Firm Boundaries in the New Economy: Theory and Evidence

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Abstract

This paper develops a theory to highlight the trade-offs that knowledge-intensive firms face when deciding among mergers/acquisitions, joint ventures, alliances, and arms-length contracts.

We contend that since knowledge is non-rival in nature, its owners cannot restrict usage ex-post once they provide access ex-ante. Therefore, unlike physical asset-intensive firms, ownership is not enough to provide optimal incentives in knowledge-intensive firms. Both ownership, which confers the legal right to make residual decisions, and access, which provides the necessary expertise to make such decisions, are necessary to provide optimal incentives in knowledge-intensive firms. To capture the incentive effects of the boundary decisions in knowledge-intensive firms, we model them using access and ownership. Optimally choosing both provides stronger incentives since access and ownership have complementary effects on incentives: increasing access enhances both firms' incentives while providing one firm ownership enhances its incentives but dampens those of the firm losing ownership.

Our theory rationalizes the dominance of alliances and joint ventures as well as the sharing of knowledge assets through contractual arrangements in the knowledge intensive industries. Using a novel dataset, which combines alliances and joint ventures with the NBER patents data, we test and find support for the prediction that access has a symmetric effect on incentives while ownership has an asymmetric effect.

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

In a series of seminal articles and a book, Grossman-Hart-Moore develop the Property Rights Theory to explain firms' decisions to integrate vis-à-vis employ an arms-length contract (Grossman and Hart, 1986; Hart and Moore, 1990; Hart, 1995). Starting from the premise that contracts are incomplete, they define a firm as a collection of nonhuman assets that it *owns.* Therefore, they model integration decisions such as mergers/ acquisitions as *changes* in the ownership of assets. Since mergers/ acquisitions remain the dominant mode of integration in the traditional industries, the Property Rights Theory (hereafter PRT) provides an elegant framework to understand boundary decisions in the traditional industries.

However, organizational and contractual arrangements between firms in the knowledge-intensive industries cannot be explained using the PRT. Over the past two decades, strategic alliances have become an important organizational arrangement, particularly in the knowledge intensive sectors. As the National Science Foundation Science and Technology Indicators (2006) states, "Firms use, *inter alia*, alliances to acquire knowledge... over seventy percent of these are in biotechnology and information technology." Also, as we document in this paper, firms in the knowledge intensive industries share their knowledge assets between each other through contractual arrangements such as licenses, research and development agreements and cross-technology transfer agreements – a feature rarely observed between firms in the traditional industries. However, the PRT cannot rationalize these organizational and contractual arrangements since they do not involve any changes in ownership of assets. Furthermore, since employees cannot be legally owned, they cannot belong to a firm in the framework of the PRT. Since knowledge is unalienable from an employee, we cannot use this theory to distinguish between a firm that has access to important knowledge through its employees and one without it. To illustrate this point, contrast the acquisition of Netscape Communications by AOL with the acquisition of Level One by Intel. As *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, enabling Intel to extend its dominance in chips from personal computers to high-speed connectivity (Chaudhiri and Tabrizi, 1999). The PRT cannot differentiate between these disparate acquisitions since both AOL and Intel acquired ownership rights over their respective target's knowledge assets.

In this paper, we develop a theory to rationalize mergers/ acquisitions, hybrids such as strategic alliances and majority joint ventures, and arms-length contracts in knowledge intensive industries. We also attempt to distinguish between organizational and contractual arrangements in the knowledge intensive industries and those in the traditional industries. Using a novel dataset, we test and find strong support for the theory's main prediction.

We define a knowledge-intensive firm as a collection of the knowledge assets that it *owns* and the agents who have complete *access* to these assets, where access is defined as the ability to use or work with an asset (Rajan and Zingales, 1998, 2001). To understand the need to model knowledge-intensive firms in this way, recall Coase's (1937) argument that in contrast to arms-length transactions, transactions inside firms are organized through power or fiat. In this framework, PRT proposes that ownership confers power over specific assets since the owner can let an agent use the asset ex-ante and yet withdraw access to the asset ex-post. However, since knowledge assets are non-rival in nature, once an agent gets exposed to a knowledge asset such as an idea, the owner cannot withdraw access to it ex-post. Therefore, in environments where Intellectual Property Right (IPR) protection is imperfect,[1] the user can employ the knowledge asset for production despite not owning it, and the owner can prevent the user from doing so only through legal recourse. Thus, the owner's and the user's ex-post power over a knowledge asset is a function of who owns the knowledge asset *and* the level of access provided to it ex-ante.

We analyze a setting where two firms derive synergies from pooling their complementary knowledge assets. To fix ideas, consider two biotechnology firms, Antibody Inc. and Biodelivery Inc. Antibody Inc. (A) specializes in discovering antibodies to cure diseases while Biodelivery Inc. (B) specializes in generating new drug delivery techniques; however neither firm has expertise in the complementary technology to start with. A and B can decide through an *incomplete contract* the level of access that they would provide to each other and the ownership of these technologies. Access enables A to familiarize itself to B's drug delivery technology and to learn how to work with it. However, since knowledge assets are non-rival in nature, access also gives A the opportunity to expropriate B's drug delivery technology. Therefore, we assume that *both* A and B can make two kinds of investments. If A invests to tailor its antibody technology to B's drug delivery technology, such investment enhances the joint output and is socially beneficial. In contrast, if A invests to expropriate B's drug delivery technology, such rent-seeking investment is socially wasteful.[2] As in the PRT, these investments are observable but not verifiable. Higher access enhances the marginal effect of both kinds of investments while ownership only enhances the marginal value of the owner's investments. Finally, if the drug delivery technology is easier to expropriate, then the marginal effect of A's expropriating investment is higher.

Firms decide the optimal boundary choice, which corresponds to the optimal combination of access and ownership, to maximize their joint surplus. In the model, the boundary choices translate into access and ownership as follows. In an arms-length contract and in a strategic alliance, A and B own the antibody and drug delivery technologies respectively. In contrast, if A acquires B or A is the majority partner in a joint venture with B, A owns both the antibody and drug delivery technologies.[3] Access between A and B is full (non-existent) if they decide to undertake a merger/ acquisition (an arms-length contract). Since strategic alliances and joint ventures are

[1] The importance of examining environments where IP protection is imperfect can be motivated using evidence from Cohen, Nelson and Walsh (2000). In their survey across 140 industries, they note that strong protection provided to patents is more an exception in such industries as Chemicals and Drugs & Biotechnology than the norm. In most industries, firms rely on secrecy and the presence of complementary assets to appropriate returns from their investments in knowledge assets.

[2] Note that, in other settings, investments to expropriate knowledge may be ex-post socially beneficial. Here, such investment is wasteful ex-post since it duplicates what another agent already knows.

[3] In the Property Rights framework, joint ownership is always sub-optimal (Hart, 1995). Therefore, we exclude joint ventures in which each firm has an equal stake since analyzing them requires a theory of joint ownership in the incomplete contracting setup. Such a theory is outside the scope of this paper.

more integrated than arms-length contracts but less so compared to a merger/ acquisition, access is moderate in these cases.

We first contrast boundary choices in knowledge-intensive firms from those in physical-asset intensive ones by showing that access is not a choice variable in physical-asset intensive firms since it is *always optimal* to provide full access in such firms. We proceed to show that in knowledge-intensive firms both access and ownership play an important role in providing stronger incentives to both firms. Choosing access and ownership optimally – corresponding to the optimal boundary choice in such firms – serves the dual purpose of providing both firms with stronger incentives to tailor their assets to each other, on the one hand, and dampening their incentives to expropriate each other's knowledge assets, on the other hand. In fact, we illustrate through an example that the optimal boundary choice *may* provide both firms the incentive to make the first-best level of investments.

The central prediction of the model is that access and ownership have contrasting effects on A's and B's incentives. When A and B provide each other more access, they both have stronger incentives to make socially beneficial and socially wasteful investments since the marginal effect of both kinds of investments is higher. Thus, access affects their incentives *symmetrically.* In contrast, if B transfers ownership of its technology to A, B's incentives to make socially beneficial and socially wasteful investments are weakened while those of A are strengthened since the marginal value of A's outside option increases while B's decreases. Thus, ownership affects their incentives *asymmetrically.* Therefore, when both firms underinvest (overinvest), increasing (decreasing) access brings their investments closer to the first-best. In contrast, when B overinvests and A underinvests, transferring ownership of B's drug delivery technology to A brings their investments closer to the first-best. Since B(A) would overinvest more in expropriating A(B)'s knowledge when it is easier to do so, it follows that the optimal level of access decreases as both firms ability to expropriate increases. In contrast, ownership of B's asset should be transferred to A if B can expropriate knowledge easily while A cannot.

Using a novel dataset that combines alliances and joint ventures in high technology industries from SDC Platinum with the NBER patent data (Hall, Jaffe and Trajtenberg, 2001), we test the prediction that access has a symmetric effect on the incentives while ownership has an asymmetric effect. To identify differences in access while keeping ownership unchanged, we compare alliances which include a license, an R&D agreement or a cross-technology transfer to those alliances which do not include these. Since a license, a joint R&D effort or a technology transfer enables a firm to use its alliance partner's assets without owning them, these proxies capture our definition of access as the ability to use or work with an asset. To identify changes in ownership, we combine strategic alliances and majority joint ventures. Since the majority partner exercises residual rights of control, comparing majority joint ventures to alliances identifies changes in ownership. To ensure that we test for changes in ownership without any concomitant changes in access, we examine those alliances and joint ventures in which no license is provided or no R&D agreement is included.

We follow Trajtenberg, Jaffe and Henderson (1992) in using *self-citations* to construct a proxy a firm's ability to expropriate its partner's knowledge asset. Since self-citations reflect follow-up innovation/ knowledge flowing from the knowledge underlying a firm's predecessor patents, the percentage of these self-citations capture a firm's ability to appropriate returns from its knowledge, and in turn, the difficulty faced by its alliance/ JV partner in expropriating this knowledge. Therefore, we define A's ability to expropriate B's knowledge as one minus B's appropriability measured using self-citations (similarly for B). We also employ the breadth of A's patent portfolio and one minus the originality of B's portfolio as other proxies for A's ability to expropriate (similar for B). In our tests, we control for other determinants of our proxies of access and ownership. We also employ specifications where we control for unobserved heterogeneity using firm, industry and year fixed effects. Across all our specifications, we find that a license, R&D agreement and cross-technology transfer become less likely in a strategic alliance when *both* firms' ability to expropriate each other's asset increases. Having controlled for alternative motivations, we interpret this evidence as supporting the symmetric effect of access of incentives. In our tests of the effect of ownership, we find that a majority joint venture becomes more likely than an alliance when one firm's ability to expropriate increases while the other firm's decreases. We interpret this as evidence supporting the asymmetric effect of access on incentives.

Our attempt to rationalize mergers/ acquisitions, majority joint ventures, strategic alliances and arms-length contracts in a single framework helps to bring theory proximate to all the choices that firms in knowledge-intensive industries confront. To our knowledge, this is the first attempt to do so. Our modeling of knowledge intensive firms using both access and ownership enables us to rationalize differences in the nature of organizational and contractual arrangements between knowledge intensive and traditional industries. Relatedly, we highlight that the incentive effects of boundary choices differ substantially between physical-asset intensive and knowledge-intensive firms. Since ownership ensures the exclusive use of physical assets, ownership is a dominant organizational choice variable in physical-asset intensive firms. In contrast, both ownership, which confers the legal right to make residual decisions, and access, which provides the necessary expertise to make such decisions, are necessary to provide optimal incentives in knowledge-intensive firms.

The rest of the paper is organized as follows. In the next section, we characterize the difference in control over knowledge assets vis-à-vis that over physical assets. Section 3 lays out the framework for the theory while Section 4 presents the results from the theory. Section 5 reviews the related literature. Section 6 presents the empirical test of the theory. Section 7 concludes the paper.

2 Ownership of Knowledge Assets

Before describing the formal model, we highlight the difference between ownership of physical assets and that over knowledge assets. To draw this distinction, recall Coase's (1937) theory that, in contrast to arms-length transactions, transactions inside firms are organized through power or fiat. In this framework, Grossman-Hart-Moore (hereafter GHM) define a (*nonhuman* asset intensive) firm as a collection of assets that it owns. In their definition, ownership confers residual rights of control. These residual rights of control provide power since the owner can withdraw access to the (nonhuman) asset after the user of the asset has specialized his human capital to the asset. In other words, the owner of the physical asset can provide full access to the user ex ante, yet can completely withdraw access to that asset ex post. Since the user's specialized human capital is practically useless without the asset, this ability to withdraw access ex-post provides economic content to the owner's residual rights of control. Therefore, ownership suffices to confer power over a physical asset when the user makes asset-specific human capital investments.

Contrast this to the power over knowledge assets, which are *non-rival in nature*. Consider a firm Antibody Inc. (hereafter A), which is a biotechnology firm having expertise in discovering new antibodies for curing diseases. Say A lets another biotechnology firm Biodelivery Inc. (B hereafter) access its antibody technology through a license. Note that A has the expertise in developing antibodies to start with; B does not have this expertise initially. However, upon getting access from A, B can specialize to this antibody technology and acquire the expertise to utilize the antibody technology for production.

Once B has acquired the expertise over A's antibody technology, even if A withdraws the license ex post, B may continue to employ this technology for production. In this scenario, *A can enforce its ownership rights only through legal recourse*, i.e., by taking A to court for infringing on its Intellectual Property Rights (Crampes and Langinier, 2002).[4] This right stemming from ownership of knowledge assets can be illustrated through several anecdotes of litigation and/ or renegotiation following infringement of intellectual property. The most famous example is the 1980's patent suit between Kodak and Polaroid, in which Polaroid was awarded over $1 billion in damages for alleged patent infringement by Kodak on Polaroid's Instant Camera. Kodak was ordered to stop production of its own version of the instant camera and was forced to withdraw from this market. In this example, though Kodak gained access to Polaroid's knowledge through its patents, Polaroid was able to impose its ownership rights by taking Kodak to court.[5] Also in the 1980s, Texas Instruments sued several Japanese and Korean semi-conductor manufacturers for infringing on its patents on the DRAM technology. It simultaneously initiated negotiations about the royalty payments on these patents and was able to increase its royalty payments by ten times (!) in return for withdrawing these patent infringement suits. In this example, Texas Instruments gave access through licensing agreements and imposed its legal rights from ownership by renegotiating under the threat of litigation.

Based on the above discussion, we conclude that there are two essential differences between the control exercised over physical assets and that over knowledge assets. First, the owner of a physical (knowledge) asset can (cannot) withdraw access once it is provided to the asset ex ante. Second, the owner of a physical (knowledge) asset can exercise ownership rights by withdrawing access to

[4] In countries where property rights over physical assets are poorly enforced, owners of physical assets *too* can enforce their ownership rights only through legal recourse. However, in regimes where property rights over physical assets are well enforced, the owner need not have to seek redressal from a court for infringement on its ownership over a physical asset.

[5] The recent patent infringement suit filed by Verizon against Vonage is similar to the Polaroid-Kodak case.

the asset (by seeking legal recourse if his IPR are infringed).

Despite these differences, ownership of knowledge assets is similar to ownership of physical assets since ownership confers the legal right to make residual decisions (similar to GHM). Thus, ownership of a knowledge asset confers on the owner the right to (i) make residual decisions; and (ii) to seek legal recourse if the IPR is infringed.

Given this definition of ownership, if A were to transfer ownership over the antibody technology to B, these legal rights would be transferred. However, the expertise required to utilize this knowledge for production is not immediately transferred. This will have to be acquired by B (over time) by making specialized investments.

