusive license and the likelihood of a worldwide license within the sample of licenses. Thus I test by replacing $Prob(License_k = 1)$ with $Prob(Exclusive\_License_k = 1)$ and $Prob(Worldwide\_License_k = 1)$ in the above specification (equation (12)). Similarly, to ensure robustness of the results to different specifications of ease of stealing, $Pat\_Breadth_1$, $Pat\_Breadth_2$ and $log(number\_of\_patents)$ are all used.

### 6.6 Test for Ownership

Part (a) of proposition 5.2 predicts that access decreases as knowledge of both firms becomes easier to replicate. The basic formulation to test this hypothesis is

$$Prob\left(JV_k = 1\right) = b_0 + b_1 \cdot \theta_i + b_2 \cdot \theta_j + BX + \in_k \tag{14}$$

where $k = 1, \ldots, N$ are strategic alliances in hi-tech industries from 1990-2002. $License_k = 1$ if a license was provided by a partner in the alliance while $License_k = 0$ if there was no license provided. $\theta_i$ and $\theta_j$ are proxies for replicability of firms $i$ and $j$ in alliance $k$ while $X$ is a set of control variables.

Part (a) of proposition 5.2 states that

$$Hypothesis : b_1 > 0, b_2 < 0 \tag{15}$$

To ensure robustness of the results to different specifications of ease of stealing, $Pat\_Breadth_1$, $Pat\_Breadth_2$ and $log(number\_of\_patents)$ are all used.

### 6.7 Control Variables

Since licenses are the outcome analyzed, I control for other factors which affect the likelihood of a license.

The likelihood of a license will be affected by the proximity in the primary industries of the alliance partners. A license could be one method for two partners in the same industry to collude and enhance their competitive position relative to other firms in the industry. The effect could be reversed too: two firms in the same industry may be wary of providing a license to the other for fear of jeopardizing their competitive positions. Therefore, I include a dummy variable to capture whether the alliance partners have the same primary SIC code at the n-digit level (n=2,3,4).

*Industry fixed effects* are included in the regressions to account for unobserved factors which may drive licensing in specific industries. For example, whether the dominant technology in the industry is discrete or complex (Cohen, Nelson and Walsh (1996)) affects licensing in that industry. When the technology is discrete, licensing is easier since intellectual property can be specified clearly. In contrast, when the technology is complex, delineating intellectual property can be difficult. Furthermore, with complex technologies, no single firm owns all the component technologies and hence cross licensing may be quite prevalent. Furthermore, industries which are more R&D intensive or rely more on intangible assets may be expected to rely more on licensing technologies compared to others. Also, the degree of competitiveness in an industry could also influence licensing through motivations for collusion. Finally, including industry fixed effects would account for bias in coefficients resulting from sample selection. This is necessary since there is substantial difference across industries between the distribution of licenses in the original SDC sample and its distribution in the merged SDC-NBER sample.

*Calendar year effects* are also included in the regressions. Even though the OLS regressions treat the sample as a pooled cross-section, the samples across years may not be independent. Dependence in samples across years could result because the same firms may be involved in alliances across different years. Furthermore, unobserved calendar effects like the appearance of a breakthrough technology or differences in number of patents across years may impact licensing in a particular year. Also, including calendar fixed effects would account for bias in coefficients resulting from sample selection. This is necessary since there is substantial difference across years between the distribution of licenses in the original SDC sample and its distribution in the merged SDC-NBER sample.

Finally, *firm fixed effects* are also included in the regressions to account for unobserved heterogeneity at the individual firm level. For example, if a particular firm has greater ability to successfully litigate infringements on its licenses, such a firm will license more even if its technology is easy to replicate. Including firm-fixed effects corresponding to the *licensor* provides evidence on the variation in access depending upon the nature of knowledge of a firm's licensees.

Logit specification is used to test equation (12) since the fixed effects logit estimator is consistent while the fixed effects estimator is problematic in probit regressions (Wooldridge (2002)).

## 6.8 Empirical Results

### 6.8.1 Access

Table 6 presents the results from logit regression for the likelihood of a license among all strategic alliances in the merged SDC-NBER sample. Across all specifications in this table, the coefficient of breadth of patent portfolio is negative for both firms. These coefficients are all statistically significant from zero at the 95% level of confidence. The effect of patent breadth is *economically significant* too: a one standard deviation increase in $Pat\_Breadth_1$ from its median value decreases the probability of a license by 23% while a two standard deviation increase decreases the probability by 38%. Since 43% of the strategic alliances in the merged SDC-NBER sample involve licenses, these changes are economically large.

Specifications (2) and (3) show that the basic result does not change when using $Pat\_Breadth_2$ or Log Patents as the primary explanatory variable (see Table 2 for a description of the variables). Specifications (4) - (7) add the log of the firm size[17] to account for sample selection based on firm size. (5) adds calendar year dummies, (6) includes firm fixed effects while (7) includes both calendar year and firm dummies. The basic result remains robust to all these specifications.

Specifications (6) and (7) provide strong evidence in support of the hypotheses since they include firm fixed effects and industry fixed effects as well. They thus take into account omitted variables at the firm level and also any relevant omitted variables at the level of the industry.

To ensure that the results are robust to other ways of measuring access, I test the hypothesis using the sample of licenses from the SDC-NBER data. Table 7 shows that an exclusive license is likelier than a non-exclusive one when both firms have a narrower patent portfolio. Table 8 similarly shows that a worldwide license is likelier compared to a license which is restricted to specific geographies when both the firms have a narrower patent portfolio. Even though this sample is a more selective one (it excludes those licenses on which there is no information about geographical restrictions), it is reassuring to find the result similar to the ones in Tables 6 and 7.

[17] The maximum of the size of the two firms is used since the selection effect would be more pronounced for the larger firms.

#### 6.8.2 Ownership

Table 9 presents the results from logit regression for the likelihood of a joint venture versus a strategic alliance in the merged SDC-NBER sample. Across all specifications in this table, the coefficient of breadth of patent portfolio is positive for firm 1 and negative for firm 2. These coefficients are all statistically significant from zero at the 95% level of confidence. The effect of patent breadth is *economically significant* too: a one standard deviation increase in $Pat\_Breadth_1$ from its median value decreases the probability of a JV by 7% while a two standard deviation increase decreases the probability by 12%. Since 25% of the deals involving no licenses are joint ventures strategic alliances in the merged SDC-NBER sample involve licenses, these changes are economically large.

#### 6.8.3 Other Robustness checks: selection biases, errors in variables

There are, mainly, two kinds of biases that may result from the analysis of the above sample.

Firstly, the sample includes only those deals in which there exists a match in the NBER patents database for both the firms. In the process, about 70% of the strategic alliances in hi-tech industries during the period 1990-2002 had to be discarded for want of a match in the NBER patents database. The main source of bias when using this merged sample could be the following. The NBER patent database contains firms which have at least one patent. So the merging process is likely to discard firms having no patents. Given my proxy for ease of replicating knowledge, the excluded deals represent cases where the (potential) licensee has low ability to replicate the licensor's technology. Since sample selection based on an exogenous explanatory variable does not lead to a bias (Wooldridge (2002)), the merged NBER-SDC sample does not lead to bias in the estimates of $b_1$ and $b_2$.

The second source of selection bias originates from the data in SDC Platinum not being comprehensive. The deals in SDC may include more the ones done by large firms than those by small firms. Furthermore, larger firms have more patents and hence their patent portfolios could be broader. Also, licenses provided in strategic alliances may be reported better for larger firms than smaller firms. This correlation of size with both the independent and dependent variable could result in bias in the coefficients. In order to account for the bias, I include the log size of the firms in the alliance in the regressions. The basic result, however, remains robust to including log of size.

# 7 Discussion

## 7.1 Success or failure of Mergers/ Acquisitions in Knowledge Intensive Industries

We saw in Proposition 1 that access affects the incetives of both firms symmetrically while ownership affects their incentives asymmetrically. This difference in the incentive effects of access and ownership has important consequences for the outcome of mergers/ acquisitions in knowledge intensive industries. Given the asymmetric effect of ownership on incentives, the incentives of the acquired firm get dampened in an acquisition. This is particularly the case when big established firms such as AOL acquire startups such as Netscape Communications. Incentives in startup firms are high-powered; employees working in these startups exhibit a revealed preference for such high-powered incentives. However, big established incumbents cannot replicate such high-powered incentives when the startup becomes a division of the large firm [Gertner, Scharfstein, Stein (1994), Amador and Landier (2003)]. When such employees face the likelihood of working in an environment where their incentives are not high powered, they may leave as happened in the case of the AOL-Netscape acquisition. *Without the important employees of the acquired firm, the acquirer is left without access to the crucial knowledge.* Such acquisitions may be doomed to fail because, as the theory shows, both access to knowledge and ownership over knowledge are required to provide optimal incentives for investment in knowledge assets. Therefore, when potential acquirers cannot alleviate the reduction in incentives of the target's employees due to transfer of ownership, it is optimal for the two firms to provide access to each other's knowledge through an alliance or joint venture. This is because access through an alliance or a joint venture has a symmetric effect on the firms' incentives while a change in ownership due to a merger/ acquisition has an asymmetric effect on incentives. In contrast, when the acquirer can retain the key employees of the acquired firm by providing them strong incentives, and thus mitigate the asymmetric effect of ownership, then a merger/ acquisition dominates other alternatives since maximum access can be achieved through a merger/ acquisition. This was the case when Intel acquiring Level-One.

## 7.2 Implications of Intellectual Property Regulation on Firm Boundaries

The results in this paper can be used to understand the impact of legislation that change the protection provided to intellectual property. Two pieces of regulation are pertinent – the World Trade Organization (WTO)'s agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) and the Cooperative Research and Technology Enhancement Act (CREATE) act passed by the US Senate in June 2004.

The TRIPS agreement stipulates that, starting January 2005, developing countries must implement product patents on drugs. Since this enhances the protection provided to US drug companies on their drug products, their local collaborators would find it more difficult to replicate the US companies' knowledge. Thus, we can expect US drug companies to provide more access to their knowledge to local pharmaceutical companies through cross-country research ventures and alliances.

The CREATE act is intended to promote research among universities, the public sector, and private enterprise by allowing a patent application to be approved if it involves collaborators from more than one organization. In the past, prior work by one of the partners in a joint research program could be used as prior art to deny a patent for discoveries made under the joint research program. The CREATE act removes such obstacles for collaborative research. In the framework of this paper, the CREATE act enhances protection to intellectual property generated through collaborative research by allowing them to be patented. As a result, firms (and research institutions) would be expected to provide more access to their knowledge through research alliances and joint ventures.

The ease with which knowledge can be replicated can be a function of various other characteristics of the knowledge. For example, the nature of Intellectual Property protection and appropriability prevailing in the industry would affect the ability to steal the knowledge. When the patent protection accorded in an industry is very tight (as in drugs and chemicals), then knowledge is difficult to steal. Hence the optimal level of access provided to knowledge would be high. In industries where the level of patent protection is low (as in semiconductors), knowledge is easy to steal and hence the optimal level of access provided would be quite low. Similarly, when the firms involved in the relationship have very broad knowledge (diversified firms for example) or have more resources to devote to learning (larger firms for example), stealing is easier and hence the optimal level of access is lower.

## 8 Conclusion

This paper modeled knowledge intensive firms as a collection of the knowledge assets that it *owns* and the agents who have complete *access* to such assets. Following this, boundary decisions between two knowledge intensive firms were modeled using ownership of knowledge and access to knowledge. This enabled us to model simultaneously the trade-offs that knowledge intensive firms confront when deciding among mergers/acquisitions, joint ventures, alliances, and arm's length contracts. The theory showed that *both* the firms can be provided *first best* incentives by choosing ownership of knowledge and access to knowledge together; neither ownership nor access can accomplish the same individually. Modeling firms using access and ownership together also enabled to model the separation between ownership and control in an incomplete contract setting.

In order to focus on the incentive effects of the boundary decisions, this paper did not model explicitly the specific control rights that firms in an alliance or a joint venture choose. The benefit of such an approach was that it delivered clear insights about how the boundary decision between two knowledge intensive firms can resolve the problems of over- and under-investment by both firms. However, this approach left out the interaction between the boundary decisions and the control rights given a particular boundary choice. This limitation prevents this paper from addressing some interesting questions. For example, do these two sets of tools – boundary decisions and control rights given that boundary choice – substitute or complement each other? If they substitute or complement, then in what ways? Related to these is the question of how the boundary decision and the explicit financing contract influence each other. These are potential areas for future research.

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# 9 Appendix A – Robustness Checks

## A.1 Changing the Bargaining Model

In this Appendix, I show that the problem of over-investment and under-investment by both A and B would exist even in if the Bargaining model for deciding the split of surplus at $t = 2$ is changed. Then, I proceed to argue that the analysis in the paper would remain unaltered in this case.

As an alternative model of bargaining, I use the alternating-offers protocol of Rubinstein (1982) that is employed by De Meza and Lockwood (1998) to question the generality of the Grossman-Hart-Moore results on ownership. As specified in Section **??**, the bargaining for the surplus $R$ occurs at $t = 2$ after the contract has been signed at $t = 0$ and after the investments are already sunk by both the scientist and the financier.

Bargaining occurs over multiple rounds $k = 1, 2, \ldots$. At the beginning of the first round, either A or B is selected to be the proposer with probability 0.5. If the proposer is agent $i$, he proposes a split $x_i$ so that A gets $x_i$, while B gets $R - x_i$. After agent i proposes, the responder $j \neq i$ has three choices. First, $j$ can accept the proposal in which case the bargaining game ends. Second, $j$ can reject the proposal in which case both agents get zero over that round and bargaining proceeds to the next round where $j$ gets to make a proposal. Third, $j$ could choose to terminate the bargaining process, in which case both $A$ and $B$ are obliged to pursue their own opportunities individually. In this case, $A$ and $B$ get their outside options $r^A$ and $r^B$ respectively. I allow only the responders to terminate the bargaining process since this ensures uniqueness of the solution to this bargaining game. Finally, the discount factor for both agents is $\tau < 1$.

The realized payoffs to A and B in equilibrium depend upon whether their outside options bind or they are slack. The realized payoffs to A and B, $v^A$ and $v^B$, respectively are as follows:

$$\left(v^A, v^B\right) = \begin{cases} (0.5R, 0.5R) & \text{if} \quad r^A \leq 0.5R \text{ and } r^B \leq 0.5R \\ \left(R - r^B, r^B\right) & \text{if} \quad r^A > 0.5R \text{ and } r^B \leq 0.5R \\ \left(r^A, R - r^A\right) & \text{if} \quad r^A \leq 0.5R \text{ and } r^B > 0.5R \end{cases}$$

Given ex ante uncertainty about the returns from investment and the respective outside options, the expected payoff for each agent is the expectation of the payoff over the above three scenarios. To account for this uncertainty, say that the ex ante probability (i.e. probability at $t = 0$) that the outside option of the scientist is binding (i.e. $r^A > 0.5R$) is $p^A$. Similarly, say that the ex ante probability that the outside option of the financier is binding (i.e. $r^B > 0.5R$) is $p^B$. Then, the probability that neither agent's outside option is binding is $1 - p^A - p^B$. Therefore the expected payoff of the scientist is

$$\begin{aligned} TS^A &= \left(1 - p^A - p^B\right) \cdot \frac{R}{2} + p^A\left(R - r^B\right) + p^B r^A \\ &= \left(1 + p^A - p^B\right) \cdot \frac{R}{2} - p^A r^B + p^B r^A \end{aligned}$$

where the expectation is taken at $t = 1$ when the scientist decides the level of investment to make. Similarly, the expected payoff to the financier is

$$TS^B = \left(1 - p^A + p^B\right) \cdot \frac{R}{2} + p^A r^B - p^B r^A$$

Given these payoffs, the second-best investment levels $e^{A*}$ and $e^{B*}$ are given by the following first order conditions

$$\begin{aligned} \left(1 + p^A - p^B\right) \cdot \frac{R_A\left(e^{A*}, e^{B*}\right)}{2} + p^B \cdot r_A^A\left(e^{A*}\right) &= 1 \\ \left(1 - p^A + p^B\right) \cdot \frac{R_B\left(e^{A*}, e^{B*}\right)}{2} + p^A \cdot r_B^B\left(e^{B*}\right) &= 1 \end{aligned}$$

Comparing the above first order conditions to the those for the first-best level of investments, we can see that agent $i, i \in A, B$ strictly over-invests when $r_i^i > \left(\frac{1-p_s+p_B}{2p_B}\right) R_i$, while the agent weakly under-invests when $r_i^i \leq \left(\frac{1-p_s+p_B}{2p_B}\right) R_i$. Therefore, we get the problem of over-investment and under-investment as in the case of the 50:50 Nash bargaining solution.

The intuition for the generality of the results is the following. The over-investment and the under-investment result from the difference in the marginal values of the outside option and that of the surplus produced in the relationship. For the bargaining game used here, the no trade payoffs $\mathrm{r}^A$ and $\mathrm{r}^B$ do not affect the equilibrium payoffs over a certain range of the levels of the outside options. However, what is important for the analysis here is that the no-trade payoffs sometimes matter, not that they always matter. Therefore, with some amount of *ex ante* uncertainty about the investment returns (i.e. surplus R and the no-trade payoffs), the no-trade payoffs will affect the equilibrium division of surplus with positive probabilities. Therefore, the analysis under alternative-offers bargaining is similar to the axiomatic 50:50 Nash bargaining.

## A.2 Multi-tasking in investments

Here, I show that the results derived in the theory are unaltered if we allowed for multi-tasking in the investments. Since the additional notation makes the exposition very messy without providing any additional intuition, this part is presented as a separate appendix.

Define the output generated in the relationship $R$ as a separable function: $R \equiv R^A + R^B$. Note that the separability here is in line with the separable technology assumed in the main model.

Say, $i^A$ and $i^B$ denote investments by A and B to develop the idea; $e^B$ denotes investments by B to understand the scientist's idea while $e^A$ denotes investments by A to understand how to use the financier's assets. The joint output generated by each agent is affected by his investments to develop the idea and by his investments to understand how to use the asset of his partner. Thus $R\left(i^A, i^B, e^A, e^B, \alpha\right) \equiv R^A\left(i^A, e^A, \alpha\right) + R^B\left(i^B, e^B, \alpha\right)$. In contrast, the outside option of each party is affected only by that party's investment to understand the partner's technology. Thus $r^A \equiv r^A\left(e^A, \alpha, \delta\right)$ and $r^B \equiv r^B\left(e^B, \alpha, \delta\right)$.

The technological assumptions remain similar to that in the main model:

$$\begin{aligned}
R_k^j &> 0, R_{kk}^j < 0, R_{k\alpha}^j > 0, \quad j \in \{A, B\}, k \in \{i, e\} \\
r_e^j &> 0, r_{ee}^j < 0, r_{e\alpha}^j > 0, \quad j \in \{A, B\} \\
r_e^A(\delta = 1) &> r_e^A(\delta = 0); r_e^B(\delta = 1) < r_e^B(\delta = 0) \\
r_{e\theta}^B &> 0, r_{e\psi}^A < 0
\end{aligned}$$

The net surplus generated in the relationship is given by

$$TS \equiv R^A\left(i^A, e^A, \alpha\right) + R^B\left(i^B, e^B, \alpha\right) - i^A - e^A - i^B - e^B$$

Therefore, the first order conditions for the first best level of investments, which maximize TS, are given by

$$R_k^j\left(i^{jF}, e^{jF}, \alpha\right) = 1, \quad j \in \{A, B\}, k \in \{i, e\}$$

Using 50:50 Nash bargaining, the individual payoffs are given by

$$\begin{aligned} TS^A &= 0.5R^A\left(i^A, e^A, \alpha\right) + 0.5R^B\left(i^B, e^B, \alpha\right) + 0.5r^A\left(e^A, \alpha\right) - 0.5r^B\left(e^B, \alpha\right) - i^A - e^A \\ TS^B &= 0.5R^A\left(i^A, e^A, \alpha\right) + 0.5R^B\left(i^B, e^B, \alpha\right) + 0.5r^B\left(e^B, \alpha\right) - 0.5r^A\left(e^A, \alpha\right) - i^B - e^B \end{aligned}$$

Therefore, the first order conditions for the second-best level of investments are

$$\begin{aligned} R_i^j\left(i^{j*}, e^{j*}, \alpha\right) &= 2, \quad j \in \{A, B\} \\ R_e^j\left(i^{j*}, e^{j*}, \alpha\right) + r_e^j\left(e^{j*}, \alpha\right) &= 2, \quad j \in \{A, B\} \end{aligned}$$

Now, it can be seen that if $r_e^B > R_e^B$, there is over-investment by the financier in understanding the idea. In other words, the financier invests in replicating the idea and in the process enhance his bargaining power. Similarly, if $r_e^A > R_e^A$, the scientist over-invests in understanding how to use the financier's assets. In other words, the scientist invests in reducing his dependency on the financier's assets and thus enhance his bargaining power.

In sum by examining the first-best and second-best investments, we can see that there is an optimal level of investment by the financier in understanding the scientist's idea so that he could develop the idea. Any additional investment by the financier is essentially to replicate the idea and thus enhance his bargaining power. Similar is the case with the innovator too.