3 Model

3.1 Setup, Timing and Events

Consider two biotechnology firms, Antibody Inc. (A) and Biodelivery Inc. (B), and two knowledge assets P and Q. Say P represents the technology required for developing antibodies while Q represents the technology to deliver such antibodies to humans. To start with, A has the expertise in developing antibodies (P) but has no expertise in drug delivery (Q). Similarly, B has the expertise in drug delivery (Q) but has no expertise in developing antibodies (P). Since P and Q are complementary to each other, A and B enter into an economic relationship. Both agents are risk-neutral and neither is liquidity-constrained.

Figure 2 summarizes the timeline and events in the model. There are three dates, $t = 0, 1$ and 2. We now describe the sequence of events in the model.

3.1.1 Access

At date 0, A and B decide to provide access α to each other to benefit from the complementarity in their knowledge assets. Following Rajan and Zingales (1998, 2001), we define access as the opportunity to use, or work with, an asset. *Access is reciprocal*: A provides as much access to its antibody technology as it gets to B's drug delivery technology. To illustrate access, say that A and B enter into an agreement in which the employees in their respective R&D departments meet periodically and share their expertise with each other. Whether or not senior R&D personnel are involved in such meetings, the frequency of such meetings, etc. represent the level of access decided at date 0. $\alpha \in [0, 1]$, where 0 implies that access is non-existent while 1 represents full access.

As in Rajan and Zingales (1998, 2001), access is necessary for the user to learn how to produce using the complementary asset. For example, A's employees have to learn about the drug delivery technology so that they can tailor their antibody to B's drug delivery technology. Thus, access enables users to *specialize* to an asset by learning how to work with it.

However, as in Rajan and Zingales (2001), access also gives each user the opportunity to *expropriate* the asset. A may learn and expropriate B's drug delivery technology, thus dispensing with

B (same for B). As we explained in Section 2, given the non-rival nature of knowledge assets, A can steal B's drug delivery technology even when B owns the IPR to the same.

3.1.2 Ownership

Apart from deciding the level of access, the firms decide the pattern of ownership of the knowledge assets at date 0. Let $\delta = 0$ denote that A and B own their respective assets while $\delta = 1$ denote, without loss of generality, that A owns both assets. Based on the discussion in Section 2 above, $\delta = 1$ only means that, at date 0, B has transferred to A the legal rights to (i) make decisions regarding the drug delivery technology; and (ii) seek legal recourse if A's IPR is infringed upon.

3.1.3 Investment

As described in Section 3.1.1, access to a knowledge asset enables the user to *specialize* to the knowledge asset as well as the opportunity to *expropriate* the asset. In order to expropriate the asset, the user has to understand the asset in its totality. In contrast, to tailor its asset the user needs to understand *only* those features that affect how well its asset fits together with the complementary asset. To model these investment incentives, we consider that A and B make investments e^A and e^B respectively at date 1. A makes investments (i) to tailor its antibody technology to B's drug delivery technology, and (ii) to expropriate B's drug delivery technology (similar for B). To economize on the notation, the multi-tasking in investments is not explicitly modeled here though Appendix A.1 shows that the results are identical when multi-tasking is incorporated into the model. The cost of investment is equal to the level of investment. As in the incomplete contracting framework, we assume that these *investments are observable but not verifiable*.

3.1.4 Output and Bargaining

At date 2, the joint output R and the outside options r^A and r^B are realized. The joint output is the output that A and B produce if they decide to continue their relationship. A's outside option r^A is the output that A can produce without B (similar for B). A and B bargain over the split of the joint output R using $50 : 50$ Nash bargaining.[6] As shown in Appendix A.2, the results are robust to alternative bargaining solutions.[7]

[6] 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.

[7] de Meza and Lockwood (1998) show that the GHM results do not generalize when the alternative-offers bargaining protocol of Rubinstein (1982) is used. I therefore show in the Appendix that the results in this paper are not altered when the alternative-offers bargaining model is employed.

3.2 Technology

The joint output is an increasing, concave function of specific investments and access.[8]

$$R = R\left(e^A, e^B, \alpha\right) : R_i \equiv \frac{\partial R}{\partial e^i} > 0, R_{ii} \equiv \frac{\partial^2 R}{\partial \left(e^i\right)^2} < 0 \ , i \in \{A, B, \alpha\} \tag{1}$$

A's outside option r^A is a function of its specific investment,[9] access, ownership of assets, and A's ability to expropriate B's asset, which we denote by θ^A (similar for B).

$$r^i = r^i\left(e^i, \alpha, \delta; \theta^i\right) : r_i^i \equiv \frac{\partial r^i}{\partial e^i} > 0, r_{ii}^i \equiv \frac{\partial^2 r^i}{\partial \left(e^i\right)^2} < 0 \ ; i \in \{A, B\} \tag{2}$$

The functional dependence on access and the ability to expropriate θ^A is described below in Section 3.3.

We assume that P and Q are complementary to each other. Specifically, the complementarity of P and Q implies the following three assumptions. First, we assume that the joint output is always greater than the sum of the outside options

$$R > r^A + r^B \quad \forall e^A, e^B, \alpha, \delta, \theta^A, \theta^B \tag{3}$$

Second, as in Hart (1995), we assume that the marginal productivity of output that can be produced when an agent has ex-post access to both assets is always greater than the marginal productivity of output when the agent has ex-post access to only one asset. As we argued in Section 2, ex-post access can be strictly restricted only for physical assets. Therefore, we assume that

$$\begin{aligned} R_A &> r_A^A\left(\delta = 0, PhysicalAsset\right) \\ R_B &> r_B^B\left(\delta = 0, PhysicalAsset\right) \end{aligned} \tag{4}$$

Third, we assume that neither A's nor B's investment is redundant. To capture this relatively equal importance of both agents' investments, we assume a symmetric technology.

$$\begin{aligned} R_A &= R_B = R_e; R_{AA} = R_{BB} = R_{ee}; r_{AA}^A = r_{BB}^B = r_{ee} \\ R_{A\alpha} &= R_{B\alpha} = R_{e\alpha}; r_{A\alpha}^A = r_{B\alpha}^B = r_{e\alpha}; r_{A\theta}^A = r_{B\theta}^B = r_{e\theta} \end{aligned} \tag{5}$$

Unlike GHM, this formulation allows us to focus on situations in which the boundary choice matters even when there is no difference between the marginal productivity of the two firms.

[8] Note that even though uncertainty is not modeled explicitly here, our analysis is not affected if we replace the payoffs at date 2 by their expectations [see Hart and Moore(footnote 5, 1990)].

Also, 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.

[9] The assumption that A's outside option is not a function of B's investment is not critical to the results.

Since A and B specialize their assets to each other, increasing access increases the marginal product of investment on the joint output. When access provided is higher, agents are exposed to more intricate details and can learn to familiarize themselves to the same. This makes specialization more fruitful within the relationship. Formally,

$$R_{i\alpha} \equiv \frac{\partial^2 R}{\partial e^i \partial \alpha} > 0, i \in \{A, B\} \tag{6}$$

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

$$R_{AB} \equiv \frac{\partial^2 R}{\partial e^A \partial e^B} = 0 \tag{7}$$

While this assumption is not critical to the results,[10] it simplifies the analysis.

3.3 Outside Options

A's outside option is the output that A would produce (without B) in the product market competition that would ensue after A and B part ways at date 2.[11]

As argued in Section 2, the owner of a knowledge asset cannot ensure exclusive access to the asset at date 2. Therefore, if A provides more access to its antibody technology, B can acquire greater expertise over it. If A and B part ways at date 2, then B can then combine the expertise acquired over the antibody technology along with its original expertise in the drug-delivery technology for production. Therefore, greater access provided by A enhances B's outside option. Since ownership only provides the legal right to make residual decisions and the right to sue if this right is infringed upon, the effect of access is independent of the pattern of ownership. In other words, irrespective of whether A owns both P and Q or just P, greater access enables B to gain more expertise over the antibody technology and thus enhances the marginal value of its outside options.[12] Since access is assumed to be reciprocal, increased access also implies A getting more access to Q which enhances

[10] 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.

[11] While such product market competition can be incorporated into the model to endogenously derive the outside options as a function of the product market characteristics, I find that the additional insights gained from the same are limited. A variant of the model with endogenous outside options would deliver similar functional dependencies if it incorporated the following features. First, product market competition is driven by the quality of a firm's products, which are in turn driven by their expertise in the complementary assets P and Q. Second, if A and B continue their relationship, they operate as a monopoly. In contrast, if A and B decide to part ways at $t = 2$, then they would compete in a duopoly with differentiated products or in an oligopoly in which their products are differentiated from each other and from the rest of the competing firms. Third, the price that a firm can charge in a duopoly increases in its expertise in the complementary assets but decreases in the expertise of its competitor. Given the environment we are modelling, where innovation and expertise are crucial, these product market features are natural.

[12] Readers may argue that since B also specializes its human capital and its drug delivery technology to A's antibody technology, the marginal value of B's outside option may fall when access is higher. However, as Rajan and Zingales (1998) mention, "When human capital but not the (physical) asset is specialized to the relationship, it is no longer obvious that the owner's outside value with the asset falls with specialization." For example, if A specializes its AIDS antibody to B's oral drug delivery technology, that does not preclude it from tailoring the same antibody to the intra-venal delivery technology of another firm.

the marginal value of A's outside options too. Therefore, we assume that

$$r_{i\alpha} \equiv \frac{\partial^2 r^i}{\partial e^i \partial \alpha} > 0, i \in \{A, B\} \ \forall \delta \tag{8}$$

Following the discussion in Section 2 above, recall that ownership of the idea confers on the owner the legal right to make residual decisions about its use. Therefore, we follow GHM in assuming that ownership of the idea enhances the marginal product of investment on the outside options.[13] Since $\delta = 1$ corresponds to A owning P and Q while $\delta = 0$ corresponds to A owning P and B owning Q,

$$r_A^A(\delta = 1) > r_A^A(\delta = 0), r_B^B(\delta = 1) < r_B^B(\delta = 0) \tag{9}$$

When B can expropriate A's antibody technology more easily, the marginal value of B's outside option is higher (similar for A). Thus,

$$r_{i\theta}^i \equiv \frac{\partial^2 r^i}{\partial e^i \partial \theta^i} > 0 \ ; \ i \in \{A, B\} \tag{10}$$

3.4 Nature of contracts

As in PRT, contracts are assumed to be incomplete. Explicitly, two important assumptions characterize the incomplete contracts environment. First, the investments at date 1 are observable but not verifiable. Second, the payoffs R and r^j ,$j \in A, B$ are assumed to be non-contractible at date 0, though they are contractible at date 2. These assumptions are justified by invoking two more primitive assumptions. First, the contract at date 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 date 0 not to resort to ex-post renegotiation at date 2 after threatening to exercise its outside option.

The assumption of indescribable contingencies being studied since it is unlikely that the two firms will be able to write a contract describing precisely the specific details 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 date 0 if the two parties can commit to a contract that would not be renegotiated at date 2. Indescribability leads contracts 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). Given the setting involving innovation and knowledge assets being studied here, the inability to commit not to renegotiate is natural to assume as well.

[13] Note that Rajan and Zingales (1998) consider the case where ownership of physical assets *reduces* the marginal value of outside options. However, as argued for the marginal effect of increasing access, specialization of knowledge assets is unlikely to reduce the marginal value of the owner's outside options.

3.5 Solving the model

The model is solved using backward induction. Given (3), at date 2, the outside options are never exercised in equilibrium; they only affect the split of the joint output R. Since the joint output is split using 50:50 Nash Bargaining, A's and B's share of the joint output is given by $0.5\left(R + r^A - r^B\right)$ and $0.5\left(R - r^A + r^B\right)$ respectively.

The investments are chosen at date 1. The first-best investment $\left(e^{AF}, e^{BF}\right)$, which maximizes $R - e^A - e^B$, is given by

$$R_i\left(e^{AF}, e^{BF}\right) = 1,\ i \in A, B \tag{11}$$

The second-best Nash equilibrium level of investment $\left(e^{A*}, e^{B*}\right)$, which firm i chooses to maximize its share of the joint output net of its cost of investment, $0.5(R + r^i - r^j) - e^i$, is given by

$$\frac{1}{2}R_i\left(e^{A*}, e^{B*}, \alpha\right) + \frac{1}{2}r_i^i\left(e^{i*}, \alpha, \delta; \theta^i\right) = 1;\ i \in \{A, B\} \tag{12}$$

Concavity of the joint output and the outside options, along with the technical boundary conditions (39), ensure the existence and uniqueness of $\left(e^{AF}, e^{BF}\right)$ and $\left(e^{A*}, e^{B*}\right)$.

The second-best investments $\left(e^{A*}, e^{B*}\right)$ determine the joint surplus TS^*, where

$$TS^* = R\left(e^{A*}, e^{B*}, \alpha\right) - e^{A*} - e^{B*} \tag{13}$$

Since A and B are not liquidity constrained, access and ownership are chosen at date 0 to maximize this joint surplus.

$$(\alpha^*, \delta^*) \equiv \underset{(\alpha,\delta)}{\arg\max}\left[TS^*\left(e^{A*}\left(\alpha, \delta; \theta^A\right), e^{B*}\left(\alpha, \delta; \theta^B\right), \alpha\right)\right] \tag{14}$$

3.6 Boundary decisions

We now use the above framework to define mergers/ acquisitions, arms-length contracts and hybrids such as strategic alliances and majority joint ventures.

As argued in the Introduction, we view a knowledge-intensive firm as a collection of the knowledge assets that it *owns* and the agents who have *full access* to these assets. Thus, in a merger/ acquisition, the surviving entity retains ownership rights over its knowledge assets and those of the target. Also, the access that the two firms provide to each other is maximum. Thus $(\alpha^*, \delta^*) = (1, 1)$ corresponds to a merger/ acquisition being optimal. In contrast to a merger/ acquisition, if the two firms transact through an arms length contract, then each firm owns its respective knowledge asset. Furthermore, in an arms-length contract, access between the two firms is non-existent. Thus $(\alpha^*, \delta^*) = (0, 0)$ corresponds to an arms-length contract being optimal.

Hybrids such as strategic alliances and joint ventures lie in between the two extremes of arms-length contracts and merger/ acquisitions. In a Joint Venture (hereafter JV), the partners create a new legal and organizational entity in which they share equity. A strategic alliance is commonly a voluntarily initiated cooperative agreement among firms that involves exchange, sharing, or the co-development of assets. Partners in an alliance (JV) often contribute capital, technology and firm-specific assets to the alliance (JV). Therefore, joint ventures and strategic alliances are more integrated than an arms-length contract but less so than a merger/ acquisition. Therefore, we model access as moderate in joint ventures and strategic alliances.[14] Consistent with this mapping, Gomes-Casseres, et. al. (2006) note that "Knowledge flows will be the smallest between firms that have only arms-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."

Similar to mergers/ acquisitions we model majority JVs as involving a change of ownership.[15] Compared to an arms-length contract or a strategic alliance, the majority partner in a JV exercises greater residual rights of control. To illustrate, consider the majority JV between Lucent Technologies and Chartered Semiconductor Manufacturing in 1997. Lucent was the majority owner with 51% stake in the JV which was reflected in their majority on the board. The JV agreement states that the "board was to consist of three directors appointed by Lucent and two appointed by Chartered Semiconductors."[16] Given this board majority, it is clear that the power to make residual decisions resided with Lucent rather than with Chartered Semiconductors. Thus for $0 < \underline{\alpha} < 1$, $(\alpha^*, \delta^*) = (\underline{\alpha}, 0)$ corresponds to a strategic alliance being optimal while $(\alpha^*, \delta^*) = (\underline{\alpha}, 1)$ corresponds to a majority JV being optimal.

4 Theoretical Results

We now state the results obtained using the model.

Lemma 1: Given α, δ, (a) $r_i^i \leq R_i \ \forall e^i \Rightarrow e^{i*} \leq e^{iF}$ and (b) $r_i^i > R_i \ \forall e^i \Rightarrow e^{i*} > e^{iF}, i \in \{A, B\}$.

A and B underinvest (overinvest) when their investment enhances the marginal value of joint output more (less) than the marginal value of outside option. The intuition for this result is quite standard: the first-best level of investment maximizes the joint output net of the cost of investment while the second best investment is made by also taking into account the value of the outside option. This result is similar to that in Hart (1995) – the only difference is that condition (b) is not considered in their analysis.

[14] While it is quite likely that joint ventures involve greater access than strategic alliances, we do not take a stance on the same since it is empirically not possible to infer or measure such distinctions.

[15] We exclude 50:50 joint ventures from our analysis since neither firm has the residual rights of control in this case. As Hart (1995) states, joint ownership implies that if trade negotiations between the two partners break down, neither partner firm has the right to operate the asset independently. Therefore, Hart notes that under the incomplete contracting paradigm, joint ownership does not dominate individual ownership or joint ownership in any situation. To be able to model 50:50 joint ventures, we need a theory of joint ownership in the incomplete contracting paradigm, which is beyond the scope of this study.

[16] Source: Joint Venture contracts listed at www.onecle.com

4.1 Benchmark Case of Physical Assets

As we argued in Section 2, the essential difference between physical assets and knowledge assets is that access can be withdrawn ex-post to physical assets while the same is not possible with knowledge assets. To distinguish the differences in the provision of incentives between physical assets and knowledge assets, we show that full access is always optimal with physical assets.

Proposition 1 (Full Access Always Optimal with Physical Assets): If Assumption (4) holds, then

$$\alpha^* = 1$$

The intuition for the result is as follows. When A and B own P and Q respectively, neither can overinvest due to the complementarity in the assets as well as each agent's *credible* threat to withdraw access to the asset ex-post. Both agents underinvest and therefore increased access enhances both their incentives. Consequently, full access is always optimal. If A owns both P and Q, then B always underinvests since B does not own either asset and can therefore produce very little outside the relationship. In contrast, A can produce using both assets. If the marginal effect of A's investment is higher on the joint output than on the outside option $\left(R_A \geq r_A^A\right)$, then A underinvests as well. Again, full access is optimal. In contrast, if the marginal effect of A's investment is lower on the joint output than on the outside option $\left(R_A < r_A^A\right)$, then A will overinvest. In this case, transferring ownership of Q to B is optimal since doing so enhances B's incentives and reduces A's and thus brings both agent's incentives closer to first-best. With this optimal transfer of ownership, A and B own P and Q respectively and full access is again optimal (as argued above). Therefore, in the case of physical assets, full access is always optimal.

This result would not be altered even if we were to adopt the bargaining model as in deMeza and Lockwood (1998).[17] Consistent with the conclusions derived here, GHM focus only on the problem of underinvestment by assuming that the marginal product of an agent's outside option is lower than that of the joint output.

4.2 Knowledge assets

In the case of knowledge assets, access provided ex-ante cannot be withdrawn ex-post. Therefore, *outside their joint relationship, both A and B can potentially produce using both assets* (as long as they are not legally found guilty of infringing on their partner's IP asset and ordered not to produce). Therefore, with knowledge assets, (a) underinvestment in tailoring complementary pieces of knowledge and (b) overinvestment in stealing knowledge are both material concerns.

[17] deMeza and Lockwood (1998) point out that the no-trade payoffs in GHM are really inside options. In contrast in DeMeza and Lockwood (1998), the no-trade payoffs are outside options that capture either agent's ability to sign some other contracts with parties outside the relationship. For their results, they analyze the case where both agent's outside options are really unproductive ($0.5R' > r'$). Extending their assumption to our setup, we find that both firms would always underinvest by a good margin irrespective of the outcome of the bargaining game, i.e., irrespective of whether the two agents split the joint output by half or one agent's outside option binds. Therefore, even in the DeMeza and Lockwood (1998) modification of GHM, access has no role to play since access should be optimally one.

Before describing our main results, we illustrate using an example. Consider the following functional forms for the joint output R and the outside options r^A and r^B:

$$
\begin{aligned}
R &= (9+4\alpha)\, e^A - \frac{1}{2}\left(e^A\right)^2 + (9+4\alpha)\, e^B - \frac{1}{2}\left(e^B\right)^2 \text{ where } e^A, e^B \in \mathbb{R}^+ \\
r^A &= \left\{1 + 12\alpha + (1-\alpha)\, 4\delta + 8\theta^A\right\} e^A - \frac{1}{2}\left(e^A\right)^2 \text{ where } \theta^A \in [0,1] \\
r^B &= \left(1 + 12\alpha - 4\alpha\delta + 8\theta^B\right) e^B - \frac{1}{2}\left(e^B\right)^2 \text{ where } \theta^B \in [0,1]
\end{aligned}
$$

Thus

$$
\begin{aligned}
R_A &= 9 + 4\alpha - e^A;\; R_B = 9 + 4\alpha - e^B \\
r_A^A &= 1 + 12\alpha + (1-\alpha)\, 4\delta + 8\theta^A - e^A;\; r_B^B = 1 + 12\alpha - 4\alpha\delta + 8\theta^B - e^B
\end{aligned} \tag{15}
$$

The first-best investments derived using the first order conditions (11) are given by

$$
e^{AF} = e^{BF} = 8 + 4\alpha \tag{16}
$$

Therefore, when access increases the first-best level of investments increase which follows from the marginal product of investment being higher when access is higher (refer (6)).

The second-best investments, derived using the first order conditions (12) , are given by

$$
\begin{aligned}
e^{A*} &= 4 + 8\alpha + 2(1-\alpha)\,\delta + 4\theta^A \\
e^{B*} &= 4 + 8\alpha - 2\alpha\delta + 4\theta^B
\end{aligned} \tag{17}
$$

We note in equation (17) that as access increases, both A's and B's investments increase. This result follows from the marginal product of investment being higher when access is higher (refer (6) and (8)). In contrast to this symmetric effect of access on incentives, we note in equation (17) that transferring ownership of Q from B to A increases A's investment but reduces B's investment. This result, which is identical to that in GHM, follows from ownership enhancing the marginal product of investment on the outside option (see equation (9)). Thus, the effects of access and ownership on investment contrast with each other: changing *access has a symmetric effect* on A's and B's incentives while transferring *ownership has an asymmetric effect.* We generalize this result in Proposition 2.

We consider four cases to show under what conditions each of the four boundary choices is optimal. Refer to Figures 3, 4, 5 and 6 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): First, say that both A and B can very easily expropriate Q and P ($\theta^A = \theta^B = 1$). Figure 3 shows that if A and B own P and Q respectively (i.e.

$\delta = 0$), they both overinvest. Using (15), it is easy to verify that in this case, for $i \in A, B : R_i \leq r_i^i (\delta = 0)\ \forall e^i$, leading to the overinvestment.

In this case, transferring Q from B to A does not help to align A and B's incentives. When A owns both assets, it overinvests more compared to the situation in which A and B own P and Q respectively, illustrating that *ownership can have the adverse effect of encouraging overinvestment* by the owner. Unlike changing ownership, changing access aligns the incentives of A and B towards the first-best. In fact, when access is minimal, their investments equal the first-best. In essence, when both A and B overinvest, reducing access *can* align incentives for both A and B since access has a symmetric effect on incentives. However, transferring ownership *will* not achieve this outcome since ownership has an asymmetric effect on incentives. Therefore, when both firms can expropriate each other's knowledge very easily, minimal access through an arms-length contract is optimal.

Case 2 (Strategic Alliance optimal): Say that both A and B can expropriate Q and P with moderate ease ($\theta^A = \theta^B = 0.5$). Figure 4 shows that both A and B underinvest (overinvest) when access is less (more) than 0.5. As in Case 1 above, changing access to 0.5 aligns incentives towards first-best while changing ownership does not. Therefore, when both firms can expropriate each other's knowledge with moderate ease, moderate access through an alliance is optimal.

Case 3 (Majority Joint Venture optimal): Say that B can expropriate P easily $\left(\theta^B = 0.75\right)$ while A cannot expropriate Q easily $\left(\theta^A = 0.25\right)$. Figure 5 shows that when A and B own P and Q respectively $(\delta = 0)$, A underinvests while B overinvests for most levels of access. It is easy to see that keeping ownership unchanged, it is not possible to bring both A's and B's investment equal to first-best. Since B overinvests while A underinvests for most levels of access, transferring ownership of Q to A dampens B's and enhances A's incentives. When A owns both P and Q $(\delta = 1)$, the symmetric effect of access ensures that changing access to 0.5 provides first-best incentives to both A and B. Therefore, when B can expropriate easily but A cannot, majority JV (A owning both assets and access being moderate) is optimal.

Case 4 (Merger/ Acquisition optimal): Finally, consider the case in which A cannot expropriate Q ($\theta^A = 0$) but B can expropriate with moderate ease ($\theta^B = 0.5$). Following arguments similar to that in Case 3 above, it follows that A owning both P and Q ($\delta = 1$) and full access ($\alpha^* = 1$) provides first best incentives to both A and B. See Figure 6 for the illustration. Therefore, when A cannot expropriate but B can do so with moderate ease, a Merger/ Acquisition (A owning both assets and access being full) is optimal.

We see through these four cases that varying the boundary choice with the nature of the knowledge asset *can* provide first-best investment incentives to both agents.

Proposition 2 (Incentive Effects of Access and Ownership):

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

As access increases, both A's and B's investments increase. In contrast, transferring the ownership of Q from B to A increases A's investment but reduces B's investment. The intuition behind this result is described in the example above.

This Proposition highlights two incentive drawbacks associated with ownership in the context of knowledge-intensive firms: (i) an adverse effect of ownership on an agent's incentives and (ii) the zero-sum nature of ownership in providing incentives simultaneously to two agents.

Adverse Effect of Ownership: Given the possibility of overinvestment, we highlight an *adverse effect of ownership* in knowledge assets. The adverse effect can be seen by juxtaposing part (b) of Lemma 1 with part (b) above. The intuition for this result is as follows. If ownership of B's asset is transferred to A, A's bargaining power is enhanced since A can threaten to develop products without B's cooperation. Such a threat was less credible when B owned the asset since B had the legal rights to decide the use of the asset. However, A can't follow up on its threat of dispensing with B unless A understands B's drug-delivery technology in its totality. Therefore, once A owns B's asset, A overinvests more in expropriating B's asset. Note that this *adverse effect of ownership is absent in physical assets* since A's threat of depriving ex-post access to B is quite credible even if A does not invest to learn how to use B's asset.

This adverse effect of ownership alters an important claim in GHM that a merger/ acquisition is optimal for complementary assets (see Proposition 2 (D) in Hart, 1995). GHM predict that an arms-length contract is optimal only when the two assets are independent. However, though the assets are complementary to each other in our setup, A owning both assets may not be optimal if transferring ownership to A accentuates A's overinvestment. In other words, merging firms with complementary knowledge assets may not always lead to synergies. The acquiring division of the new firm may divert costly resources away from its core activities to expropriate the acquired division's knowledge asset since doing so enhances the acquiring division's bargaining power vis-a-vis the acquired division and positions it favorably with the corporate headquarters. Thus, when the problem of overinvestment by the potential acquirer or the majority JV partner is severe, an arms-length contract or a strategic alliance may be optimal.

Symmetric Effect of Access vis-à-vis Asymmetric Effect of Ownership: To examine the implications of the symmetric effect of access, we compare (i) an arms-length contract to a strategic alliance, and (ii) a majority JV to a merger/ acquisition. These comparisons involve differences in access without any difference in ownership and therefore relate to the *ceteris paribus* predictions made by the above proposition. Since a strategic alliance involves greater access than an arms-length contract, the alliance has the benefit of providing both firms with stronger incentives to tailor their assets. However, it has the cost that both firms would invest more to expropriate their partner's asset. In a merger/ acquisition, the acquiring and acquired firms become divisions of the new firm and provide each other full access. Therefore, compared to a majority JV, a merger/ acquisition has the benefit of providing both the acquiring and acquired divisions stronger incentives to tailor their assets to each other and, thus, to exploit merger synergies. However, compared to the majority JV, the merger/ acquisition also has the cost of providing each division stronger incentives to divert costly resources away from its core activities to expropriate the other division's knowledge asset and, in the process, enhance its bargaining position with corporate headquarters.

To examine the implications of the asymmetric effect of ownership, we compare a strategic alliance to a majority JV since this comparison involves a change in ownership without any change in access. Compared to the strategic alliance, the majority (minority) JV partner has stronger (weaker) incentives to (i) tailor its knowledge to that of its partner, and (ii) to divert costly resources away from its core activities to expropriate its partner's knowledge asset.

4.2.1 Comparative Statics

As seen in the example, A underinvests (overinvests) when B's knowledge is difficult (easy) to expropriate. A similar result applies for B. The Lemma below generalizes this result.

LEMMA 3: Given α, δ, for $i \in A, B$, there exist $\widehat{\theta^i}$ such that (a) $\theta^i \leq \widehat{\theta^i} \Rightarrow e^{i*} \leq e^{iF}$ and $\theta^i > \widehat{\theta^i}$ $\Rightarrow e^{*i} > e^{iF}$

By comparing cases 1-4 in the example, we can see that when knowledge of both firms is easy (difficult) to expropriate, they will choose to restrict (provide full) access to one another by choosing less (more) integrated organizational forms. In contrast, when knowledge of one firm is easier to expropriate and another's difficult to expropriate, the firm whose knowledge is easy to expropriate must own both the assets. Proposition 3 below generalizes this main result.

PROPOSITION 3: Consider $\left(\theta_A^1, \theta_B^1\right) \neq \left(\theta_A^2, \theta_B^2\right)$.

$$\begin{aligned} (a)\ \theta_A^1 &> \theta_A^2 \text{ and } \theta_B^1 > \theta_B^2 \Rightarrow \alpha^*\left(\theta_A^1, \theta_B^1\right) \leq \alpha^*\left(\theta_A^2, \theta_B^2\right) \\ (b)\ \theta_A^1 &> \theta_A^2 \text{ and } \theta_B^1 < \theta_B^2 \Rightarrow \delta^*\left(\theta_A^1, \theta_B^1\right) \leq \delta^*\left(\theta_A^2, \theta_B^2\right) \end{aligned}$$

As *both* A's and B's ability to expropriate P and Q increases, the optimal level of access decreases weakly (part (a)). In contrast, when A's ability increases but B's decreases, it is (weakly) optimal to transfer ownership of B's knowledge to A (part (b)).[18] This result follows from the contrasting effects of access and ownership on incentives and by noting that A's and B's investment increase as the knowledge they get access to becomes easier to expropriate (as shown in Lemma 3).

Proposition 3 highlights the complementarity of access and ownership in providing stronger investment incentives to both firms. Since access has a symmetric effect on incentives, regulating access brings both A's and B's incentives closer to first-best when both agents over- or under-invest. In contrast, changing ownership helps bring both A's and B's incentives closer to first-best when one agent over-invests while the other under-invests. Thus, optimally choosing access and ownership *simultaneously* solves the problems of (a) under-investment in tailoring complementary pieces of

[18] The equality in optimal access results because access may reach its boundary value of 0 or 1 while the equality in optimal ownership results since onwership takes only two values 0 or 1 and would change at a threshold value of θ^A and θ^B.

knowledge, and (b) over-investment in stealing knowledge. As seen in the example, choosing access and ownership together *may* provide first-best incentives to both firms.