It is easy to check that

$$\begin{aligned} \frac{di^{j*}}{d\alpha} &= -\frac{R_{i\alpha}^j}{R_{ii}^j} > 0, \quad j \in \{A, B\} \\ \frac{de^{j*}}{d\alpha} &= -\frac{R_{e\alpha}^j + r_{e\alpha}^j}{R_{ee}^j + r_{ee}^j} > 0, \quad j \in \{A, B\} \\ e^{A*}(\delta = 0) &< e^{A*}(\delta = 1) \\ e^{B*}(\delta = 0) &> e^{B*}(\delta = 1) \\ \frac{de^{B*}}{d\theta} &= -\frac{r_{e\theta}^B}{R_{ee}^B + r_{ee}^B} > 0, \frac{di^{B*}}{d\theta} = 0 \\ \frac{de^{A*}}{d\psi} &= -\frac{r_{e\psi}^A}{R_{ee}^A + r_{ee}^A} < 0, \frac{di^{A*}}{d\psi} = 0 \end{aligned}$$

$$
\begin{aligned}
TS &= R^A\left(i^{A*}, e^{A*}, \alpha\right) + R^B\left(i^{B*}, e^{B*}, \alpha\right) - i^{A*} - e^{A*} - i^{B*} - e^{B*} \\
\frac{dTS}{d\alpha} &= R^A_\alpha + R^B_\alpha + \left[R^A_i - 1\right]\frac{di^{A*}}{d\alpha} + \left[R^B_i - 1\right]\frac{di^{B*}}{d\alpha} + \left[R^A_e - 1\right]\frac{de^{A*}}{d\alpha} + \left[R^B_e - 1\right]\frac{de^{B*}}{d\alpha} \\
&= \underset{+}{R_\alpha} + \underset{+}{\frac{di^{A*}}{d\alpha}} + \underset{+}{\frac{di^{B*}}{d\alpha}} + \left[\frac{R^A_e - r^A_e}{2}\right]\underset{+}{\frac{de^{A*}}{d\alpha}} + \left[\frac{R^B_e - r^B_e}{2}\right]\underset{+}{\frac{de^{B*}}{d\alpha}}
\end{aligned}
$$

For low $\theta$ and high $\psi$, $r^B_e$ and $r^A_e$ are small. In this case, $\frac{dTS}{d\alpha} > 0 \Rightarrow \alpha^* = 1$. In contrast, if $\theta$ is high and $\psi$ is low, $r^B_e$ and $r^A_e$ are quite large. Then, $\frac{dTS}{d\alpha} < 0 \Rightarrow \alpha^* = 0$. The precise proofs are similar to the ones in the main model.

$$
\frac{dTS}{d\alpha} = \left[R^A_e - 1\right]\underset{+}{\frac{de^{A*}}{d\delta}} + \left[R^B_e - 1\right]\underset{-}{\frac{de^{B*}}{d\delta}}
$$

The rest of the proof to show the asymmetric effect of ownership is similar to the proof in the main model.

# Appendix B – Proofs

## B.1 Feasibility of $R_i \geq r^i_i$ and $R_i < r^i_i \ \forall e^i$

The first order condition for $e^{i*}, i \in A, B$ is given by

$$
-1 + \frac{1}{2}R_i\left(e^{A*}, e^{B*}\right) + \frac{1}{2}r^i_i\left(e^{i*}, \alpha, \delta; \theta^i\right) = 0
$$

Since $R_i > 0, r^i_i > 0, i \in A, B$, it must be true that $0 < R_i < 2 \ \forall e^i, i \in A, B$. Similarly, $0 < r^i_i < 2 \ \forall e^i, \alpha, \delta, \theta^i$.

From $(A1)$, we know that $\lim\limits_{\theta^i \to 0}\left[r^i_i\left(\theta^i\right)\right] = 0 \ \forall e^i, \alpha, \delta$. Hence for the first order condition to be satisfied when $\theta^i \to 0$, it must be true that $R_i\left(e^{A*}, e^{B*}\right) = 2$. Hence when $\theta^i$ is close to zero $r^i_i < R_i \ \forall e^i, \alpha, \delta$. Similarly, from $(A1)$, we know that $\lim\limits_{\theta^i \to \infty}\left[r^i_i\left(\theta\right)\right] = 2 \ \forall e^i, \alpha, \delta$. Hence for the first order condition to be satisfied when $\theta^i \to \infty$, it must be true that $R_i\left(e^{A*}, e^{B*}\right) = 0$. Hence when $\theta^i$ is high $r^i_i > R_i \ \forall e^i, \alpha, \delta$. Since $r^i_i$ increases with $\theta^i$ while $R_i$ does not, $r^i_i - R_i$ is monotonously increasing in $\theta^i$. Hence, there exists at least one $\theta^i$ such that $r^i_i < R_i \ \forall e^i, \alpha, \delta$ and at least another different $\theta^i$ such that $r^i_i < R_i \ \forall e^i, \alpha, \delta$.

## B.2 Proofs of Propositions

LEMMA Consider a function $f \equiv f(x_1, x_2, \lambda)$ where $x_1, x_2, \lambda \in \mathbb{R}^+$ and $\lambda$ is a parameter. Define

$$(x_1^*(\lambda), x_2^*(\lambda)) = \underset{(x_1,x_2)}{\arg\max}\,[f(x_1, x_2, \lambda)]$$

Assume f is smooth, possesses all second order derivatives and $(x_1^*(\lambda), x_2^*(\lambda))$ is an interior solution. If $f_{11} < 0, f_{22} < 0$, and $f_{12} = 0$, then using implicit function theorem it follows that

$$\begin{aligned} \frac{dx_1^*(\lambda)}{d\lambda} &= -\frac{f_{13}}{f_{11}}, \frac{dx_2^*(\lambda)}{d\lambda} = -\frac{f_{23}}{f_{22}} \\ sign\left(\frac{dx_i^*(\lambda)}{d\lambda}\right) &= sign(f_{i3}) \;\; i \in 1, 2 \end{aligned}$$

PROOF Since f is smooth and $(x_1^*(\lambda), x_2^*(\lambda))$ is an interior solution, the first order conditions are

$$f_1((x_1^*(\lambda), x_2^*(\lambda))) = 0 \text{ and } f_2((x_1^*(\lambda), x_2^*(\lambda))) = 0$$

Using implicit function theorem, there is a $(x_1^*(\lambda), x_2^*(\lambda))$ such that

$$\begin{aligned} f_{11}\frac{dx_1^*(\lambda)}{d\lambda} + f_{13} &= 0 \\ f_{22}\frac{dx_2^*(\lambda)}{d\lambda} + f_{23} &= 0 \end{aligned}$$

where we have utilized the fact that $f_{12} = 0$. The results follow from above and from noting that $f_{11} < 0$ and $f_{22} < 0$.

LEMMA 1 Given $\alpha, \delta$, $i \in A, B$ (a) $r_i^i \leq R_i \; \forall e^i \Rightarrow e^{i*} \leq e^{iF}$ and (b) $r_i^i > R_i \; \forall e^i \Rightarrow e^{i*} > e^{iF}$.

PROOF The first best investments $(e^{AF}, e^{BF})$ are given by the first order conditions (4)

$$\begin{aligned} R_A(e^{AF}, e^{BF}) &= 1 \qquad (16) \\ R_B(e^{AF}, e^{BF}) &= 1 \end{aligned}$$

while the second best investments $\left(e^{A*}, e^{B*}\right)$ are given by the first order conditions (5)

$$\begin{aligned} \frac{1}{2} R_A\left(e^{A*}, e^{B*}\right)+\frac{1}{2} r_A^A\left(e^{A*}, \alpha, \delta ; \theta^A\right) &= 1 \\ \frac{1}{2} R_B\left(e^{A*}, e^{B*}\right)+\frac{1}{2} r_B^B\left(e^{B*}, \alpha, \delta ; \theta^B\right) &= 1 \end{aligned} \tag{17}$$

Define

$$f\left(x_1, x_2, \lambda\right)=(1-\lambda) R\left(x_1, x_2\right)+\lambda r^A\left(x_1, \alpha, \delta ; \theta^A\right)+\lambda r^B\left(x_2, \alpha, \delta ; \theta^B\right)-1$$

Then it follows that $\left(e^{AF}, e^{BF}\right)=\left(x_1^*(0), x_2^*(0)\right)$ while $\left(e^{A*}, e^{B*}\right)=\left(x_1^*(0.5), x_2^*(0.5)\right)$. Note that $f_{11}<0, f_{22}<0$ and $f_{12}=0$ are satisfied in this case. Further,

$$f_{13}=r_A^A-R_A \text{ and } f_{23}=r_B^B-R_B$$

The results then follow by applying the Lemma.

Lemma 2

$$\begin{aligned} (a) \frac{de^{A*}}{d\alpha} &= \frac{de^{B*}}{d\alpha}>0 \ \forall \alpha, \delta, \theta^A, \theta^B \\ (b)\ e^{A*}(\delta=1) &> e^{A*}(\delta=0) \ \forall \alpha, \theta^A \\ e^{B*}(\delta=1) &< e^{B*}(\delta=0) \ \forall \alpha, \theta^B \end{aligned}$$

Proof (a) Define

$$f\left(x_1, x_2, \alpha\right)=\frac{1}{2} R\left(x_1, x_2\right)+\frac{1}{2} r^A\left(x_1, \alpha, .\right)+\frac{1}{2} r^B\left(x_2, \alpha, .\right)-1$$

Then $\left(e^{A*}(\alpha), e^{B*}(\alpha)\right)=\left(x_1^*(\alpha), x_2^*(\alpha)\right)$. Note that $f_{11}<0, f_{22}<0$ and $f_{12}=0$ are satisfied in this case. Also $f_{13}=R_{A\alpha}+r_{A\alpha}^A>0 \ \forall \alpha, \delta, \theta^A, \theta^B$ and $f_{23}=R_{B\alpha}+r_{B\alpha}^B>0 \ \forall \alpha, \delta, \theta^A, \theta^B$. Further note that using symmetry assumption $(T7)$, it follows that $f_{11}=f_{22}$ and $f_{13}=f_{23}$. Using Lemma, (a) follows.

(b) The first order condition for $\left(e^{A*}(\delta), e^{B*}(\delta)\right), \delta \in \{0,1\}$ are given by

$$\begin{aligned}
\frac{1}{2}R_A\left[e^{A*}(\delta), e^{B*}(\delta)\right] + \frac{1}{2}r_A^A\left[e^{A*}(\delta), \alpha; \delta\right] &= 1 \\
\frac{1}{2}R_B\left[e^{A*}(\delta), e^{B*}(\delta)\right] + \frac{1}{2}r_B^B\left[e^{B*}(\delta), \alpha; \delta\right] &= 1
\end{aligned}$$

Now define

$$\begin{aligned}
f(x_1, x_2, \lambda) &= \frac{1}{2}R(x_1, x_2) + \frac{\lambda}{2}\left[r^A(x_1, \delta = 1) + r^B(x_2, \delta = 1)\right] \\
&\quad + \frac{1-\lambda}{2}\left[r^A(x_1, \delta = 0) + r^B(x_2, \delta = 0)\right] - 1
\end{aligned}$$

Then $\left(e^{A*}(\delta = 1), e^{B*}(\delta = 1)\right) = (x_1^*(1), x_2^*(1))$ while $\left(e^{A*}(\delta = 0), e^{B*}(\delta = 0)\right) = (x_1^*(0), x_2^*(0))$. Note that $f_{11} < 0, f_{22} < 0$ and $f_{12} = 0$. Also $f_{13} = r_A^A(., \delta = 1) - r_A^A(., \delta = 0) > 0\ \forall \alpha, \theta^A$ using $(T6)$. Similarly, $f_{23} = r_B^B(., \delta = 1) - r_B^B(., \delta = 0) < 0\ \forall \alpha, \theta^B$ using $(T6)$. It follows using Lemma that $\frac{dx_1^*(\lambda)}{d\lambda} > 0$ while $\frac{dx_2^*(\lambda)}{d\lambda} < 0$. Therefore, $e^{A*}(\delta = 1) > e^{A*}(\delta = 0)\ \forall \alpha, \theta^A$ and $e^{B*}(\delta = 1) < e^{B*}(\delta = 0)\ \forall \alpha, \theta^B$.