5 Review of Literature

We now highlight the differences between the theory proposed here and the existing theories. Primarily, the theory proposed here builds on those proposed by GHM and Rajan and Zingales (1998,2001). Therefore, we focus on distinguishing our theory from these two.

5.1 Boundary Choices and Nature of Contracts in Knowledge Intensive Industries

Recall that in the PRT, a firm is defined as a collection of the nonhuman assets that it owns. Therefore, boundary decisions are defined as changes in the structure of ownership of these assets. Under their framework, a strategic alliance (merger/ acquisition) cannot be distinguished from an arms length contract (majority JV) since neither involves (both involve) a change in control over assets. Yet, as Table 1 shows, hybrids such as strategic alliances and majority JVs have been quite popular since the 1990s, particularly in the high technology industries.[19]

Furthermore, using the PRT we cannot differentiate between the nature of contracts that are effected in the knowledge intensive industries from those in the traditional industries. As Table 1 shows the nature of contracts between firms in the high technology industries are quite different from those between firms in non-high technology sectors. Panel A shows that for each year over the period 1990-2007, over three-quarter of the alliances and majority JVs were undertaken in the high technology industries. Panels B-D show the predominance of the high technology sectors in the use of licensing, R&D and cross-technology transfer agreements. Since ownership of assets is the defining characteristic of firms in the PRT, access provided to knowledge through licensing, R&D or cross-technology transfer agreements cannot be distinguished from plain arms-length contracts. Though Rajan and Zingales (1998, 2001) analyze the regulation of access inside organizations, an extension of their theory can distinguish between arms-length contracts and the licensing, R&D and cross-technology transfer agreements documented in Table 1. However, since they do not distinguish between control over physical and knowledge assets, their framework cannot explain the predominance (absence) of such agreements in high technology (non-high technology) industries.

In contrast, we define a knowledge-intensive firm as a collection of the knowledge assets that it *owns* and the agents who have *full access* to these assets. Since we define boundary decisions using both access and ownership, the theory proposed here can distinguish among mergers/ acquisitions, hybrids such as alliances and majority JVs, and arms-length contracts. Further, the predominance of contracts that provide access in the high-technology industries and the lack of these in the non-

[19] Note that the number of alliances differ from those listed in Table 1 of Robinson (2007), who also uses SDC Platinum to compile his database of alliances and JVs. This is because, unlike Robinson (2007), we restrict our attention to alliances involving two firms only.

high technology sectors is consistent with the claim in this paper that both access and ownership and required to provide optimal incentives in knowledge intensive industries while ownership suffices for the same in physical asset intensive industries.

5.2 Definition of a Firm

In the PRT, a firm is defined at date 0 as a collection of the nonhuman assets that will be jointly owned at date 2. Thus, until the agents agree to continue their relationship with each other at date 2, only the owner of the asset has access to the asset whereas if they do agree to continue their relationship at date 2, both agents have access to both assets. Thus, what effectively matters is ownership (or equivalently the right to provide/ deny access) at date 2 rather than ownership at date 0. Therefore, investment incentives in the PRT are determined by the pattern of ownership that will prevail at date 2. By contrast, in the framework proposed here, a (knowledge-intensive) firm is defined at date 0 as a collection of the assets that it will own at date 2 and the agents who have full access to these assets at *date* 0. Since we provide a role for ownership as well as ex ante access, we can define a firm both in terms of its unique physical and knowledge assets as well as the people who have access to these assets at *date* 0. Not only does this bring people other than owners of assets within the boundaries of the firm but also introduces a separate role for the firm in creating an ex ante environment that encourages investment, which is different from its ex post role in protecting the returns to specific investment. Thus our definition of a firm using both access and ownership imposes well-defined ex ante boundaries.

To model the regulation of access inside organizations, Rajan and Zingales (1998) define a firm as a collection of agents who have access to its unique assets. However, since they do not model ownership, the legal rights that ownership confers are irrelevant in their definition of a firm. To examine the implications of the same, consider the strategic alliance between two biotechnology firms MedImmune Inc and Ixsys Inc. As part of the alliance, MedImmune provided Ixsys a license to its patented antibody technology. Thus Ixsys had access to this technology though it did not own it. However, the alliance contract restricted Ixsys from using this license for any activities outside those detailed in the contract. If Ixsys had acquired MedImmune, then Ixsys would be able to put the antibody technology to unrestricted use. In sum, the activities that Ixsys could undertake and, in turn, its economic boundaries were strongly a function of whether Ixsys owned the patent or MedImmune owned it. While we cannot make such distinctions using the Rajan and Zingales (1998) framework, the framework proposed here can account for such differences.

5.3 Retaining key employees in Mergers/ Acquisitions in the Knowledge Intensive Industries

As argued above, a firm's employees can be included in our definition of a firm. Therefore, we can distinguish between those acquisitions where key employees possessing expertise are retained after the acquisition and the acquisitions where such employees leave post-acquisition. As in the AOL-Netscape situation, when the key employees of the acquired firm leave, the acquirer *does not get* *full access* to the crucial knowledge. Since access between AOL's and Netscape's knowledge assets was not full, the AOL-Netscape acquisition does not qualify as a bonafide merger/ acquisition in our framework. In fact, such an acquisition is economically equivalent only to a majority JV in our framework. Therefore, the synergies expected in the AOL-Netscape acquisition were commensurate only to a majority JV and not to a fully integrated acquisition. In contrast, when the key employees of both the target and the acquirer stay after the acquisition, as in the Intel-Level One example, full access is obtained between the acquier's and target's knowledge assets. Thus, in our framework, the Intel-Level One acquisition qualifies as a bonafide acquisition. Therefore, by distinguishing between firms with and without their key employees, our theory points out that retaining key employees is crucial to achieving the synergies stemming from complementary knowledge assets in a merger/ acquisition. This is important given the unprecedented level of merger and acquisitions activity in the high-technology sectors over the past decade (see Figure 1 for the dollar volume and number of M&A transactions in the high-technology sector).

Our prediction finds support in Ranft and Lord (2000)'s survey of managers involved in 89 acquisitions in high-technology industries. The respondents indicated in 84% of the acquisitions that the acquisition was made with the express purpose of acquiring specific technologies. And, consistent with the prediction above, over 70% of the managers responded that the retention of key employees with technical skills was the dominant force in achieving the transfer of technology between the acquirer and acquired firm. Further, in this survey, research and development personnel followed by engineering personnel were cited as the two most important sources of the acquired firm's knowledge resource.

5.4 Other Related Literature

Apart from the above papers related to the theory of the firm, this paper is related to an evolving literature on alliances and other hybrid organizational forms. Baker, Gibbons and Murphy (2004) model a variety of hybrid governance structures by emphasizing the spillover effects of such governance structures and the role of relational contracts in overcoming ex post inefficiencies that arise in one-shot interactions. While they model the differences among the plethora of hybrid governance structures, we examine alliances and majority JVs vis-a-vis mergers/ acquisitions and arms-length contracts. Robinson (2007) models strategic alliances as long-term contracts between legally distinct organizations that provide for sharing the costs and benefits of a mutually beneficial activity. He shows that alliances have positive ex-ante incentive effects compared to internal capital markets when corporate headquarters cannot commit to not picking winners ex-post between projects. Mathews and Robinson (2007) examine the optimality of stand-alone firms, internal capital markets and strategic alliances in deterring entry into product markets. In their setting, internal capital markets present the advantage of ex-post resource flexibility but have the attendant cost of ex-ante commitment difficulties. Strategic alliances provide synergy benefits similar to internal capital markets without its attendant costs. Mathews (2007) models a setting where a strategic alliance between an entrepreneurial firm and an established firm improves efficiency for both, on the one hand, and heightens the established firm's incentive to enter one its partner's markets, on the other hand. He considers equity ownership as the solution to the incentive problems that arise in such a setup. This paper resembles Robinson (2007) and Mathews and Robinson (2007) in examining the optimality of strategic alliances, and it resembles Mathews (2007) in examining efficiency and expropriation together. However, there are substantial differences. We examine the optimality of arms-length contracts, strategic alliances, majority joint ventures and mergers/ acquisitions in the context of ex-ante incentives of both firms to (a) specialize their expertise to each other, and (b) to expropriate each other's expertise. Furthermore, we emphasize the difference between incentive effects faced by knowledge-intensive firms and those observed in physical-asset intensive firms. Dessein (2006) develops a theory of control rights in alliances as a signal of the congruence of interests between an entrepreneur and the investor. Elfenbein and Lerner (2003a, 2003b) examine empirically the control rights in internet portal alliances while Lerner and Merges (1998) and Lerner and Malmendier (2004) analyze this in the context of biotech alliances.

This paper is related to the literature on sharing and expropriation of knowledge. Anton and Yao (1994) analyze knowledge-sharing situations in which, once the knowledge is partially or fully revealed, the innovator's contribution is minimal. They show that by creating competitors, the innovator can extract rents for his innovation. Their analysis is more likely to describe innovations in which the innovator's specific knowledge ceases to be valuable after the knowledge/ technology is revealed. In contrast, this paper considers knowledge-sharing in which the original owner's continued involvement is necessary for at least some time. Anton and Yao (2002, 2004) examine partial disclosure of knowledge. Rajan and Zingales (2001) examine how vertical versus horizontal hierarchies can be employed to prevent stealing of ideas by employees.

6 Empirical Evidence

We test the prediction in Proposition 3 by using a sample of alliances and JVs. The prediction about optimal access assumes a given level of ownership and vice-versa. Since mergers/ acquisitions involve a change in access *and* a change in ownership, they are not suitable to test *ceteris paribus* predictions of this nature.

6.1 Construction of the Dataset

The dataset is constructed by merging four different data sources: (i) strategic alliance and joint venture deals from the Securities Data Company (SDC)'s Platinum database, (ii) the NBER patent database compiled by Hall, Jaffe and Trajtenberg (2001), which contains the patents filed by US and international firms and citations to these patents, (iii) CRSP/ Compustat for firm level financial information, and (iv) the S&P Directory of Corporate Affiliations to complete the corporate family of each firm. Completing the corporate family is essential since firms often file patents through their subsidiaries and divisions. Firm identifiers in the SDC Platinum data were first matched to CRSP/ Compustat. Then, to assess the correct number of patents and citations filed by each firm, the corporate family for each firm identified in SDC-CRSP/ Compustat was completed. Using this completed corporate family for each firm, each member of the corporate family was matched to the NBER patent data using a name matching algorithm. SDC Platinum identifies a firm using cusip, which is not unique. Therefore, the first step was to generate unique matches from the cusip provided in SDC to the gvkey identifier in CRSP/ Compustat. In this step, duplicate matches were isolated and manually checked to ensure accuracy of the match. The patent data is identified based on the patent assignee. Here again the name matching was done through a meta-text searching algorithm. The matches were also picked randomly and checked manually for their accuracy.

While the NBER dataset itself provides a set of matches from CRSP/ Compustat to the patent data, the match suffers from various drawbacks. First, it is based on the list of Compustat firms in 1986. Second, the number of firms matched is limited particularly when combined with the SDC data. Finally, the match does not account for firms filing patents through their various subsidiaries and divisions.[20]

The SDC module on Joint Ventures and Alliances primarily includes joint ventures and strategic alliances for both US and non-US firms.[21] Although the strategic alliances database dates back to 1986, SDC initiated systematic data collection procedures for tracking such deals only in 1989. Hence, our sample includes alliances and majority JVs from 1990 onwards. Since the NBER Patent data is available only till the year 2002, we end our sample in the same year.

Due to inadequate corporate reporting requirements on alliances, the SDC data does not include all deals consummated by US firms over this period. However, it provides the most comprehensive information on such deals and has been used in recent empirical research on alliances/ JVs (Robinson, 2007). For our empirical analysis, we exploit the detailed information about the various contractual features of the alliance/ JV.

To restrict our analysis to knowledge-intensive industries, we include strategic alliances and majority JVs categorized in SDC as belonging to the *High-Technology* sectors. Gomes-Casseres, et. al. (2006) point out that firms undertake alliances in the High-Technology sector "to promote technology sharing." We only use alliances/ JVs involving two partners. Both these selection criteria are employed to ensure that the empirical tests adhere closely to the setup modeled in the theory. Finally, since the coverage for US firms is more comprehensive than non-US firms, we restrict our analysis to US based alliances only.

6.2 Proxy for Access

Among strategic alliances, we use the presence of (i) licenses to technologies, (ii) Research and Development (R&D) agreements, and (iii) cross-technology transfer agreements to proxy access.

[20] I thank Ron Harris in Research Support at Goizueta Business School for programming and implementing the name-matching and to several undergraduate Research Assistants for compiling the corporate family from the S&P Directory of Corporate Affiliations and performing the manual checks to verify the accuracy of the name matching.

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

In our tests of access, we keep ownership unchanged by including strategic alliances but excluding majority JVs.

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, the strategic alliance between MedImmune Inc and Ixsys Inc (described earlier in Section 5) in which MedImmune provided a license to Ixsys. The licensing agreement required MedImmune to provide access to the antibody and other knowledge as illustrated by the following excerpt 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."

Similarly, an alliance which includes a research and development (R&D) agreement or a cross-technology transfer agreement indicates greater access than an alliance where no such agreement is employed. To illustrate, consider the following alliance which SDC records as containing a cross-technology transfer agreement:

> "Headstrong Corp. (HS) and Portellus Inc. (PI) . . . agreed to *establish a Technology Resource Center* . . . The Center was to be staffed by *HS employees working closely with PI technology and marketing specialists*."

Panel A of Table 3 shows the distribution of strategic alliances for each of these three proxies of access. We see that in the original SDC data (SDC-NBER merged dataset), the percentage of licenses, R&D agreements and cross-technology transfer agreements are 25%, 24% and 10% respectively (23%, 20% and 9% respectively). Thus, the overall percentages of these contractual features are quite similar in the original and merged datasets.

Panel A of Table 4 shows that the correlation of licensing with joint R&D and cross-technology transfers is quite high (0.67 and 0.78 respectively). However, the correlation between cross-technology transfers and joint R&D is quite low (0.16). This pattern of correlation should be expected since joint R&D and cross-technology transfers would need licenses to the relevant technologies.

6.3 Proxy for ownership

We employ strategic alliances and majority JVs together to construct a proxy for ownership. To ensure that the test for ownership is unaffected by changes in access, we use only those JVs and strategic alliances in which either of the following three conditions holds: (i) no license is involved, and (ii) no joint R&D agreement is signed. Each of these conditions leads to a separate sample, and we perform our tests on each individual sample. In keeping with our theoretical analysis, we include only those JVs in which one partner owns more than 50% of the equity in the JV company.

Since, in an alliance, neither firm enjoys residual rights of control, comparing alliances to majority JVs captures the changes in ownership. Panel B of Table 3 shows the distribution of alliances and majority JVs for each of the two samples mentioned above. We see that in the original SDC data (SDC-NBER merged dataset), the percentage of majority JVs for the samples (i) and (ii) is 11% and 9% respectively (15% and 13% respectively). Thus, as in the proxy for access, the overall percentages are similar in the original and merged datasets.