Lemma 3 Given $\alpha, \delta$, there exists $\widehat{\theta^i}$ such that (a) $\theta^i \leq \widehat{\theta^i} \Rightarrow e^{i*} \leq e^{iF}$ and $\theta^i > \widehat{\theta^i} \Rightarrow e^{*i} > e^{iF}$,

$i \in A, B$

Proof Given $\alpha, \delta$ chosen at $t = 0$, we know from section A.1 that there exists a $\theta^i$ ,$i \in \{A, B\}$ such that both $R_i > r_i^i \forall e^i$ and another $\theta^i$ such that $R_i > r_i^i \forall e^i$.

Since $r_i^i$ increases with $\theta^i$ while $R_i$ is not affected by $\theta^i$ ,$i \in \{A, B\}$, we can define $\widehat{\theta^i}$ such that $r_i^i\left(\widehat{\theta^i}\right) = R_i$.

Then, using Proposition **??** we get $\theta^i < \widehat{\theta^i} \Leftrightarrow r_i^i < R_i \forall e^i \Rightarrow e^{i*} < e^{iF}$ and $\theta^i > \widehat{\theta^i} \Leftrightarrow r_i^i > R_i \forall e^i \Rightarrow e^{i*} > e^{iF}$.

Proposition 1 Consider $\left(\theta_A^1, \theta_B^1\right) \neq \left(\theta_A^2, \theta_B^2\right)$.

(a)

$$\theta_A^1 > \theta_A^2 \text{ and } \theta_B^1 > \theta_B^2 \Rightarrow \alpha^*\left(\theta_A^1, \theta_B^1\right) \leq \alpha^*\left(\theta_A^2, \theta_B^2\right)$$

(b)

$$\theta_A^1 > \theta_A^2 \text{ and } \theta_B^1 < \theta_B^2 \Rightarrow \delta^*\left(\theta_A^1, \theta_B^1\right) \leq \delta^*\left(\theta_A^2, \theta_B^2\right)$$

Proof $\alpha^*$ maximizes

$$TS^*\left(\alpha,\theta^A,\theta^B\right)=R\left(e^{A*}(.),e^{B*}(.),\alpha\right)-e^{A*}\left(\alpha,\delta;\theta^A\right)-e^{B*}\left(\alpha,\delta;\theta^B\right)$$

as given by $(6)$. For part (a) of the proof, we drop $\delta$ from the notation since we focus on access, $\alpha$ here.

$$TS^*\left(\alpha,\theta^A,\theta^B\right)=R\left(e^{A*}(.),e^{B*}(.),\alpha\right)-e^{A*}\left(\alpha,\delta;\theta^A\right)-e^{B*}\left(\alpha,\delta;\theta^B\right)$$

$$\begin{aligned}\frac{dTS^*\left(\alpha,\theta^A,\theta^B\right)}{d\alpha} &= R_\alpha\left(e^{A*},e^{B*},\alpha\right)+\left[R_A\left(e^{A*},e^{B*},\alpha\right)-1\right]\frac{de^{A*}}{d\alpha}+\left[R_B\left(e^{A*},e^{B*},\alpha\right)-1\right]\frac{de^{B*}}{d\alpha}\\ &= R_\alpha+\left[1-r_A^A\left(e^{A*},\alpha,\theta^A\right)\right]\frac{de^{A*}}{d\alpha}+\left[1-r_B^B\left(e^{B*},\alpha;\theta^B\right)\right]\frac{de^{B*}}{d\alpha}\\ &= R_\alpha+\left[2-r_A^A\left(e^{A*},\alpha,\theta^A\right)-r_B^B\left(e^{B*},\alpha;\theta^B\right)\right]\frac{de^{B*}}{d\alpha}\end{aligned}$$

using the first order condition for the investment $e^{A*}$ and $e^{B*}$ – (5) and using $\frac{de^{A*}}{d\alpha}=\frac{de^{B*}}{d\alpha}$ from Proposition **??**.

Using $(A1)$, we know that $0\leq r_B^B(.)\leq 2$. Given any value of $\theta^A$, the minimum value of $\frac{dTS^*}{d\alpha}$ is achieved when $r_B^B(.)=2$. Since $0\leq r_A^A(.)\leq 2$, this minimum of $\frac{dTS^*}{d\alpha}$ given some $\theta^A$ is negative. Similarly, given $\theta^A$, the maximum of $\frac{dTS^*}{d\alpha}$ is achieved when $r_B^B(.)=0$. Since $0\leq r_A^A(.)\leq 2$, this maximum of $\frac{dTS^*}{d\alpha}$ given some $\theta^A$ is positive. Since $r_B^B(.)$ decreases monotonously in $\theta^B$, there exist $\theta^B$ such that $\frac{dTS^*}{d\alpha}=0$.

Also

$$\begin{aligned}\frac{d^2TS^*}{d\alpha^2} &= \frac{d}{d\alpha}\left[\frac{dTS^*}{d\alpha}\right]=\frac{\delta}{\delta e^{A*}}\left[\frac{dTS^*}{d\alpha}\right]\frac{de^{A*}}{d\alpha}+\frac{\delta}{\delta e^{B*}}\left[\frac{dTS^*}{d\alpha}\right]\frac{de^{B*}}{d\alpha}+\frac{\delta}{\delta\alpha}\left[\frac{dTS^*}{d\alpha}\right]\\ &= \left(R_{AA}\frac{de^{A*}}{d\alpha}+R_{A\alpha}\right)\frac{de^{A*}}{d\alpha}+\left(R_{BB}\frac{de^{B*}}{d\alpha}+R_{B\alpha}\right)\frac{de^{B*}}{d\alpha}+R_{\alpha\alpha}+R_{A\alpha}\frac{de^{A*}}{d\alpha}+R_{B\alpha}\frac{de^{B*}}{d\alpha}\\ &= R_{\alpha\alpha}+2R_{A\alpha}\frac{de^{A*}}{d\alpha}+2R_{B\alpha}\frac{de^{B*}}{d\alpha}+R_{AA}\left(\frac{de^{A*}}{d\alpha}\right)^2+R_{BB}\left(\frac{de^{B*}}{d\alpha}\right)^2\\ &= R_{\alpha\alpha}+4R_{e\alpha}\frac{de^*}{d\alpha}+2R_{ee}\left(\frac{de^*}{d\alpha}\right)^2 \text{ using symmetry assumption }(T7)\\ &= R_{\alpha\alpha}+2\frac{de^*}{d\alpha}\left[2R_{e\alpha}+R_{ee}\frac{de^*}{d\alpha}\right]=R_{\alpha\alpha}+2\frac{de^*}{d\alpha}\left[2R_{e\alpha}-R_{ee}\frac{R_{e\alpha}+r_{e\alpha}}{R_{ee}+r_{ee}}\right]\\ &= R_{\alpha\alpha}+2\frac{de^*}{d\alpha}\left[\frac{R_{ee}R_{e\alpha}+2R_{e\alpha}r_{ee}-R_{ee}r_{e\alpha}}{R_{ee}+r_{ee}}\right]<0 \text{ using assumption }(A2)\end{aligned}$$

$$\Rightarrow \frac{d^2TS^*}{d\alpha^2} < 0$$

Hence there exist interior solutions for $\alpha$.

The first order condition for an interior solution for $\alpha$ as

$$\frac{dTS^*\left(\alpha,\theta^A,\theta^B\right)}{d\alpha} = 0 \tag{18}$$

$$\begin{aligned}\frac{d^2TS^*}{d\alpha d\theta^B} &= \frac{d}{d\theta^B}\left[\frac{dTS^*}{d\alpha}\right] = \frac{\delta}{\delta e^{A*}}\left[\frac{dTS^*}{d\alpha}\right]\frac{de^{A*}}{d\theta^B} + \frac{\delta}{\delta e^{B*}}\left[\frac{dTS^*}{d\alpha}\right]\frac{de^{B*}}{d\theta^B} + \frac{\delta}{\delta\theta^B}\left[\frac{dTS^*}{d\alpha}\right] \\ &= R_{BB}\frac{de^{B*}}{d\alpha}\frac{de^{B*}}{d\theta^B}\end{aligned}$$

since the first and third terms are zero.

Using the first order condition for $e^{B*}$ and differentiating wrt $\theta^B$, we can derive that $\frac{de^{B*}}{d\theta^B} = -\frac{r^B_{B\theta}}{R_{BB}+r^B_{BB}} > 0$. Since $R_{BB} < 0$ and $\frac{de^*_B}{d\alpha} > 0$, it follows that

$$\frac{d^2TS^*}{d\alpha d\theta^B} < 0 \tag{19}$$

. Similarly, following identical steps to above, we can show that

$$\frac{d^2TS^*}{d\alpha d\theta^A} < 0 \tag{20}$$

$$\frac{dTS\left(\alpha,\theta^1_A,\theta^1_B\right)}{d\alpha} - \frac{dTS\left(\alpha,\theta^2_A,\theta^2_B\right)}{d\alpha} = \frac{d^2TS}{d\alpha d\theta^A}\left(\theta^1_A - \theta^2_A\right) + \frac{d^2TS}{d\alpha d\theta^B}\left(\theta^1_B - \theta^2_B\right)$$

Since $\frac{d^2TS^*}{d\alpha d\theta^A} < 0$ and $\frac{d^2TS^*}{d\alpha d\theta^B} < 0$, it follows that $\theta^1_A > \theta^2_A$ and $\theta^1_B > \theta^2_B \Rightarrow$

$$\frac{dTS\left(\alpha,\theta^1_A,\theta^1_B\right)}{d\alpha} < \frac{dTS\left(\alpha,\theta^2_A,\theta^2_B\right)}{d\alpha}\ \forall\alpha$$

Therefore,

$$\frac{dTS\left(\alpha^*\left(\theta^1_A,\theta^1_B\right),\theta^1_A,\theta^1_B\right)}{d\alpha} < \frac{dTS\left(\alpha^*\left(\theta^1_A,\theta^1_B\right),\theta^2_A,\theta^2_B\right)}{d\alpha}$$

Now $\frac{dTS\left(\alpha^*\left(\theta_A^1,\theta_B^1\right),\theta_A^1,\theta_B^1\right)}{d\alpha} = \frac{dTS\left(\alpha^*\left(\theta_A^2,\theta_B^2\right),\theta_A^2,\theta_B^2\right)}{d\alpha} = 0$. So

$$\frac{dTS\left(\alpha^*\left(\theta_A^2,\theta_B^2\right),\theta_A^2,\theta_B^2\right)}{d\alpha} < \frac{dTS\left(\alpha^*\left(\theta_A^1,\theta_B^1\right),\theta_A^2,\theta_B^2\right)}{d\alpha}$$

Since $\frac{d^2TS}{d\alpha^2} < 0$, it follows that $\alpha^*\left(\theta_A^2,\theta_B^2\right) > \alpha^*\left(\theta_A^1,\theta_B^1\right)$. Since the boundary solutions $\alpha^* = 0$ and $\alpha^* = 1$ also exist (proof available on request), it follows that $\alpha^*\left(\theta_A^2,\theta_B^2\right) \geq \alpha^*\left(\theta_A^1,\theta_B^1\right)$.