6.4 Proxies for θ

We follow Trajtenberg, Jaffe and Henderson (1992) and Hall, Jaffe and Trajtenberg (2001) in using patent citations to construct proxies for θ. Patents are a good representation of the stock of technological knowledge in firms and have long been used as an indicator of innovative activity and technological change in both the micro- and macro-economic studies (Griliches, 1990). Although patents provide an imperfect measure of innovation, there is no other widely accepted method which can be applied to capture technological advances. Nevertheless, we are aware that using patents has its drawbacks. Not all firms patent their innovations, because some inventions do not meet the patentability criteria and because the inventor might rely on secrecy or other means to protect its innovation. In addition, patents measure only successful innovations. To that extent, our results are subject to the same criticisms as previous studies that use patents to measure innovation (e.g., Griliches, 1990; Trajtenberg, Jaffe and Henderson (1992)).

We use three different proxies for θ: (i) Expropriability of a firm's alliance/ JV partner's knowledge, (ii) Breadth of Own Knowledge, and (iii) Replicability of a firm's alliance/ JV partner's knowledge. All these measures are constructed using citations to patents since citations delimit the scope of the property rights awarded by the patent and they capture the economic value of an innovation better than simple patents (Hall, Jaffe and Trajtenberg, 2001).

6.4.1 Expropriability of Alliance/ JV partner's Knowledge

Our first proxy – the expropriability of a firm's *alliance/ JV partner's knowledge* – is motivated by the fact that if A's knowledge is difficult for other firms to expropriate, then A's alliance/ JV partner B would have difficulty expropriating A's knowledge, which translates into a lower value for θ_B. Thus, we define our first proxy for θ as

$$Expropriability = \sum_{i=1}^{N} \left(1 - \frac{SelfF_i + SelfB_i}{2} \right) \tag{18}$$

This measure is calculated using a *firm's alliance partner's patent portfolio*: N is the total number of patents, $SelfF_i$ is defined for patent i as the ratio of own patents that cite patent i to the total number of patents that cite patent i and $SelfB_i$ is defined as the ratio of own patents cited in patent i to the total patents cited in patent i.

The rationale for this measure is as follows. Citations *received* by a particular patent reflect follow-up developments of the original innovation/ knowledge and that these developments are the conduit that leads to the realization of benefits from the original patent. Thus, the higher the proportion of these later developments that take place "in-house", i.e. larger $SelfF_i$, the larger would be the fraction of the benefits captured by the original producer of the knowledge. $SelfB_i$ is the equivalent measure calculated using citations *made* by the particular patent. It captures virtually the same notion, that is, it measures the extent by which the originating innovation represents appropriation of benefits to its predecessors housed in the same firm.

6.4.2 Breadth of Own Knowledge

Our second proxy for θ is motivated by the fact that if a firm has broad technological expertise, 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. As in Trajtenberg, Jaffe and Henderson (1992), we measure the breadth of a patent as a Herfindahl Index measure using citations *received by* a firm's patents. Thus, the second proxy for θ is defined as

$$Breadth = \sum_{i=1}^{N} bp_i = \sum_{i=1}^{N} \left(1 - \sum_{j}^{n} s_{ij}^2\right) \tag{19}$$

This measure is calculated using a *firm's own patent portfolio:* N is the total number of patents, s_{ij} denotes the percentage of citations received by patent i that belong to patent class j and n is the number of patent classes.

6.4.3 Replicability of Alliance/ JV partner's Knowledge

We use one minus the patent originality measure constructed in Hall, Jaffe and Trajtenberg (2001) to capture how easily replicable a firm's alliance/ JV partner's knowledge is. Hall, Jaffe and Trajtenberg (2001) construct the measure of a patent's originality using the trail of backward citations, i.e., the citations made by the particular patent. The rationale for the originality measure is that if the technological roots of the knowledge underlying a patent are broader, then such knowledge is more original since the synthesis of divergent ideas arguably constitutes an element of originality. Since more original patents would be an output of more divergent ideas and hence less easily replicable, θ_A would be lower if firm B's knowledge is more original, or in other words less replicable. Thus, our third proxy for θ is defined as

$$Replicability = \sum_{i=1}^{N} r_i, r_i = \sum_{j=1}^{n} s_{ij}^2 \tag{20}$$

This measure is calculated using a *firm's alliance partner's patent portfolio*: N, s_{ij} and n are as defined in (19).

Panel B of Table 4 shows the correlation between Expropriability, Breadth, Replicability and Logarithm of firm size. While the three proxies for θ are positively correlated with each other, their correlation is not perfect. Therefore, they can be employed as separate proxies for θ. We also find that all these proxies correlate positively with firm size.

6.5 Test for Access

Part (a) of Proposition 3 predicts that access decreases as knowledge of both firms becomes easier to expropriate. We test this hypothesis using the following regression

$$Prob\,(y_{kt} = 1) = b_0 + b_1 \cdot \theta_{A,t-1} + b_2 \cdot \theta_{B,t-1} + BX_t + \varepsilon_{kt} \tag{21}$$

where $k = 1, \ldots, N$ are strategic alliances in High Technology sectors from 1990-2002. We test separately for licenses, R&D agreements, and cross-technology transfers as proxies for access. When we employ license as a proxy, $y_{kt} = 1$ if the alliance includes a license and $y_{kt} = 0$ otherwise. The dependent variable is defined similarly for the other proxies as well. X_t represents the set of control variables. According to part (a) of Proposition 3

$$Hypothesis : b_1 < 0, b_2 < 0 \tag{22}$$

6.6 Test for Ownership

Part (b) of Proposition 3 predicts that changing ownership is optimal when the knowledge of one firm is easy to expropriate while the other's is difficult to expropriate. We test this hypothesis using the following regression

$$Prob\,(JV_{kt} = 1) = c_0 + c_1 \cdot \theta_{A,t-1} + c_2 \cdot \theta_{B,t-1} + CX_t + \varepsilon_{kt} \tag{23}$$

where $k = 1, \ldots, N$ are majority JVs and strategic alliances in High Technology sectors from 1990-2002. To ensure that access is unchanged, we restrict our sample to those where no license is involved and where no joint R&D agreement is signed. $JV_{kt} = 1$ if the deal was a majority JV, while $JV_{kt} = 0$ if the deal is a strategic alliance. In the sub-sample of majority JVs, $\theta_{A,t-1}$ ($\theta_{B,t-1}$) captures majority (minority) JV partner's ability to expropriate knowledge.[22] According to part (b) of Proposition 3

$$Hypothesis : c_1 < 0, c_2 > 0 \tag{24}$$

[22] Unlike the majority joint venture deals, identifying θ_i and θ_j to either of the alliance partners is not possible. Ideally, in keeping with the way θ_i and θ_j were defined for the sub-sample of majority JVs, θ_i (θ_j) should be the measure of replicability for the firm which would the majority (minority) partner if the alliance were, in fact, a majority JV. However, it is not possible to infer in the alliance which of the two firms could be the potential majority/ minority partner. Therefore, I run robustness tests to ensure that the results are not affected by this choice of θ_i and θ_j. In particular, I test by having θ_i as the larger of the replicability measures for the two firms, then by making θ_i the smaller of the two measures, and also by randomizing this choice of θ_i and θ_j. The results remain unchanged. The result we report is using the firm A and firm B defined in the SDC Platinum database. The order of firms in the SDC data is the order in which they appeared in the press clipping announcing the alliance.

6.7 Control Variables

We control for various other determinants of alliances and JVs and the contractual features witnessed in these hybrids. First, we include various firm level control variables. To control for effects of firm size, we include the logarithm of the Total Assets for both firms. Since firms with greater investments in R&D may undertake more alliances/ JVs as well as be involved in providing access to their technologies, we include the ratio of R&D to Sales for both firms. We include Tobin's Q for both firms to proxy their investment opportunities. Second, we control for strategic considerations that may drive the decision to undertake an alliance/ JV or the decision to provide access. The proximity in the primary industries of the alliance partners may influence these decisions because these contractual choices could be a way for two firms 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 or entering into an alliance for fear of jeopardizing their competitive positions. Therefore, we include a dummy variable to capture whether the alliance partners have the same primary SIC code at the n-digit level ($n = 2, 3, 4$) which captures how strong the potential competition between them would be. We also include the Herfindahl index (calculated using the book value of assets) for the degree of competition in the 4-digit SIC industry of the alliance. Since Baker, Gibbons and Murphy (2004) argue that firms could use an alliance/ JV to complement or compete with their core activities, we include the overlap in the primary industries of each partner firm with the primary industry of the alliance/ JV.

We include industry fixed effects in the regressions to account for unobserved factors at the industry level. The strength of Intellectual Property Protection in the industry may influence firm's desire to undertake cooperative ventures such as alliance/ JV. We include Calendar year effects since the samples across years may not be independent. Dependence in samples across years result because the same firms may be involved in alliances or JVs across different years. Furthermore, unobserved calendar effects like the appearance of a breakthrough technology or differences in the number of patents across years may impact collaboration through alliance or JVs in a particular year. 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 expropriate. To include firm fixed effects, we restrict our analysis to a sample in which at least one of the firms has been involved in multiple alliances. We then include dummies for the firm which has been involved in more deals. The industry, time and firm fixed effects also enable us to control for biases resulting from sample selection since there may be differences between the original SDC and merged SDC-NBER sample in their industries, calendar years and firms.

Logit specification is used to test equations (21) and (23) 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 5 presents the results from logit regression for the likelihood of a license among all strategic alliances in the merged SDC-NBER sample. In specifications (1)-(3), we examine the basic result using Exprobriability, Breadth and Replicability as the three proxies for θ (see Table 2 for a description of these variables). We find that in these basic specifications, the coefficients b_1 and b_2 as specified in (21) are strongly negative.

In specifications (4) and (5), we include all the control variables described in Section 6.7. In specification (4), we include year and industry dummies while in specification (5) we include year dummies along with dummies for the alliance partner which is involved in more number of deals. Among our control variables, we find that while Tobin's Q and R&D/ Sales are statistically significant in specification (4), they lose their significance when in specification (5) where we include the firm fixed effects. We find that firm size is not statistically significant in either specification.

As for the strategic considerations that drive licensing in alliances, we find that the coefficient of Partners in same SIC is strongly positive, which suggests that firms belonging in the same primary SIC industry are more likely to provide a license to each other. This result is consistent with the point made by Gomes-Casseres, et. al. (2006) that firms undertake alliances in the High-Technology sector "to promote technology sharing" since technology sharing would be more likely between firms in similar industries. We also find that the coefficient of Alliance in same SIC is strongly positive for both partner firms, which suggests that firms are likely to provide a license in an alliance when the alliance industry overlaps with their core industry. Since spillovers may be more likely when firms undertake alliance activities that are close to their core activity, this evidence suggests that firms may be providing licenses in anticipation of their positive spillover effects as argued by Baker, Gibbons and Murphy (2004). Furthermore, the evidence suggesting positive spillover effects combined with partner firms in similar industries providing access through a license is consistent with the setting examined in the theory, i.e., synergies stemming from pooling complementary knowledge assets. Finally, we also find that a license is less likely in an alliance if the degree of competition in the industry of the alliance is higher.

Importantly, across all these specifications, we find that coefficients the coefficients b_1 and b_2 as specified in (21) are strongly negative. As the probabilities from the F-test of the statistical significance of both coefficients indicate, both these coefficients are negative at the 95% level of confidence. The economic effects are significant too: a one standard deviation increase in Expropriability from its median value for firm A decreases the probability of a license by 13% while a two standard deviation increase decreases the probability by 18%. The effects are quite similar for the other proxies. Since 23% of the strategic alliances in the merged SDC-NBER sample involve licenses, these changes are economically large.

In Table 6, we perform identical tests to the above using R&D agreements instead of license as the proxy for access and find the results to be just as strong. In Table 7, we use cross-technology transfer as a proxy for access. Here, the tests using firm fixed effects lack power given the lower incidence of cross-technology transfers. Both in Table 6 and 7, we find similar results to those in Table 5 for our various control variables. More importantly, we find across the various specifications in Table 6 and 7 that the coefficients b_1 and b_2 as specified in (21) are both strongly negative.

These tests indicate that access through a license, an R&D agreement, or a cross-technology transfer is less likely when both firms have a higher ability to expropriate their partner's knowledge. This result demonstrates that access has a symmetric effect on the incentives of both firms.

6.8.2 Ownership

Table 8 presents the results from logit regression for the likelihood of a majority JV versus a strategic alliance in the merged SDC-NBER sample. The specifications that we employ are identical to those employed in Tables 5 and 6. Across all the specifications in this table, we find that the coefficient c_1 as specified in (23) is strongly negative while c_2 is strongly positive. The joint F-test on both these coefficients indicates that they are jointly significant. The economic effects are significant too: a one standard deviation increase in Expropriability for firm A from its median value decreases the probability of a JV by 7% while a two standard deviation increase decreases the probability by 11%. The economic effect is of a similar order of magnitude for the other proxies. Since 15% of the deals involving no licenses in the merged dataset are majority JVs, these changes are economically large.

In Table 9, we perform tests identical to those in Table 8. However, the sample employed here keeps access unchanged by examining those deals in which there is no R&D agreement. Again, we find that c_1 as specified in (23) is strongly negative while c_2 is strongly positive.[23]

Collectively, these results suggest that compared to strategic alliances, the likelihood of majority JVs is higher when the ability to expropriate decreases for the majority JV partner while it increases for the minority JV partner. Therefore, these results demonstrate that ownership has an asymmetric effect on the incentives of agents.

6.9 Discussion

The empirical results obtained here are consistent with Proposition 3. However, can these results enable us to separate our theory from other existing ones, in particular the theories proposed by GHM and Rajan and Zingales (1998,2001)? As we argued in Section 5, the PRT cannot distinguish strategic alliances and contracts such as licenses, R&D and cross-technology transfer agreements from arms-length contracts. Thus, the results that we obtain supporting the symmetric effect of access cannot be obtained in the PRT. The results we obtain supporting the asymmetric effect of ownership may appear to be supportive of the PRT since in their theory too ownership enhances the incentives of the agent receiving ownership but dampens the incentives of the agent losing

[23] We find that the results for our control variables are similar to those obtained in Tables 6-8 suggesting that other determinants have similar effects on the incidence of licenses, R&D agreements in alliances as well as on the alliance versus majority JV decision.

ownership. However, Proposition 2 (iv) in Chapter 2 of Hart (1995) concludes that some form of integration is always optimal when the assets are complementary to each other, which is the setting that we study here. Therefore, for the complementary asset setting examined here, GHM predicts that a majority JV will always be optimal. Therefore, neither the result supporting the symmetric effect of access nor the one supporting the asymmetric effect of ownership would be obtained in the PRT.

As we argued in Section 5, an extension of the theory proposed by Rajan and Zingales (1998) can explain differences between strategic alliances and arms-length contracts as well as features such as licenses. Therefore, the result supporting the symmetric effect of access is consistent with the Rajan and Zingales (1998) theory as well. However, since they do not model ownership, the distinction between majority JV and alliance cannot be made in their framework. Therefore, the result supporting the asymmetric effect of ownership cannot be obtained using their framework.

Collectively, the evidence shown in Tables 5-8 combined with the aggregate evidence in Table 1, which we discussed in Section 5, provide evidence that is uniquely consistent with the theory proposed here.

7 Conclusion

Since knowledge assets are non-rival in nature, access provided to knowledge assets ex ante cannot be revoked ex post. Therefore, we 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. To capture the incentive effects of the boundary decisions in knowledge-intensive firms, we model them using both access and ownership. This approach enabled us to model simultaneously the trade-offs that knowledge-intensive firms confront when deciding among mergers/acquisitions, joint ventures, alliances, and arms-length contracts. The model showed that *both* the firms can be provided stronger incentives by choosing ownership of knowledge and access to knowledge together; neither ownership nor access can accomplish the same on their own. The model helps rationalize the dominance of alliances and joint ventures as well as the sharing of knowledge assets through contractual arrangements in the knowledge intensive industries.

To focus on the incentive effects of boundary decisions, we did not model explicitly the control rights in an alliance/ JV. The benefit of our approach was that it delivered clear insights about how the boundary decision between two knowledge-intensive firms can resolve the problems of over- and underinvestment 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 the control rights given a boundary choice – substitute for or complement each other? If they substitute or complement one another, 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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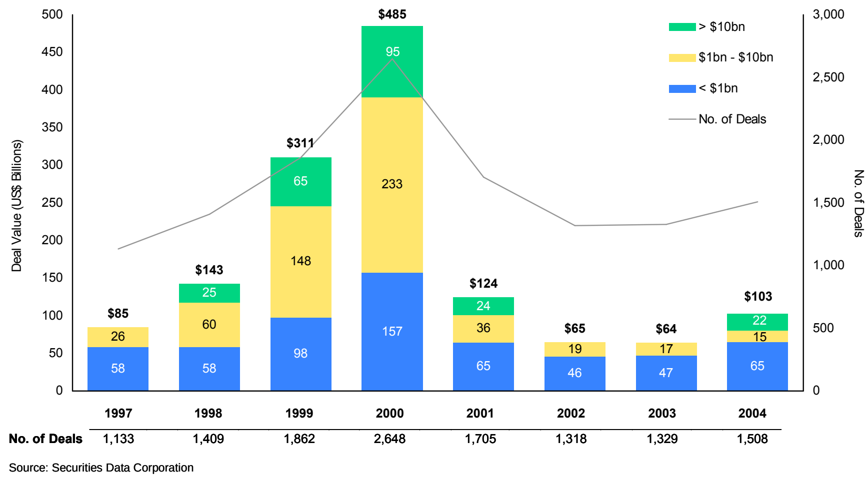

Figure 1: Mergers and Acquisitions Activity in the Knowledge Intensive Industries (1997-2004)

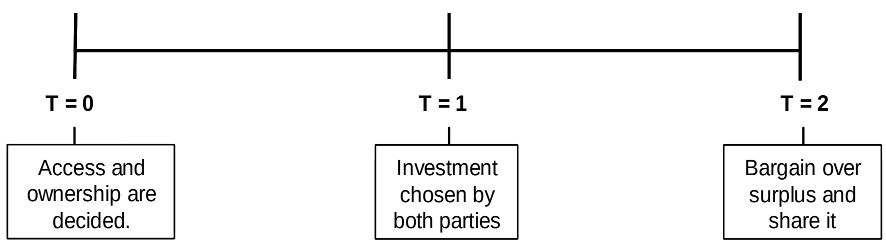

Figure 2: Sequence of events

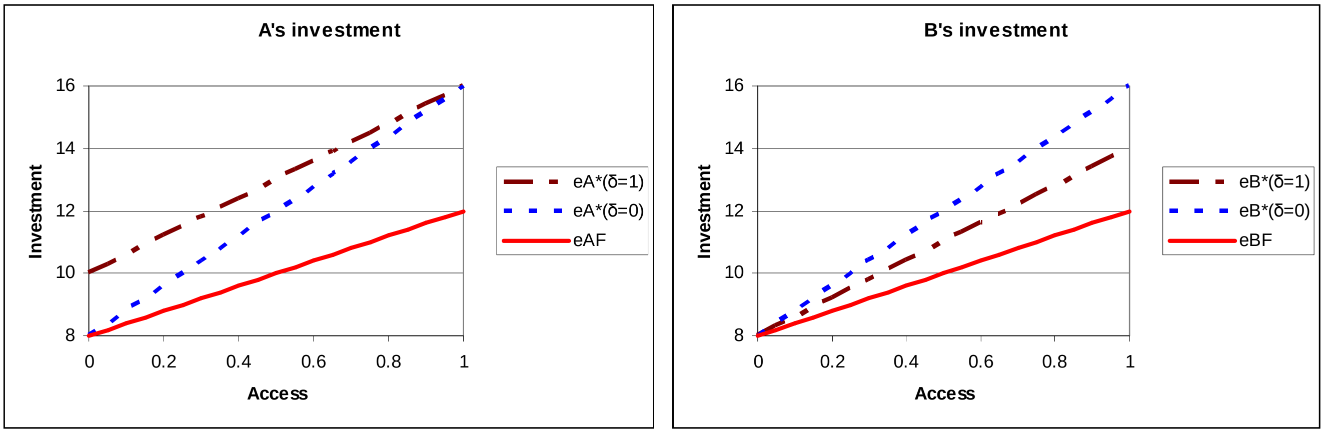

Figure 3: Arms-length contract ($\alpha = 0, \delta = 0$) is optimal when both A and B can expropriate very easily $\left(\theta^A = \theta^B = 1\right)$

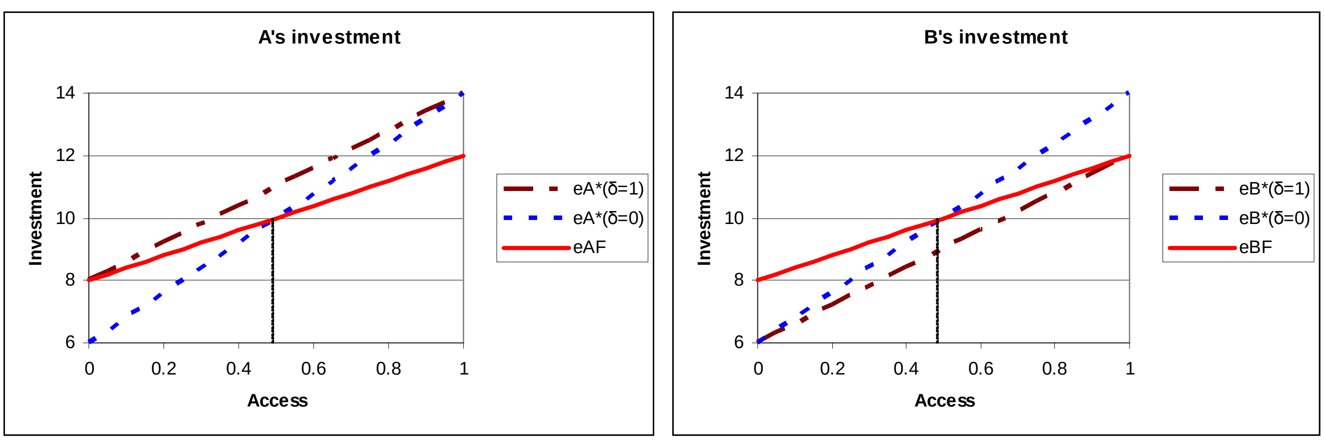

Figure 4: Strategic Alliance ($\alpha = 0.5, \delta = 0$) is optimal when both A and B can expropriate with moderate ease $\left(\theta^A = \theta^B = 0.5\right)$

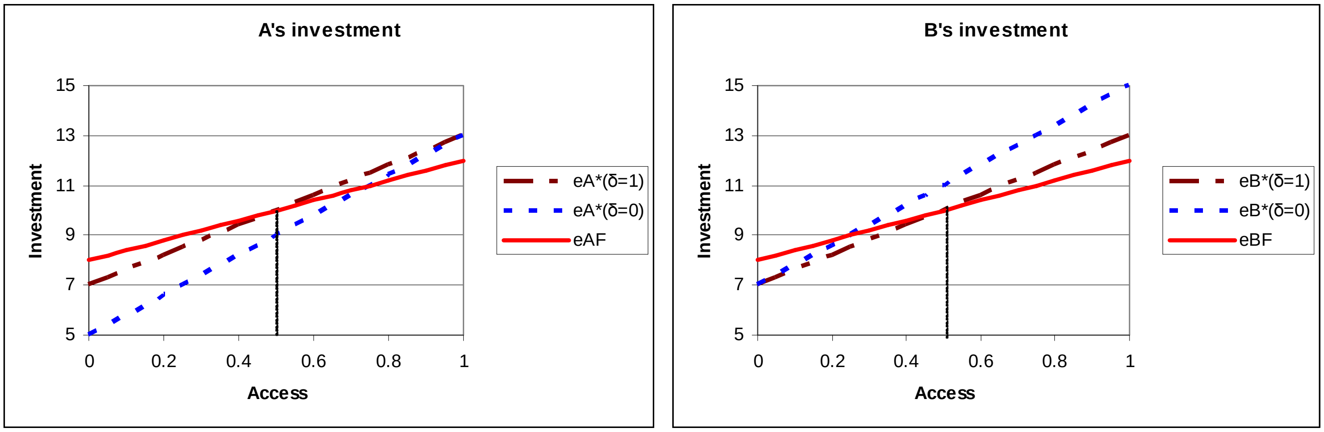

Figure 5: Majority Joint Venture ($\alpha = 0.5, \delta = 1$) is optimal when B can expropriate easily $\left(\theta^B = 0.75\right)$ while A cannot expropriate easily $\left(\theta^A = 0.25\right)$

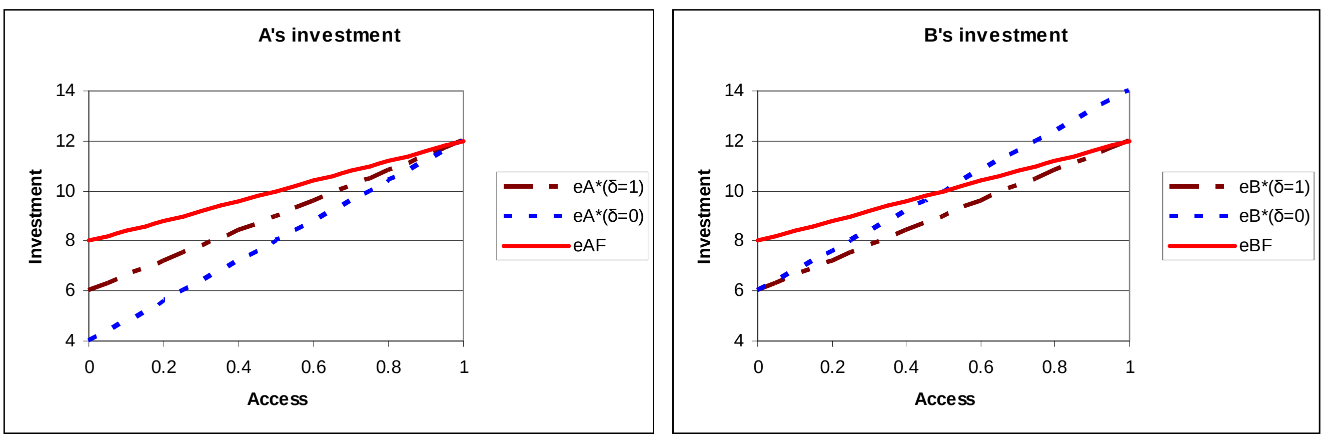

Figure 6: Merger/ Acquisition ($\alpha = 1, \delta = 1$) is optimal when A cannot expropriate $\left(\theta^A = 0\right)$ while B can expropriate with moderate ease $\left(\theta^B = 0.5\right)$

Table 1: Alliances and Majority JVs between two firms: High Technology and Non High Technology Industries

This table describes differences between High Technology and Non High Technology industries in (i) incidence of and (ii) contractual features in strategic alliances and majority joint ventures. The sample is drawn from SDC Platinum's Alliances and Joint Ventures Database. The classification of industries as High Technology and Non High Technology is as done by SDC Platinum. We only include Alliances and JVs undertaken between two firms. Panel A points out difference in the frequency of alliances and majority joint ventures; Panel B describes the difference in the use of licenses; Panel C details the difference in the use of R&D agreement and Panel D describes the difference in the use of cross-technology transfer agreements.

	Panel A: Alliances and Joint Ventures			Panel B: Licensing Agreements		
Year	Hitech	Non-Hitech	% Hitech	Hitech	Non-hitech	% Hitech
1990	506	135	79%	114	6	95%
1991	858	257	77%	180	26	87%
1992	1172	280	81%	238	43	85%
1993	1113	260	81%	300	43	87%
1994	1323	500	73%	419	98	81%
1995	1307	562	70%	524	136	79%
1996	834	360	70%	330	77	81%
1997	1257	486	72%	464	95	83%
1998	1384	572	71%	469	121	79%
1999	1852	578	76%	365	99	79%
2000	1776	351	83%	75	12	86%
2001	1039	337	76%	56	9	86%
2002	855	192	82%	53	11	83%
2003	1333	230	85%	129	41	76%
2004	1094	231	83%	110	34	76%
2005	1169	250	82%	88	24	79%
2006	1226	284	81%	61	17	78%
2007	700	206	77%	65	13	83%
Total	20798	6071	77%	4040	905	82%

	Panel C: R&D agreements			Panel D: Cross-technology transfers		
Year	Hitech	Non-Hitech	% Hitech	Hitech	Non-hitech	% Hitech
1990	85	6	93%	39	0	100%
1991	195	25	89%	64	2	97%
1992	564	31	95%	17	0	100%
1993	537	50	91%	189	29	87%
1994	682	63	92%	493	60	89%
1995	497	65	88%	286	40	88%
1996	244	29	89%	73	3	96%
1997	353	35	91%	74	4	95%
1998	156	24	87%	119	10	92%
1999	107	11	91%	61	5	92%
2000	59	11	84%	43	1	98%
2001	83	12	87%	8	0	100%
2002	87	7	93%	4	0	100%
2003	105	9	92%	14	0	100%
2004	108	15	88%	16	0	100%
2005	124	9	93%	320	3	99%
2006	94	12	89%	481	5	99%
2007	74	6	93%	201	1	100%
Total	4154	420	91%	2502	163	94%

Table 2: Description of Variables

This table describes the construction of the explanatory variables used for empirical analysis

Variable	Description	Definition
N	Total number of patents	Total patents of all subsidiaries and divisions where the Corporate Family of each firm is obtained from the *S&P Directory of Corporate Affiliations*. This includes patents issued till the year before which the alliance was initiated.
Expropriability	Expropriability of Alliance/ JV **Partner's** patent portfolio	Expropriability $= 1 - \sum_{i=1}^{N} \frac{SelfF_i + SelfB_i}{2}$. $SelfF_i$ is defined for patent i as the ratio of own patents that cite patent i to the total number of patents that cite patent i. $SelfB_i$ is defined as the ratio of own patents cited in patent i to the total patents cited in patent i.
Breadth	Breadth of Firm's **Own** Patent portfolio	Breadth $= \sum_{i=1}^{N} b_i, b_i = 1 - \sum_{j=1}^{36} s_{ij}^2$, s_{ij} is percentage of citations *received* by patent i in industry category j.
Replicability	Replicability of Alliance/ JV **Partner's** patent portfolio	Replicability $= \sum_{i=1}^{N} r_i, r_i = \sum_{j=1}^{n} s_{ij}^2$, s_{ij} is percentage of citations *made* by patent i in patent class j, where n is the number of patent classes.
Log Firm Size	Logarithm of size of firms	Log Firm Size = ln(Total Assets) where Total Assets is Data Item 6 in *Compustat* Annual Files.
Herfindahl Index	Herfindahl Index of the degree of competition in the 4-digit Primary SIC of the Alliance/ JV	$\sum_{j=1}^{N} s_{ij}^2$, s_{ij} is ratio of Total Assets for firm j in 4-digit SIC industry i where Total Assets is Data Item 6 in *Compustat* Annual Files.
R&D to Sales	Ratio of R&D Expenditure to Sales	=Data46/Data12 from *Compustat* Annual files
Tobin's Q	Ratio of the Market Value of Assets to their Book Value	The Market Value of Assets is constructed as the Total book value of assets (Data 6) minus the book value of common equity (Data 60) minus the book value of deferred taxes (Data 74) plus the market value of equity (Data 24 * Data 25).
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 $= n - 1$ if primary SIC codes of both firms is same to n-digits $\forall n = 2, 3, 4; = 0$ otherwise
Alliance/ JV in same SIC$_i$	Does alliance partner i have identical primary SIC code as the alliance/ JV at the 2 digit, 3 digit or 4 digit level.	Alliance/ JV in same SIC$_i$ $= n - 1$ if primary SIC codes of firm i is same as primary SIC code of Alliance/ JV to n-digits $\forall n = 2, 3, 4; = 0$ otherwise

Table 3: Average Values and Distribution of Proxies of Access and Ownership

This table shows the distribution of various proxies of access among strategic alliances and that of the proxy for ownership for various samples that keep access unchanged. These statistics are displayed for the original number of deals categorized as High-Technology in the SDC Platinum database and in the sample resulting after merging these 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 proxies for access. Panel B shows the distribution of majority joint ventures and alliances for deals: (i) not containing a license, and (iii) not containing a R&D agreement.