For part (b) of the proof, I treat $\delta$ as a continuous variable even though it is discrete. The proof is similar for $\delta$ being discrete and is available from the author on request.

$$\frac{dTS^*\left(\delta,\theta^A,\theta^B\right)}{d\delta} = \left[R_A\left(e^{A*},e^{B*}\right)-1\right]\frac{de^{A*}}{d\delta} + \left[R_B\left(e^{A*},e^{B*}\right)-1\right]\frac{de^{B*}}{d\delta}$$

$$\begin{aligned}\frac{d^2TS^*}{d\delta^2} &= \frac{d}{d\delta}\left[\frac{dTS^*}{d\delta}\right] = \frac{\delta}{\delta e^{A*}}\left[\frac{dTS^*}{d\delta}\right]\frac{de^{A*}}{d\delta} + \frac{\delta}{\delta e^{B*}}\left[\frac{dTS^*}{d\delta}\right]\frac{de^{B*}}{d\delta} + \frac{\delta}{\delta\delta}\left[\frac{dTS^*}{d\delta}\right] \\ &= R_{AA}\left(\frac{de^{A*}}{d\delta}\right)^2 + R_{BB}\left(\frac{de^{B*}}{d\delta}\right)^2 < 0 \text{ since } R_{AA} = R_{BB} < 0\end{aligned}$$

$$\begin{aligned}\frac{d^2TS^*}{d\delta d\theta^B} &= \frac{d}{d\theta^B}\left[\frac{dTS^*}{d\delta}\right] = \frac{\delta}{\delta e^{A*}}\left[\frac{dTS^*}{d\delta}\right]\frac{de^{A*}}{d\theta^B} + \frac{\delta}{\delta e^{B*}}\left[\frac{dTS^*}{d\delta}\right]\frac{de^{B*}}{d\theta^B} + \frac{\delta}{\delta\theta^B}\left[\frac{dTS^*}{d\delta}\right] \\ &= R_{BB}\frac{de^{B*}}{d\delta}\frac{de^{B*}}{d\theta^B} > 0 \text{ since } R_{BB} < 0, \frac{de^{B*}}{d\delta} < 0, \frac{de^{B*}}{d\theta^B} > 0\end{aligned}$$

$$\begin{aligned}\frac{d^2TS^*}{d\delta d\theta^A} &= \frac{d}{d\theta^A}\left[\frac{dTS^*}{d\delta}\right] = \frac{\delta}{\delta e^{A*}}\left[\frac{dTS^*}{d\delta}\right]\frac{de^{A*}}{d\theta^A} + \frac{\delta}{\delta e^{B*}}\left[\frac{dTS^*}{d\delta}\right]\frac{de^{B*}}{d\theta^A} + \frac{\delta}{\delta\theta^A}\left[\frac{dTS^*}{d\delta}\right] \\ &= R_{AA}\frac{de^{A*}}{d\delta}\frac{de^{A*}}{d\theta^A} < 0 \text{ since } R_{AA} < 0, \frac{de^{A*}}{d\delta} > 0, \frac{de^{A*}}{d\theta^A} > 0\end{aligned}$$

Now

$$\frac{dTS\left(\delta,\theta_A^1,\theta_B^1\right)}{d\delta} - \frac{dTS\left(\delta,\theta_A^2,\theta_B^2\right)}{d\delta} = \frac{d^2TS}{d\delta d\theta^A}\left(\theta_A^1-\theta_A^2\right) + \frac{d^2TS}{d\delta d\theta^B}\left(\theta_B^1-\theta_B^2\right)$$

Since $\frac{d^2TS^*}{d\delta d\theta^A} < 0$ and $\frac{d^2TS^*}{d\delta d\theta^B} > 0$, it follows that $\theta_A^1 > \theta_A^2$ and $\theta_B^1 < \theta_B^2 \Rightarrow$

$$\frac{dTS\left(\delta,\theta_A^1,\theta_B^1\right)}{d\delta} < \frac{dTS\left(\delta,\theta_A^2,\theta_B^2\right)}{d\delta}\ \forall\delta$$

Therefore,

$$\frac{dTS\left(\delta^*\left(\theta_A^1,\theta_B^1\right),\theta_A^1,\theta_B^1\right)}{d\delta} < \frac{dTS\left(\delta^*\left(\theta_A^1,\theta_B^1\right),\theta_A^2,\theta_B^2\right)}{d\delta}$$

Now $\frac{dTS\left(\delta^*\left(\theta_A^1,\theta_B^1\right),\theta_A^1,\theta_B^1\right)}{d\delta} = \frac{dTS\left(\delta^*\left(\theta_A^2,\theta_B^2\right),\theta_A^2,\theta_B^2\right)}{d\delta} = 0$. So

$$\frac{dTS\left(\delta^*\left(\theta_A^2,\theta_B^2\right),\theta_A^2,\theta_B^2\right)}{d\delta} < \frac{dTS\left(\delta^*\left(\theta_A^1,\theta_B^1\right),\theta_A^2,\theta_B^2\right)}{d\delta}$$

Since $\frac{d^2TS}{d\delta^2} < 0$, it follows that $\delta^*\left(\theta_A^2,\theta_B^2\right) > \delta^*\left(\theta_A^1,\theta_B^1\right)$. Noting that $\delta$ is discrete, it follows $\delta^*\left(\theta_A^2,\theta_B^2\right) \geq \delta^*\left(\theta_A^1,\theta_B^1\right)$.

COROLLARY There exist $\underline{\theta^i}$, $\overline{\theta^i} \geq \underline{\theta^i}, i \in A, B$ such that if

$$\begin{aligned}
(a)\ \theta^A &> \overline{\theta^A} \text{ and } \theta^B > \overline{\theta^B} \Rightarrow \alpha^* = 0\ \forall\delta \\
(b)\ \theta^A &\leq \underline{\theta^A} \text{ and } \theta^B \leq \underline{\theta^B} \Rightarrow \alpha^* = 1\ \forall\delta \\
(c)\ \theta^A &\leq \underline{\theta^A} \text{ and } \theta^B > \overline{\theta^B} \Rightarrow \delta^* = 1\ \forall\alpha \\
(d)\ \theta^A &> \overline{\theta^A} \text{ and } \theta^B \leq \underline{\theta^B} \Rightarrow \delta^* = 0\ \forall\alpha
\end{aligned}$$

PROOF

$$\begin{aligned}
\frac{dTS^*}{d\alpha} &= \left\{R_A\left(e^{A*},e^{B*},\alpha\right)-1\right\}\frac{de^{A*}}{d\alpha} + \left\{R_B\left(e^{A*},e^{B*},\alpha\right)-1\right\}\frac{de^{B*}}{d\alpha} \qquad (21)\\
&= \left[1-r_A^A\left(e^{A*},\alpha;\theta^A\right)\right]\frac{de^{A*}}{d\alpha} + \left[1-r_B^B\left(e^{B*},\alpha;\theta^B\right)\right]\frac{de^{B*}}{d\alpha}
\end{aligned}$$

Note that $\frac{de^{A*}}{d\alpha} = \frac{de^{B*}}{d\alpha} > 0$ from Proposition **??**.

Define $\overline{\theta^A} = \max_{\alpha,\delta}\left[\theta^A : r_A^A\left(e^{A*},\alpha;\theta^A\right)=1\right]$ and $\underline{\theta^A} = \min_{\alpha,\delta}\left[\theta^A : r_A^A\left(e^{A*},\alpha;\theta^A\right)=1\right]$. Since $r_{A\theta}^A > 0, \theta^A > \overline{\theta^A} \Rightarrow r_A^A > 1\ \forall\alpha,\delta$ while $\theta^A < \underline{\theta^A} \Rightarrow r_A^A < 1\ \forall\alpha,\delta$. Similarly define $\overline{\theta^B} = \max_{\alpha,\delta}\left[\theta^B : r_B^B\left(e^{B*},\alpha;\theta^B\right)=1\right]$ and $\underline{\theta^B} = \min_{\alpha,\delta}\left[\theta^B : r_B^B\left(e^{B*},\alpha;\theta^B\right)=1\right]$. Since $r_{B\theta}^B > 0, \theta^B < \underline{\theta^B} \Rightarrow r_B^B < 1\ \forall\alpha,\delta$ while $\theta^B > \overline{\theta^B} \Rightarrow r_B^B > 1\ \forall\alpha,\delta$.

By applying mean value theorem, we have

$$
\begin{aligned}
& TS^*(\alpha,\delta=1) - TS^*(\alpha,\delta=0) \qquad (22)\\
= \; & \left[R_A\left(e^{Ac},e^{Bc}\right)-1\right]\left\{e^{A*}(1)-e^{A*}(0)\right\}+\left[R_B\left(e^{Sc},e^{Fc}\right)-1\right]\left\{e^{B*}(1)-e^{B*}(0)\right\}
\end{aligned}
$$

where

$$\left(e^{Ac},e^{Bc}\right)=\lambda\cdot\left(e^{A*}(1),e^{B*}(1)\right)+(1-\lambda)\cdot\left(e^{A*}(0),e^{B*}(0)\right),0<\lambda<1$$

Case 1: $\theta^A > \overline{\theta^A}$ and $\theta^B > \overline{\theta^B}$

We use equation $(21)$. In this case, $(R_A - 1) < 0$ (overinvestment by A) $\forall e^A, \alpha, \delta$ and $(R_B - 1) < 0$ (overinvestment by B) $\forall e^B, \alpha, \delta$ . Hence

$$\frac{dTS^*}{d\alpha} < 0 \; \forall \alpha, \delta \Rightarrow \alpha^* = 0 \; \forall \delta$$

Case 2 : $\theta^A \le \underline{\theta^A}$ and $\theta^B \le \underline{\theta^B}$

We use equation $(21)$. In this case, $(R_A - 1) > 0$ (underinvestment by A) $\forall e^A, \alpha, \delta$ and $(R_B - 1) > 0$ (underinvestment by B) $\forall e^B, \alpha, \delta$ . Hence

$$\frac{dTS^*}{d\alpha} > 0 \; \forall \alpha, \delta \Rightarrow \alpha^* = 1 \; \forall \delta$$

Case 3 : $\theta^A \le \underline{\theta^A}$ and $\theta^B > \overline{\theta^B}$

We use equation (22) first. In this case, $(R_A - 1) > 0$ (underinvestment by A) $\forall e^A, \alpha, \delta$ and $(R_B - 1) < 0$ (overinvestment by B) $\forall e^B, \alpha, \delta$. Therefore, using $e^{B*}(1) < e^{B*}(0)$ and $e^{A*}(1) > e^{A*}(0)$, we get

$$
\begin{aligned}
TS^*(\alpha,\delta=1) \;&>\; TS^*(\alpha,\delta=0) \;\; \forall\alpha \\
\therefore \;&\; \delta^* = 1 \;\; \forall\alpha
\end{aligned}
$$