Panel A: Proxies for Access

1. License vs. No License	SDC	SDC-NBER
License	3549	893
No License	10424	2990
Total Alliances	13973	3883
% License in Alliances	25%	23%

2. With/ Without R&D agreement	SDC	SDC-NBER
R&D Agreement	3371	777
No R&D Agreement	10602	3106
Total Alliances	13973	3883
% R&D Agreement in Alliances	24%	20%

3. Cross-technology transfer	SDC	SDC-NBER
Cross-Technology Transfer	1343	349
No Cross-Technology Transfer	12630	3534
Total Alliances	13973	3883
% Cross-technology Trasnfer among Licenses	10%	9%

Panel B: Proxies for Ownership

1. Sample containing No Licenses	SDC	SDC-NBER
Majority Joint Venture	1265	528
Alliance	10424	2990
Total Deals with No License	11689	3518
% Majority Joint Ventures	11%	15%

2. Sample containing No R&D Agreements	SDC	SDC-NBER
Majority Joint Venture	1025	464
Alliance	10602	3106
Total Deals with R&D agreement	11627	3570
% Majority Joint Ventures	9%	13%

Table 4: Correlations among proxies of Access and among Explanatory Variables

In Panel A, the correlations between the various proxies of Access are shown while Panel B shows the correlation between the principal explanatory variables.

Panel A: Correlation between Proxies of Access

	License	Technology Transfer
Technology Transfer	0.668	
R&D Agreement	0.762	0.163

Panel B: Correlation between primary explanatory variables

	Expropriability	Breadth	Replicability
Breadth	0.224		
Replicability	0.451	0.651	
Log(Total Assets)	0.556	0.432	0.816

Table 5: 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 which are categorized as belonging to the High Technology sector and in which both the partnering firms had a match in the NBER Patents database. The dependent variable in these *logit regressions* 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 the 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)
Proxy for θ	Expropriability	Breadth	Replicability	Expropriability	Expropriability
θ_A	-0.99***	-1.19***	-1.38**	-1.11***	-1.22***
	(0.30)	(0.39)	(0.63)	(0.41)	(0.43)
θ_B	-0.86***	-1.44***	-1.22**	-1.32***	-1.45***
	(0.28)	(0.49)	(0.59)	(0.32)	(0.42)
Log Firm Size$_A$				-0.06	-0.11
				(0.04)	(0.10)
Log Firm Size$_B$				-0.08	-0.28
				(0.05)	(0.20)
R&D/Sales$_A$				0.13**	0.06
				(0.06)	(0.12)
R&D/Sales$_B$				0.21**	0.07
				(0.10)	(0.10)
Tobin's Q$_A$				0.71*	0.86
				(0.36)	(0.52)
Tobin's Q$_B$				0.86*	0.97
				(0.50)	(0.60)
Partners in same SIC				0.08***	0.07**
				(0.03)	(0.03)
Alliance in same SIC$_A$				0.53**	0.34*
				(0.24)	(0.16)
Alliance in same SIC$_B$				0.16*	0.27**
				(0.09)	(0.12)
Herfindahl Index				-0.06***	-0.08***
				(0.02)	(0.03)
Year Dummies	No	No	No	Yes	Yes
Industry Dummies	No	No	No	Yes	No
Firm Dummies	No	No	No	No	Yes
F-test probability	0.00	0.01	0.04	0.01	0.00
Psuedo R-squared	6.1%	5.2%	4.3%	9.2%	18.9%
Observations	3883	3883	3883	3883	2762

Table 6: Test of Symmetric Effect of Access: R&D Agreements in Alliances

The sample consists of *strategic alliances* over the period 1990-2002 in the SDC Platinum database which are categorized as belonging to the High Technology sector and in which both the partnering firms had a match in the NBER Patents database. The dependent variable in these *logit regressions* is an indicator variable equal to 1 if, the alliance includes an R&D agreement and 0 if no R&D agreement is included. 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 heteroskedasticity 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)
Proxy for θ	Expropriability	Breadth	Replicability	Expropriability	Expropriability
θ_A	-0.85***	-1.16**	-1.14*	-1.11***	-1.22***
	(0.30)	(0.46)	(0.66)	(0.41)	(0.43)
θ_B	-0.82**	-1.33**	-1.18**	-1.32***	-1.45***
	(0.34)	(0.52)	(0.60)	(0.32)	(0.42)
Log Firm Size$_A$				-0.03	-0.05
				(0.03)	(0.12)
Log Firm Size$_B$				-0.06	-0.26
				(0.05)	(0.22)
R&D/Sales$_A$				0.14**	0.17
				(0.06)	(0.14)
R&D/Sales$_B$				0.32*	0.23
				(0.17)	(0.20)
Tobin's Q$_A$				0.53*	0.74
				(0.29)	(0.52)
Tobin's Q$_B$				0.75*	0.81
				(0.42)	(0.60)
Partners in same SIC				0.11***	0.10
				(0.03)	(0.08)
Alliance in same SIC$_A$				0.41**	0.34**
				(0.19)	(0.16)
Alliance in same SIC$_B$				0.58**	0.21*
				(0.28)	(0.12)
Herfindahl Index				-0.12**	-0.17**
				(0.05)	(0.07)
Year Dummies	No	No	No	Yes	Yes
Industry Dummies	No	No	No	Yes	No
Firm Dummies	No	No	No	No	Yes
F-test probability	0.03	0.05	0.05	0.05	0.04
Psuedo R-squared	10.8%	5.2%	5.4%	14.4%	17.6%
Observations	3883	3883	3883	3883	2531

Table 7: Test of Symmetric Effect of Access: Cross-technology transfer in Alliances

The sample consists of *strategic alliances* over the period 1990-2002 in the SDC Platinum database which are categorized as belonging to the High Technology sector and in which both the partnering firms had a match in the NBER Patents database. The dependent variable in these *logit regressions* is an indicator variable equal to 1 if, the alliance includes an cross-technology transfer agreement and 0 if no cross-technology transfer agreement is included. 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)
Proxy for θ	Expropriability	Breadth	Replicability	Expropriability
θ_A	-0.67***	-0.83*	-0.54**	-1.82**
	(0.17)	(0.44)	(0.27)	(0.80)
θ_B	-0.38*	-0.78*	-0.52*	-1.06**
	(0.21)	(0.42)	(0.31)	(0.53)
Log Firm Size$_A$				-0.02
				(0.05)
Log Firm Size$_B$				-0.09
				(0.11)
R&D/Sales$_A$				0.26**
				(0.12)
R&D/Sales$_B$				0.22**
				(0.10)
Tobin's Q$_A$				0.42
				(0.34)
Tobin's Q$_B$				0.66
				(0.48)
Partners in same SIC				0.20*
				(0.12)
Alliance in same SIC$_A$				0.41**
				(0.19)
Alliance in same SIC$_B$				0.37**
				(0.18)
Herfindahl Index				-0.24***
				(0.08)
Year Dummies	No	No	No	Yes
Industry Dummies	No	No	No	Yes
F-test probability	0.04	0.08	0.06	0.02
Psuedo R-squared	6.8%	6.3%	5.5%	9.3%
Observations	3883	3883	3883	3883

Table 8: Asymmetric Effect of Ownership: Alliances and JVs not including a License

The sample consists of *joint ventures* (where one partner has majority stake) *and strategic alliances* over the period 1990-2002. Only those deals which are categorized as belonging to the High Technology sector and in which both the partnering firms had a match in the NBER Patents database are used. To keep access unchanged, only those deals which did not involve a license are included for analysis. The dependent variable in these *logit regressions* equals 1 if the deal is a JV and 0 if it is an alliance. *Firm A corresponds to the majority stake owner if the deal is a JV.* 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 firm 1 and positive for firm 2. The heteroskedascticity and autocorrelation robust standard errors reported in parentheses are adjusted for clustering of observations by year. ***, ** and * respectively denote significance at 1%, 5% and 10%.

	(1)	(2)	(3)	(4)	(5)
Proxy for θ	Expropriability	Breadth	Replicability	Expropriability	Expropriability
θ_A	-0.19***	-0.19**	-0.38***	-0.21***	-0.32***
	(0.05)	(0.09)	(0.13)	(0.05)	(0.07)
θ_B	0.26***	0.44***	0.22**	0.32***	0.43***
	(0.05)	(0.18)	(0.09)	(0.11)	(0.08)
Log Firm Size$_A$				0.03***	0.18
				(0.01)	(0.10)
Log Firm Size$_B$				0.03*	0.31
				(0.02)	(0.35)
R&D/Sales$_A$				0.26**	0.15
				(0.10)	(0.12)
R&D/Sales$_B$				0.32**	0.17
				(0.13)	(0.15)
Tobin's Q$_A$				0.38*	0.36
				(0.20)	(0.22)
Tobin's Q$_B$				0.45*	0.43
				(0.25)	(0.32)
Partners in same SIC				0.08**	0.07**
				(0.04)	(0.03)
Alliance in same SIC$_A$				0.78*	1.04*
				(0.41)	(0.55)
Alliance in same SIC$_B$				0.86*	1.11*
				(0.45)	(0.58)
Herfindahl Index				0.03	0.04
				(0.03)	(0.05)
Year Dummies	No	No	No	Yes	Yes
Industry Dummies	No	No	No	Yes	No
Firm Dummies	No	No	No	No	Yes
F-test probability	0.00	0.01	0.04	0.01	0.00
Psuedo R-squared	5.1%	4.5%	4.8%	8.9%	13.2%
Observations	3518	3518	3518	3518	1871

Table 9: Asymmetric Effect of Ownership: Alliances and JVs not including an R&D agreement

The sample consists of *joint ventures* (where one partner has majority stake) *and strategic alliances* over the period 1990-2002. Only those deals which are categorized as belonging to the High Technology sector and in which both the partnering firms had a match in the NBER Patents database are used. To keep access unchanged, only those deals which did not involve a R&D agreement are included for analysis. The dependent variable in these *logit regressions* equals 1 if the deal is a JV and 0 if it is an alliance. *Firm A corresponds to the majority stake owner if the deal is a JV*. 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 firm 1 and positive for firm 2. The heteroskedascticity and autocorrelation robust standard errors reported in parentheses are adjusted for clustering of observations by year. ***, ** and * respectively denote significance at 1%, 5% and 10%.

	(1)	(2)	(3)	(4)	(5)
Proxy for θ	Expropriability	Breadth	Replicability	Expropriability	Expropriability
θ_A	-0.23***	-0.29***	-0.46***	-0.31***	-0.40***
	(0.06)	(0.10)	(0.15)	(0.06)	(0.07)
θ_B	0.26***	0.49**	0.30***	0.36***	0.48***
	(0.06)	(0.19)	(0.09)	(0.12)	(0.09)
Log Firm Size$_A$				0.05*	0.21*
				(0.03)	(0.11)
Log Firm Size$_B$				0.01	0.27*
				(0.04)	(0.16)
R&D/Sales$_A$				0.26**	0.15
				(0.10)	(0.12)
R&D/Sales$_B$				0.32**	0.17
				(0.13)	(0.15)
Tobin's Q$_A$				0.12**	0.16*
				(0.06)	(0.09)
Tobin's Q$_B$				0.13**	0.15*
				(0.06)	(0.08)
Partners in same SIC				0.14**	0.13*
				(0.06)	(0.07)
Alliance in same SIC$_A$				0.41**	0.34**
				(0.19)	(0.16)
Alliance in same SIC$_B$				0.58**	0.21*
				(0.28)	(0.12)
Herfindahl Index				0.25	0.14
				(0.23)	(0.11)
Year Dummies	No	No	No	Yes	Yes
Industry Dummies	No	No	No	Yes	No
Firm Dummies	No	No	No	No	Yes
F-test probability	0.01	0.01	0.00	0.01	0.00
Psuedo R-squared	6.4%	6.1%	8.3%	11.9%	18.0%
Observations	3570	3570	3570	3570	1896

Appendix A – Robustness Checks

A.1 Multi-tasking in investments

Here, we 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 A's knowledge while e^A denotes investments by A to understand B's knowledge. The joint output generated by each firm is affected by its investments to develop the idea and by its investments to understand how to use the asset of its 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:

$$\begin{aligned} R_k^j &> 0, R_{kk}^j < 0, R_{k\alpha}^j > 0, \quad j \in \{A, B\}, k \in \{i, e\} \\ r_e^j &> 0, r_{ee}^j < 0, r_{e\alpha}^j > 0, \quad j \in \{A, B\} \\ r_e^A(\delta = 1) &> r_e^A(\delta = 0); r_e^B(\delta = 1) < r_e^B(\delta = 0) \\ r_{e\theta}^B &> 0, r_{e\psi}^A < 0 \end{aligned} \tag{25}$$

The net surplus generated in the relationship is given by

$$TS \equiv R^A\left(i^A, e^A, \alpha\right) + R^B\left(i^B, e^B, \alpha\right) - i^A - e^A - i^B - e^B \tag{26}$$

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

$$R_k^j\left(i^{jF}, e^{jF}, \alpha\right) = 1, \quad j \in \{A, B\}, k \in \{i, e\} \tag{27}$$

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

$$\begin{aligned} TS^A &= 0.5R^A\left(i^A, e^A, \alpha\right) + 0.5R^B\left(i^B, e^B, \alpha\right) + 0.5r^A\left(e^A, \alpha\right) - 0.5r^B\left(e^B, \alpha\right) - i^A - e^A \\ TS^B &= 0.5R^A\left(i^A, e^A, \alpha\right) + 0.5R^B\left(i^B, e^B, \alpha\right) + 0.5r^B\left(e^B, \alpha\right) - 0.5r^A\left(e^A, \alpha\right) - i^B - e^B \end{aligned} \tag{28}$$

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

$$R_i^j\left(i^{j*}, e^{j*}, \alpha\right) = 2, \quad j \in \{A, B\} \tag{29}$$
$$R_e^j\left(i^{j*}, e^{j*}, \alpha\right) + r_e^j\left(e^{j*}, \alpha\right) = 2, \quad j \in \{A, B\} \tag{30}$$

Now, it can be seen that if $r_e^B > R_e^B$, there is overinvestment by B in understanding A's knowledge. In other words, B invests to expropriate A's knowledge and to enhance its bargaining power in the process. Similarly, if $r_e^A > R_e^A$, A overinvests in understanding how to use B's knowledge. In other words, A invests to expropriate B's knowledge and enhance its bargaining power.