Case 4 : $\theta^A > \overline{\theta^A}$ and $\theta^B \le \underline{\theta^B}$

We use equation (22) first. In this case, $(R_A - 1) < 0$ (overinvestment by A) $\forall e^A, \alpha, \delta$ and $(R_B - 1) > 0$ (underinvestment by B) $\forall e^B, \alpha, \delta$. Therefore, using $e^{B*}(1) < e^{B*}(0)$ and $e^{A*}(1) >$

$e^{A*}(0)$, we get

$$TS^*(\alpha, \delta = 1) \quad < \quad TS^*(\alpha, \delta = 0) \;\; \forall \alpha$$
$$\therefore \quad \delta^* = 0 \;\; \forall \alpha$$

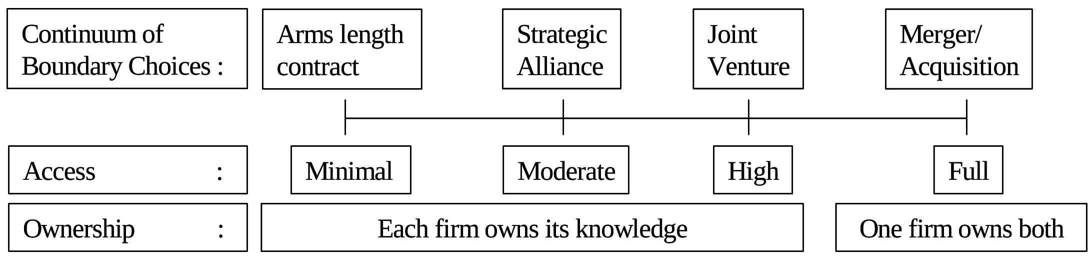


Figure 1: Definition of Boundary Choices

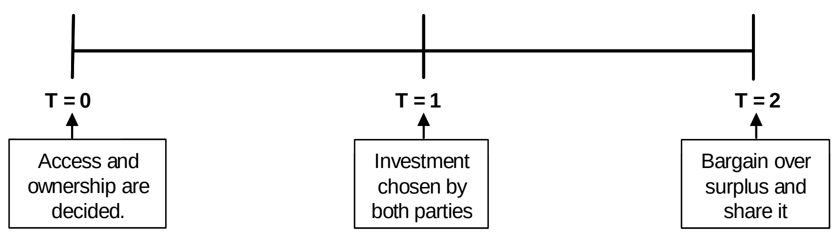


Figure 2: Sequence of events

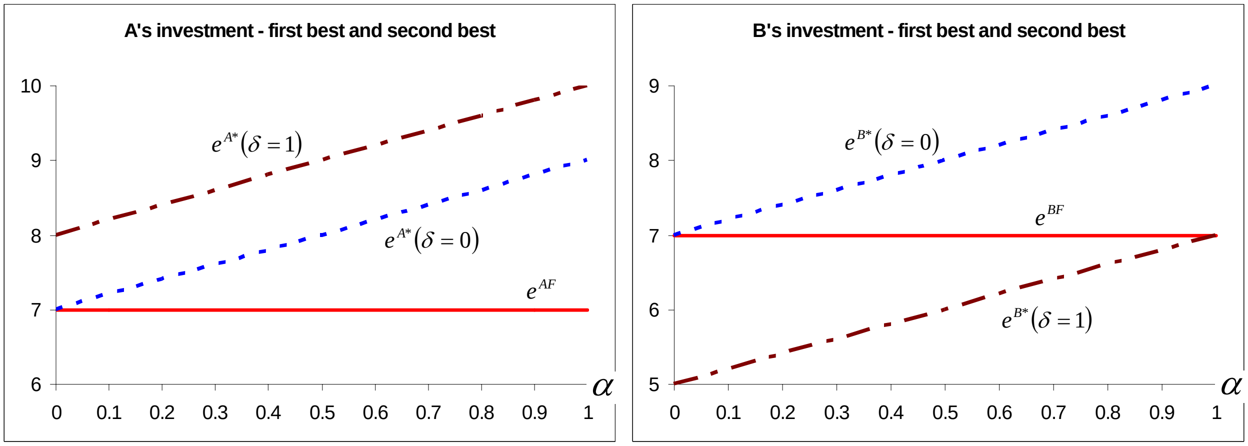


Figure 3: P and Q are very easy to replicate $\left(\theta^A = \theta^B = 1\right)$

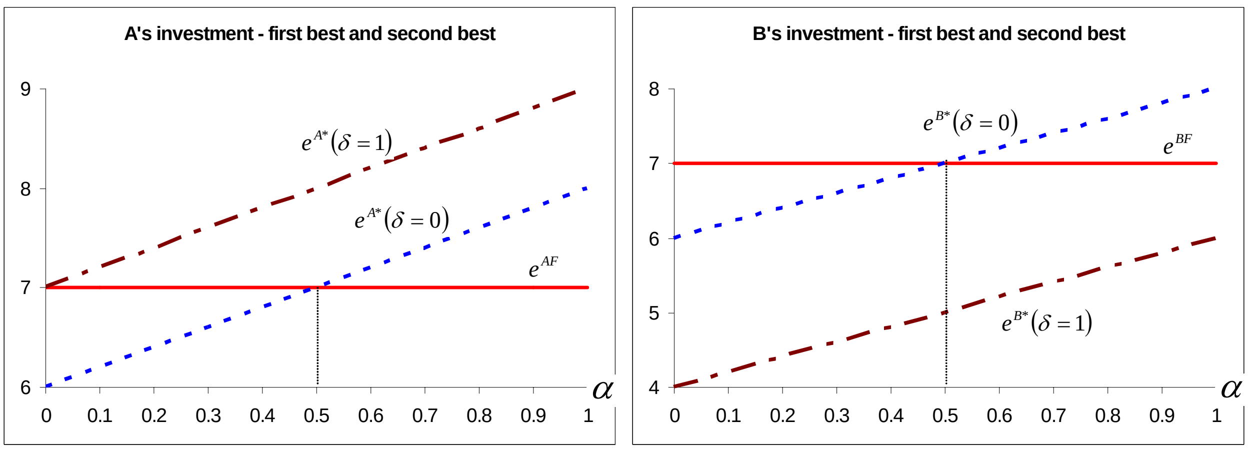


Figure 4: P and Q are moderately easy to replicate $\left(\theta^A = \theta^B = \frac{2}{3}\right)$

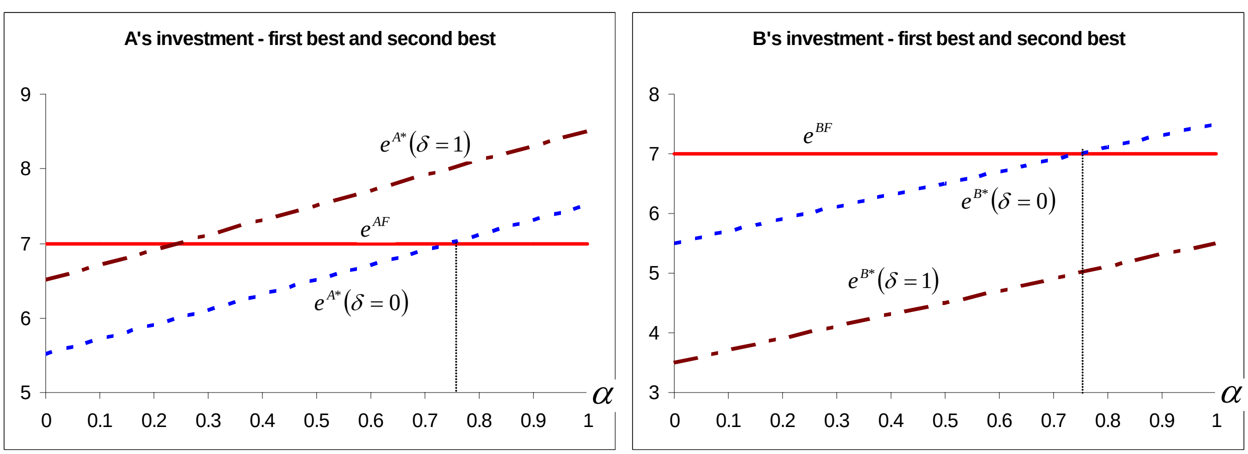


Figure 5: P and Q are moderately difficult to replicate $\left(\theta^A = \theta^B = \frac{1}{2}\right)$

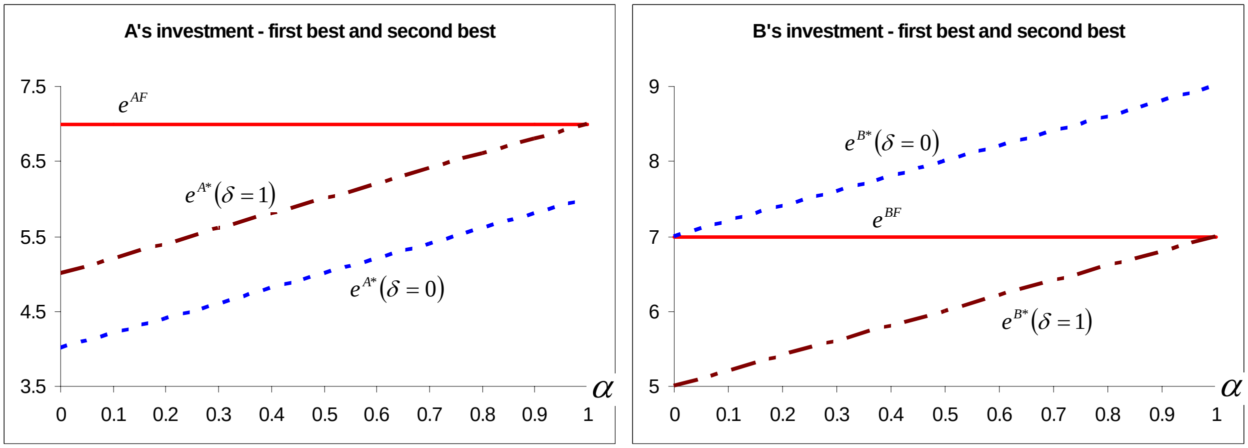


Figure 6: P is easy to replicate $(\theta^B = 1)$ while Q is difficult to replicate $(\theta^B = 0)$

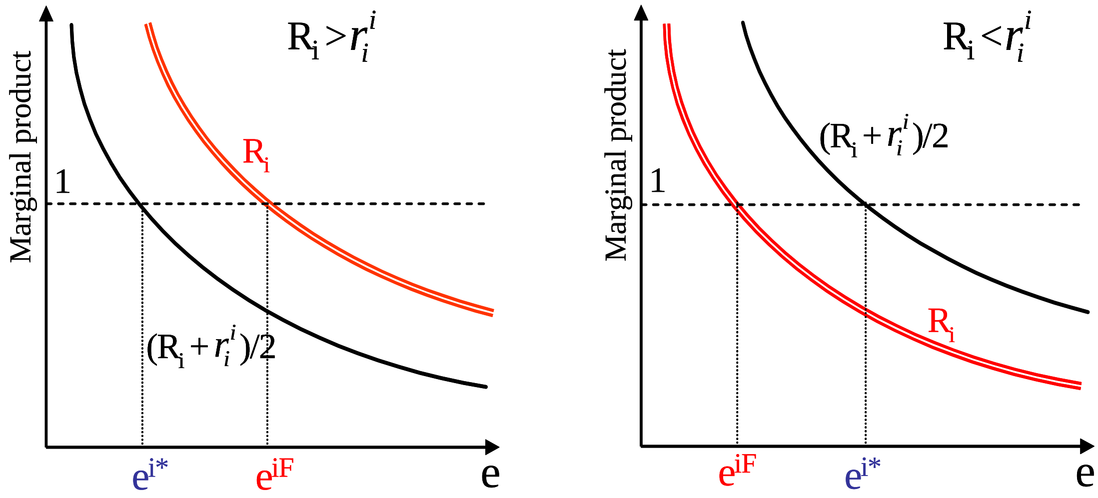


Figure 7: Under and over investment

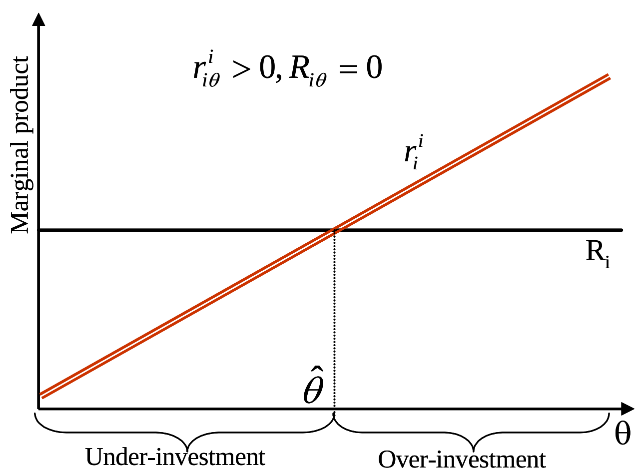


Figure 8: Effect of ease of stealing knowledge on investment

Table 1: Summary of Notation used in the Theory

**Variables:**

| Symbol | Description | Domain |
|---|---|---|
| $\alpha$ | Reciprocal access provided by A and B – A provides B access to his knowledge P while B provides A the same degree of access to his knowledge Q | $\alpha \in [0, 1]$ |
| $\delta$ | Ownership of the Knowledge Assets | $\delta = 0$ if P and Q owned by A and B respectively<br>$\delta = 1$ if A owns both P and Q |
| $e^i, i \in A, B$ | Specific investment by $i$, $i \in A, B$ | $e^A, e^B \in \mathbb{R}^+$ |
| $\theta^i, i \in A, B$ | Agent i's ability to replicate the knowledge that he gets access to | $\theta^i \in \mathbb{R}^+$ |

**Functions:**

| Symbol | Description | Technology |
|---|---|---|
| $R$ | Joint Output | $R_i > 0, R_{ii} < 0, R_{i\alpha} > 0$, $i \in A, B; R_{SC} = 0$ |
| $r^i, i \in A, B$ | Outside option of i | $r^i_i > 0, r^i_{ii} < 0, r^i_{i\alpha} > 0, r^i_{i\theta} > 0$ |

Table 2: Description of Variables used in the Empirical Analysis along with the correlations

Panel A of this table describes the construction of the explanatory variables used for empirical analysis. In Panel B, the correlations between these explanatory variables are shown.

Panel A: Description of Variables and their definition

| Variable | Description | Definition |
|---|---|---|
| N | Total number of patents | Total patents of all subsidiaries and divisions. This includes patents issued till the year before which the alliance was initiated. |
| Pat_Breadth1 | Breadth of Patent portfolio using citations to patents | Pat_Breadth1 $= \sum_{i=1}^{N} b_i, b_i = 1 - \sum_{j=1}^{36} s_{ij}^2$, s$_{ij}$ is percentage of citations for patent i in industry category j |
| Pat_Breadth2 | Breadth of Patent portfolio using patents | Pat_Breadth2 $= 1 - \sum_{j=1}^{36} \left(\frac{n_j}{N}\right)^2$, $n_j$ is number of patents in industry category j |
| Log Patents | Logarithm of number of patents | Log Patents=ln(N) |
| Patent Protection | Survey measures (from Cockburn and Grilliches (1987)) for Strength of Patent Protection in the Industry | = 11.4 if Primary SIC code of Alliance in 2833-2836, 8.37 if it is in 3841-3845, 6.5 if it is in 3663-69 or 3671-79 |
| Log Firm Size | Logarithm of size of firms | Log Firm Size = ln(Total Assets) |
| Partners in same SIC | Do alliance partners have identical primary SIC codes at the 2 digit, 3 digit or 4 digit level. | Partners in same SIC flag = n-1 if primary SIC codes of both firms is same to n-digits $\forall n = 2, 3, 4;$ = 0 otherwise |
| Drugs | Dummy variable for alliance's primary industry being Drugs and Biotechnology | = 1 if Primary SIC code of alliance in 2833-2836; =0 otherwise |
| Surgical Equipment | Dummy variable for alliance's primary industry being Surgical Equipment | = 1 if Primary SIC code of alliance in 3841-3845; =0 otherwise |
| Semiconductors | Dummy variable for alliance's primary industry being Semiconductors | = 1 if Primary SIC code of alliance in 3671-3679; =0 otherwise |

Panel B: Correlation between primary explanatory variables

| | Pat_Breadth1 | Pat_Breadth2 | Log Patents |
|---|---|---|---|
| Pat_Breadth2 | 0.224 | | |
| Log Patents | 0.451 | 0.651 | |
| Patent Protection | -0.107 | -0.051 | -0.192 |

Table 3: Distribution of Licenses by Year and Industry

This table shows the distribution of strategic alliances in the original SDC Platinum database and in the sample resulting after merging the deals in the SDC Platinum database with patent data from the NBER Patents database. The merged sample includes those deals in the SDC Platinum database in which both the firms had a match in the NBER Patent database. Panel A shows the distribution of licenses across different years while Panel B shows the same by industry. See Table 2 for classification of industry based on SIC codes.

Panel A: Distribution of Licenses by Year

All Deals in SDC Platinum

| | '90 | '91 | '92 | '93 | '94 | '95 | '96 | '97 | '98 | '99 | '00 | '01 | '02 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| License | 16 | 26 | 113 | 132 | 180 | 142 | 88 | 120 | 87 | 38 | 4 | 9 | 11 | 966 |
| No License | 15 | 51 | 199 | 168 | 183 | 90 | 70 | 97 | 75 | 92 | 55 | 43 | 46 | 1184 |
| % License | 52% | 34% | 36% | 44% | 50% | 61% | 56% | 55% | 54% | 29% | 7% | 17% | 19% | 45% |

Deals merged with NBER patent data

| | '90 | '91 | '92 | '93 | '94 | '95 | '96 | '97 | '98 | '99 | '00 | '01 | '02 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| License | 3 | 6 | 31 | 36 | 50 | 38 | 27 | 43 | 21 | 6 | 0 | 1 | 0 | 261 |
| No License | 7 | 14 | 77 | 43 | 63 | 31 | 26 | 36 | 19 | 12 | 6 | 3 | 4 | 328 |
| % License | 30% | 30% | 29% | 46% | 44% | 55% | 51% | 54% | 53% | 33% | 0% | 25% | 0% | 43% |

Panel B: Distribution of Licenses by Industry

All Deals in SDC Platinum

| | Drugs | Surg. Eqpt. | Semi-cond. | Telecom Eqpt. | Total |
|---|---|---|---|---|---|
| License | 520 | 105 | 199 | 142 | 966 |
| No License | 416 | 126 | 272 | 370 | 1184 |
| % License | 56% | 45% | 42% | 28% | 45% |

Deals merged with NBER patent data

| | Drugs | Surg. Eqpt. | Semi-cond. | Telecom Eqpt. | Total |
|---|---|---|---|---|---|
| License | 121 | 30 | 68 | 43 | 261 |
| No License | 136 | 35 | 81 | 89 | 328 |
| % License | 30% | 30% | 29% | 46% | 43% |

Table 4: Distribution of licenses by exclusivity and geographical restrictions

This table shows the distribution of licenses in the SDC Platinum – NBER Patents merged database. The merged sample includes those deals in the SDC Platinum database in which the (potential) licensee had a match in the NBER Patent database. This table only shows those strategic alliances in which a license was provided. Panel A shows the exclusive and non-exclusive licenses while Panel B shows the worldwide licenses, licenses restricted to specific geographies and those where no information on such restrictions is provided.

Panel A: Exclusivity

| Type of Licence | Number |
|---|---|
| Non-exclusive | 212 |
| Exclusive | 50 |

Panel B: Geographical Restrictions

| Type of Licence | Number |
|---|---|
| Restricted to specific geographies | 21 |
| No information on restrictions | 201 |
| Worldwide licenses | 40 |

Table 5: Distribution of Alliances and Joint Ventures by Year and Industry

This table shows the distribution of strategic alliances and joint ventures (JVs) in the original SDC Platinum database and in the sample resulting after merging the deals in the SDC Platinum database with patent data from the NBER Patents database. The merged sample includes those deals in the SDC Platinum database in which both the firms had a match in the NBER Patent database. To ensure that the test of ownership is not affected by a change in access, only those JVs and alliances which *do not* involve a license are used. Panel A shows the distribution of the deals across different years while Panel B shows the same by industry. See Table 2 for classification of industry based on SIC codes.

Panel A: Distribution of Licenses by Year

All Deals in SDC Platinum

| | '90 | '91 | '92 | '93 | '94 | '95 | '96 | '97 | '98 | '99 | '00 | '01 | '02 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JVs | 6 | 16 | 33 | 62 | 40 | 42 | 48 | 60 | 37 | 18 | 4 | 9 | 11 | 386 |
| Alliances | 15 | 51 | 199 | 168 | 183 | 90 | 70 | 97 | 75 | 92 | 55 | 43 | 46 | 1184 |

Deals merged with NBER patent data

| | '90 | '91 | '92 | '93 | '94 | '95 | '96 | '97 | '98 | '99 | '00 | '01 | '02 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JVs | 3 | 6 | 11 | 16 | 20 | 18 | 17 | 23 | 11 | 6 | 0 | 1 | 0 | 132 |
| Alliances | 7 | 14 | 77 | 43 | 63 | 31 | 26 | 36 | 19 | 12 | 6 | 3 | 4 | 328 |

Panel B: Distribution of Licenses by Industry

All Deals in SDC Platinum

| | Drugs | Surg. Eqpt. | Semi-cond. | Telecom Eqpt. | Total |
|---|---|---|---|---|---|
| JVs | 140 | 75 | 99 | 72 | 386 |
| Alliances | 416 | 126 | 272 | 370 | 1184 |

Deals merged with NBER patent data

| | Drugs | Surg. Eqpt. | Semi-cond. | Telecom Eqpt. | Total |
|---|---|---|---|---|---|
| JVs | 61 | 10 | 35 | 26 | 132 |
| Alliances | 136 | 35 | 81 | 89 | 328 |

Table 6: Test of Symmetric Effect of Access: Licensing in Strategic Alliances

The sample consists of *strategic alliances* over the period 1990-2002 in the SDC Platinum database in which both the firms had a match in the NBER Patents database. The alliance is in one of four industries: Drugs (SIC 2833-36), Telecom Equipment (SIC 3661-69), Semi-conductors (3671-79) and Surgical Equipment (3841-45). The dependent variable is an indicator variable equal to 1 if, as part of the alliance, a license is provided to a technology; it is equal to 0 if no license is provided. Refer Table 2 for description of explanatory variables. Firm fixed effects for both firms are included in specifications (6) and (7). The F-test probability states the probability that the coefficient of the main explanatory variable is negative for both firms. The heteroskedascticity and autocorrelation robust standard errors reported in parentheses are adjusted for clustering of observations by year. ***, ** and * respectively denote statistical significance at 1%, 5% and 10% levels.

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Pat_Breadth$_1$–firm 1 | -0.99*** | | | -1.18*** | -1.11*** | -1.22*** | -1.13** |
| | (0.30) | | | (0.38) | (0.41) | (0.43) | (0.51) |
| Pat_Breadth$_1$–firm 2 | -0.86*** | | | -0.96*** | -1.32*** | -1.45*** | -1.51*** |
| | (0.28) | | | (0.25) | (0.32) | (0.42) | (0.50) |
| Pat_Breadth$_2$–firm 1 | | -1.19*** | | | | | |
| | | (0.39) | | | | | |
| Pat_Breadth$_2$–firm 1 | | -1.44*** | | | | | |
| | | (0.49) | | | | | |
| Log Patents–firm 1 | | | -1.38** | | | | |
| | | | (0.63) | | | | |
| Log Patents–firm 2 | | | -1.22** | | | | |
| | | | (0.59) | | | | |
| Log Firm Size–firm 1 | | | | -0.06*** | -0.06*** | -0.08 | -0.10 |
| | | | | (0.01) | (0.02) | (0.10) | (0.10) |
| Log Firm Size–firm 2 | | | | -0.19* | -0.06* | -0.28 | -0.08 |
| | | | | (0.11) | (0.04) | (0.20) | (0.09) |
| Patent Protection | 0.15 | 0.18 | 0.05 | | | | |
| | (0.18) | (0.19) | (0.13) | | | | |
| Partners in same SIC | | | | 0.08** | 0.08** | 0.07 | 0.09 |
| | | | | (0.03) | (0.03) | (0.08) | (0.08) |
| F-test probability | 0.00 | 0.01 | 0.04 | 0.01 | 0.01 | 0.00 | 0.01 |
| Year Dummies | No | No | No | No | Yes | No | Yes |
| Industry Dummies | No | No | No | Yes | Yes | Yes | Yes |
| Firm Dummies | No | No | No | No | No | Yes | Yes |
| Psuedo R-sqaured | 6.09% | 5.20% | 4.30% | 5.89% | 7.17% | 8.19% | 9.30% |
| Observations | 603 | 603 | 603 | 603 | 593 | 429 | 421 |

Table 7: Test of Symmetric Effect of Access: Exclusive Licenses in Alliances

The sample consists of strategic alliances in which a *license* was provided. Only those deals from the SDC Platinum database are included in which both the licensor and licensee firm had a match in the NBER Patents database. The license is in one of four industries: Drugs (SIC 2833-36),Telecom Equipment (SIC 3661-69), Semi-conductors (3671-79) and Surgical Equipment (3841-45). The dependent variable is an indicator variable equal to 1 if the license is exclusive and 0 otherwise. Refer Table 2 for description of explanatory variables. The F-test probability states the probability that the coefficient of the main explanatory variable is negative for both firms. The heteroskedascticity and autocorrelation robust standard errors reported in parentheses are adjusted for clustering of observations by year. ***, ** and * respectively denote statistical significance at 1%, 5% and 10% levels.

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $Pat\_Breadth_1$–firm 1 | -0.96*** | | | -0.93*** | -0.95*** |
| | (0.32) | | | (0.28) | (0.33) |
| $Pat\_Breadth_1$–firm 2 | -0.85*** | | | -0.81*** | -0.74*** |
| | (0.28) | | | (0.26) | (0.24) |
| $Pat\_Breadth_2$–firm 1 | | -1.04** | | | |
| | | (0.50) | | | |
| $Pat\_Breadth_2$–firm 2 | | -0.66** | | | |
| | | (0.31) | | | |
| Log Patents–firm 1 | | | -1.32** | | |
| | | | (0.53) | | |
| Log Patents–firm 2 | | | -1.12** | | |
| | | | (0.44) | | |
| Log Firm Size–firm 1 | | | | -0.03 | -0.01 |
| | | | | (0.06) | (0.02) |
| Log Firm Size–firm 2 | | | | -0.07* | -0.04 |
| | | | | (0.04) | (0.07) |
| Patent Protection | 0.12 | 0.08 | 0.05 | | |
| | (0.14) | (0.13) | (0.03) | | |
| Partners in same SIC | | | | 0.08 | 0.08 |
| | | | | (0.07) | (0.09) |
| Year Dummies | No | No | No | No | Yes |
| Industry Dummies | No | No | No | Yes | Yes |
| F-test probability | 0.01 | 0.04 | 0.05 | 0.00 | 0.01 |
| Psuedo R-suqared | 2.39% | 2.67% | 2.59% | 4.31% | 5.78% |
| Observations | 262 | 262 | 262 | 262 | 255 |

Table 8: Test of Symmetric Effect of Access: Worldwide Licenses in Alliances

The sample consists of strategic alliances for which there is information about *geographical restrictions on the license* provided. Only those deals from the SDC Platinum database are included in which both the licensor and licensee firms had a match in the NBER Patents database. Only those deals from the SDC Platinum database are included for which both partner firms are found in the NBER Patents database. The license is in one of four industries: Drugs (SIC 2833-36),Telecom Equipment (SIC 3661-69), Semi-conductors (3671-79) and Surgical Equipment (3841-45). The dependent variable is equal to 1 if the license is a worldwide license while it is equal to 0 if the license is restricted to specific geographies. Licenses in which there is no information provided about the geographical restrictions are excluded from the sample. Refer Table 2 for description of explanatory variables. The F-test probability states the probability that the coefficient of the main explanatory variable is negative for both firms. The heteroskedascticity and autocorrelation robust standard errors reported in parentheses are adjusted for clustering of observations by year. ***, ** and * respectively denote statistical significance at 1%, 5% and 10% levels.

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Pat_Breadth$_1$– firm 1 | -0.71*** | | | -1.00*** | -1.89*** |
| | (0.11) | | | (0.36) | (0.71) |
| Pat_Breadth$_1$– firm 2 | -0.42*** | | | -0.93*** | -1.23** |
| | (0.13) | | | (0.26) | (0.52) |
| Pat_Breadth$_2$– firm 1 | | -1.01*** | | | |
| | | (0.38) | | | |
| Pat_Breadth$_2$– firm 2 | | -0.83** | | | |
| | | (0.41) | | | |
| Log Patents– firm 1 | | | -0.65** | | |
| | | | (0.26) | | |
| Log Patents– firm 2 | | | -0.57** | | |
| | | | (0.26) | | |
| Patent Protection | 0.15 | 0.18 | 0.05 | | |
| | (0.18) | (0.19) | (0.13) | | |
| Log Firm Size–firm 1 | | | | 0.01 | -0.02 |
| | | | | (0.06) | (0.04) |
| Log Firm Size–firm 2 | | | | -0.07 | -0.12 |
| | | | | (0.09) | (0.10) |
| Partners in same SIC | | | | -0.05 | 0.20 |
| | | | | (0.07) | (0.29) |
| Year Dummies | No | No | No | No | Yes |
| Industry Dummies | No | No | No | Yes | Yes |
| F-test probability | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| Pseudo R-squared | 3.17% | 3.04% | 2.89% | 4.78% | 6.07% |
| Observations | 61 | 61 | 61 | 61 | 59 |

Table 9: Asymmetric Effect of Ownership: Alliances and Joint Ventures

The sample consists of *joint ventures* (in which where one partner has majority stake) *and strategic alliances* over the period 1990-2002. Only those deals in which both the firms had a match in the NBER Patents database are used. The alliances and joint ventures are in one of four industries: Drugs (SIC 2833-36), Telecom Equipment (SIC 3661-69), Semi-conductors (3671-79) and Surgical Equipment (3841-45). To ensure that the level of access stays the same across the sample, I choose those joint ventures and alliances which did not involve a license between the two firms. The dependent variable is an indicator variable equal to 1 if the deal is a joint venture; it is equal to 0 if the deal is an alliance. Firm 1 corresponds to the majority stake owner if the deal is a JV; in contrast, if the deal is an alliance, firm 1 corresponds to the firm having a higher measure of patent breadth. Refer Table 2 for description of explanatory variables. Firm fixed effects corresponding to both firms involved in the deal are included in specifications (6) and (7). The F-test probability states the probability that the coefficient of the main explanatory variable is positive for firm 1 and negative for firm 2. The heteroskedascticity and autocorrelation robust standard errors reported in parentheses are adjusted for clustering of observations by year. ***, ** and * respectively denote statistical significance at 1%, 5% and 10% levels.

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Pat_Breadth$_1$–firm 1 | 0.19*** | | | 0.18*** | 0.21*** | 0.32*** | 0.43** |
| | (0.05) | | | (0.08) | (0.05) | (0.07) | (0.07) |
| Pat_Breadth$_1$–firm 2 | -0.26*** | | | -0.16*** | -0.32*** | -0.43*** | -0.42*** |
| | (0.05) | | | (0.07) | (0.11) | (0.08) | (0.10) |
| Pat_Breadth$_2$–firm 1 | | 0.19** | | | | | |
| | | (0.09) | | | | | |
| Pat_Breadth$_2$–firm 1 | | -0.44*** | | | | | |
| | | (0.18) | | | | | |
| Log Patents–firm 1 | | | 0.38*** | | | | |
| | | | (0.13) | | | | |
| Log Patents–firm 2 | | | -0.22** | | | | |
| | | | (0.09) | | | | |
| Log Firm Size–firm 1 | | | | 0.05** | 0.03*** | 0.18 | 0.21 |
| | | | | (0.02) | (0.01) | (0.10) | (0.11) |
| Log Firm Size–firm 2 | | | | -0.15** | -0.03* | -0.31 | -0.11 |
| | | | | (0.05) | (0.02) | (0.35) | (0.19) |
| Partners in same SIC | | | | 0.05* | 0.08** | 0.07 | 0.09 |
| | | | | (0.03) | (0.04) | (0.08) | (0.08) |
| Year Dummies | No | No | No | No | Yes | No | Yes |
| Industry Dummies | No | No | No | Yes | Yes | Yes | Yes |
| Firm Dummies | No | No | No | No | No | Yes | Yes |
| F-test probability | 0.00 | 0.01 | 0.02 | 0.01 | 0.01 | 0.00 | 0.02 |
| Psuedo R-squared | 5.07% | 4.55% | 4.79% | 6.78% | 6.91% | 10.17% | 12.13% |
| Observations | 518 | 518 | 518 | 518 | 461 | 429 | 401 |