Given the above, it is easy to check that

$$\begin{aligned}
\frac{di^{j*}}{d\alpha} &= -\frac{R_{i\alpha}^j}{R_{ii}^j} > 0, \ \frac{de^{j*}}{d\alpha} = -\frac{R_{e\alpha}^j + r_{e\alpha}^j}{R_{ee}^j + r_{ee}^j} > 0, \ j \in \{A, B\} \qquad (31)\\
e^{A*}(\delta = 0) &< e^{A*}(\delta = 1), e^{B*}(\delta = 0) > e^{B*}(\delta = 1)\\
\frac{de^{B*}}{d\theta} &= -\frac{r_{e\theta}^B}{R_{ee}^B + r_{ee}^B} > 0, \frac{di^{B*}}{d\theta} = 0
\end{aligned}$$

$$\begin{aligned}
TS &= R^A\left(i^{A*}, e^{A*}, \alpha\right) + R^B\left(i^{B*}, e^{B*}, \alpha\right) - i^{A*} - e^{A*} - i^{B*} - e^{B*} \qquad (32)\\
\frac{dTS}{d\alpha} &= R_\alpha^A + R_\alpha^B + \left[R_i^A - 1\right]\frac{di^{A*}}{d\alpha} + \left[R_i^B - 1\right]\frac{di^{B*}}{d\alpha} + \left[R_e^A - 1\right]\frac{de^{A*}}{d\alpha} + \left[R_e^B - 1\right]\frac{de^{B*}}{d\alpha} \qquad (33)\\
&= \underset{+}{R_\alpha} + \underset{+}{\frac{di^{A*}}{d\alpha}} + \underset{+}{\frac{di^{B*}}{d\alpha}} + \left[\frac{R_e^A - r_e^A}{2}\right]\underset{+}{\frac{de^{A*}}{d\alpha}} + \left[\frac{R_e^B - r_e^B}{2}\right]\underset{+}{\frac{de^{B*}}{d\alpha}}
\end{aligned}$$

For low θ_A and θ_B, r_e^B and r_e^A are small. In this case, $\frac{dTS}{d\alpha} > 0 \Rightarrow \alpha^* = 1$. In contrast, if θ_A and θ_B are low, r_e^B and r_e^A are quite large. Then, $\frac{dTS}{d\alpha} < 0 \Rightarrow \alpha^* = 0$. The precise proofs are similar to the ones in the main model.

$$\frac{dTS}{d\delta} = \left[R_e^A - 1\right]\underset{+}{\frac{de^{A*}}{d\delta}} + \left[R_e^B - 1\right]\underset{-}{\frac{de^{B*}}{d\delta}} \tag{34}$$

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

A.2 Changing the Bargaining Model

In this Appendix, we show that the problem of overinvestment and underinvestment by both A and B would exist even if the Bargaining model at date 2 is changed. Then, we proceed to argue that the analysis in the paper would remain unaltered in this case.

As an alternative model of bargaining, we 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 3.1, the bargaining for the surplus R occurs at date 2 after the contract has been signed at date 0 and after the investments are already sunk by both A and B.

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 firm i, it proposes a split x_i so that A gets x_i, while B gets $R - x_i$. After firm 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. We 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:

$$\left(v^A, v^B\right) = \begin{cases} (0.5R, 0.5R) & \text{if} \quad r^A \leq 0.5R \text{ and } r^B \leq 0.5R \\ \left(R - r^B, r^B\right) & \text{if} \quad r^A > 0.5R \text{ and } r^B \leq 0.5R \\ \left(r^A, R - r^A\right) & \text{if} \quad r^A \leq 0.5R \text{ and } r^B > 0.5R \end{cases} \tag{35}$$

Given ex-ante uncertainty about the returns from investment and the respective outside options, the expected payoff for each firm 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 date 0) that A's outside option is binding (i.e. $r^A > 0.5R$) is p^A. Similarly, say that the ex-ante probability that B's outside option is binding (i.e. $r^B > 0.5R$) is p^B. Then, the probability that neither firm's outside option is binding is $1 - p^A - p^B$. Therefore A's expected payoff is

$$TS^A = \left(1 - p^A - p^B\right) \cdot \frac{R}{2} + p^A \left(R - r^B\right) + p^B r^A \tag{36}$$

where the expectation is taken at date 1 when A decides the level of investment to make. Similarly, B's expected payoff is

$$TS^B = \left(1 - p^A + p^B\right) \cdot \frac{R}{2} + p^A r^B - p^B r^A \tag{37}$$

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

$$\begin{aligned} \left(1 + p^A - p^B\right) \cdot \frac{R_A\left(e^{A*}, e^{B*}\right)}{2} + p^B \cdot r_A^A\left(e^{A*}\right) &= 1 \\ \left(1 - p^A + p^B\right) \cdot \frac{R_B\left(e^{A*}, e^{B*}\right)}{2} + p^A \cdot r_B^B\left(e^{B*}\right) &= 1 \end{aligned} \tag{38}$$

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

The intuition for the generality of the results is the following. The overinvestment and the underinvestment 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 r^A and 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.

Appendix B – Proofs

B.1 *Technical Assumptions*

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

$$\begin{aligned} \lim_{e_i\to\infty}\left[R_i\left(e_i,e_j\right)\right] &= 0, \lim_{e_i\to 0}\left[R_i\left(e_i,e_j\right)\right]=\infty,\ i\in\{A,B\}\ \ j=\{A,B\}\setminus i \\ \lim_{e_i\to\infty}\left[r_i^i\left(e_i\right)\right] &= 0, \lim_{e_i\to 0}\left[r_i^i\left(e_i\right)\right]=\infty,\ i\in\{A,B\} \end{aligned} \tag{39}$$

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

$$\frac{R_{e\alpha}}{r_{e\alpha}}>\frac{R_{ee}}{R_{ee}+2r_{ee}} \tag{40}$$

As argued in the text, both underinvestment and overinvestment are important concerns for knowledge assets. To allow for the possibility of overinvestment (for some values of θ^A and θ^B) and underinvestment (for other values of θ^A and θ^B) by A and B, we assume

$$\lim_{\theta^i\to 0} r_i^i\left(\ldots;\theta^i\right)=2,\ \lim_{\theta^i\to\infty} r_i^i\left(\ldots;\theta^i\right)=0, i\in A,B \tag{41}$$

B.2 *Proofs of Propositions*

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

$$\left(x_1^*\left(\lambda\right),x_2^*\left(\lambda\right)\right)=\underset{(x_1,x_2)}{\arg\max}\left[f\left(x_1,x_2,\lambda\right)\right] \tag{42}$$

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

$$\begin{aligned} \frac{dx_1^*(\lambda)}{d\lambda} &= -\frac{f_{13}}{f_{11}}, \frac{dx_2^*(\lambda)}{d\lambda} = -\frac{f_{23}}{f_{22}} \\ sign\left(\frac{dx_i^*(\lambda)}{d\lambda}\right) &= sign\left(f_{i3}\right)\ i \in 1, 2 \end{aligned} \tag{43}$$

Proof of Lemma: Since f is smooth and $\left(x_1^*(\lambda), x_2^*(\lambda)\right)$ is an interior solution, the first order conditions are

$$f_1\left(\left(x_1^*(\lambda), x_2^*(\lambda)\right)\right) = 0 \text{ and } f_2\left(\left(x_1^*(\lambda), x_2^*(\lambda)\right)\right) = 0 \tag{44}$$

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

$$\begin{aligned} f_{11}\frac{dx_1^*(\lambda)}{d\lambda} + f_{13} &= 0 \\ f_{22}\frac{dx_2^*(\lambda)}{d\lambda} + f_{23} &= 0 \end{aligned} \tag{45}$$

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

Proof of Lemma 1: while . Define

$$f\left(x_1, x_2, \lambda\right) = (1-\lambda) R\left(x_1, x_2\right) + \lambda r^A\left(x_1, \alpha, \delta; \theta^A\right) + \lambda r^B\left(x_2, \alpha, \delta; \theta^B\right) - 1 \tag{46}$$

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

$$f_{13} = r_A^A - R_A \text{ and } f_{23} = r_B^B - R_B \tag{47}$$

The results then follow by applying the Lemma provided $R_i \geq r_i^i\ \forall e^i$ and $R_i < r_i^i\ \forall e^i$ are feasible. We argue below that this is indeed the case.

From the first order conditions (12), and $R_i > 0, r_i^i > 0, i \in A, B$, it follows that $0 < R_i < 2$, $0 < r_i^i < 2\ \forall e^i, \alpha, \delta, \theta^i$. From (39), 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 θ^i is close to zero $r_i^i < R_i\ \forall e^i$. Similarly, from (39), we know that $\lim\limits_{\theta^i \to \infty}\left[r_i^i(\theta)\right] = 2\ \forall e^i$. 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 θ^i is high $r_i^i > R_i\ \forall e^i$. Since r_i^i increases with θ^i while R_i does not, $r_i^i - R_i$ is monotonously increasing in θ^i. Hence, there exists at least one θ^i such that $r_i^i < R_i \; \forall e^i$ and at least another different θ^i such that $r_i^i < R_i \; \forall e^i$. $\diamondsuit$

Proof of Proposition 1: From (13), it follows that

$$\frac{dTS^*(\alpha,\delta)}{d\alpha} = R_\alpha + 0.5\left[R_A\left(e^{A*},e^{B*},\alpha\right) - r_A^A\left(e^{A*},\alpha,\delta\right)\right]\frac{de^{A*}}{d\alpha} + 0.5\left[R_B\left(e^{A*},e^{B*},\alpha\right) - r_B^B\left(e^{B*},\alpha,\delta\right)\right]\frac{de^{B*}}{d\alpha} \tag{48}$$

Case 1 $(\delta = 0)$: Assumption (4) implies that $r_i^i(\delta = 0) < R_i, i \in \{A,B\}$. Therefore, it follows that $\frac{dTS^*(\alpha,0)}{d\alpha} > 0$. Therefore $\alpha^* = 1$.

Case 2$(\delta = 1)$: Using 9, it follows that $r_B^B(\delta = 1) < r_B^B(\delta = 0) < R_i$ where the last step follows from Assumption (4). Therefore, $r_B^B(\delta = 1) < R_B$.

We consider two sub-cases here: $r_A^A(\delta = 1) \leq R_A$ and $r_A^A(\delta = 1) > R_A$.

Sub-case 1 $\left(r_A^A(\delta = 1) \leq R_A\right)$: Since $r_B^B(\delta = 1) < R_B$, it follows that $\frac{dTS^*(\alpha,0)}{d\alpha} > 0$. Therefore $\alpha^* = 1$.

Sub-case 2$\left(r_A^A(\delta = 1) > R_A\right)$. Using the mean value theorem, it follows that

$$\begin{aligned} & TS^*(\delta = 1) - TS^*(\delta = 0) \\ = \; & 0.5\left[R_A\left(e^{Ac},e^{Bc}\right) - r_A^A\left(e^{Ac}\right)\right]\underbrace{\left[e^{A*}(\delta = 1) - e^{A*}(\delta = 0)\right]}_{+} \\ & +0.5\left[R_B\left(e^{Ac},e^{Bc}\right) - r_B^B\left(e^{Bc}\right)\right]\underbrace{\left[e^{B*}(\delta = 1) - e^{B*}(\delta = 0)\right]}_{-} \end{aligned} \tag{49}$$

where $\left(e^{Ac},e^{Bc}\right) = \lambda \cdot \left(e^{A*}(\delta = 1), e^{B*}(\delta = 1)\right) + (1-\lambda)\cdot\left(e^{A*}(\delta = 0), e^{B*}(\delta = 0)\right)$ for $0 < \lambda < 1$. Since $r_B^B(\delta) < R_B$ for $\delta = 0, 1$ and for all e^B, it follows that $r_B^B\left(e^{Bc}\right) < R_B\left(e^{Ac},e^{Bc}\right)$ too. In contrast, since in this sub-case $r_A^A(\delta = 1) > R_A$ while $r_A^A(\delta = 0) < R_A$, both $r_A^A\left(e^{Ac}\right) < R_A\left(e^{Ac},e^{Bc}\right)$ and $r_A^A\left(e^{Ac}\right) > R_A\left(e^{Ac},e^{Bc}\right)$ are possible. If $r_A^A\left(e^{Ac}\right) > R_A\left(e^{Ac},e^{Bc}\right)$, then $TS^*(\delta = 1) < TS^*(\delta = 0)$ and $\delta^* = 0$ is optimal. We already saw in Case 1 that $\alpha^* = 1$ when $\delta = 0$. If, on the other hand, $r_A^A\left(e^{Ac}\right) < R_A\left(e^{Ac},e^{Bc}\right)$, then the analysis is similar to the sub-case 1 above where $\alpha^* = 1$. Therefore, in all situations, it follows that $\alpha^* = 1$. $\diamondsuit$

Proof of Lemma 2: (a) Define

$$f(x_1,x_2,\alpha) = \frac{1}{2}R(x_1,x_2) + \frac{1}{2}r^A(x_1,\alpha,.) + \frac{1}{2}r^B(x_2,\alpha,.) - 1 \tag{50}$$

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 (5), it follows that $f_{11} = f_{22}$ and $f_{13} = f_{23}$. Using Lemma, (a) follows.

(b) Define

$$
\begin{aligned}
f(x_1, x_2, \lambda) &= \frac{1}{2} R(x_1, x_2) + \frac{\lambda}{2}\left[r^A(x_1, \delta = 1) + r^B(x_2, \delta = 1)\right] \\
&\quad + \frac{1-\lambda}{2}\left[r^A(x_1, \delta = 0) + r^B(x_2, \delta = 0)\right] - 1
\end{aligned} \tag{51}
$$

Then $\left(e^{A*}(\delta = 1), e^{B*}(\delta = 1)\right) = \left(x_1^*(1), x_2^*(1)\right)$ while $\left(e^{A*}(\delta = 0), e^{B*}(\delta = 0)\right) = \left(x_1^*(0), x_2^*(0)\right)$. 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 (9). Similarly, $f_{23} = r_B^B(., \delta = 1) - r_B^B(., \delta = 0) < 0$ $\forall \alpha, \theta^B$ using (9). 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 $e^{B*}(\delta = 1) < e^{B*}(\delta = 0)$ $\forall \alpha, \theta^B$. $\diamondsuit$

Proof of Lemma 3: Given α, δ chosen at date 0, we know from section B.1 that there exists a θ^i,$i \in \{A, B\}$ such that $R_i > r_i^i \forall e^i$ and another θ^i such that $R_i > r_i^i \forall e^i$. Since r_i^i increases with θ^i while R_i is not affected by θ^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 Lemma 1 we get $\theta^i < \widehat{\theta^i} \Leftrightarrow r_i^i < R_i \forall e^i \Rightarrow e^{i*} < e^{iF}$ and $\theta^i > \widehat{\theta^i} \Leftrightarrow r_i^i > R_i \forall e^i \Rightarrow e^{i*} > e^{iF}$. $\diamondsuit$

Proof of Proposition 3: For part (a) of the proof, we drop δ from the notation since we focus on access, α here. From (13), it follows that

$$
\frac{dTS^*\left(\alpha, \theta^A, \theta^B\right)}{d\alpha} = R_\alpha + \left[2 - r_A^A\left(e^{A*}, \alpha, \theta^A\right) - r_B^B\left(e^{B*}, \alpha; \theta^B\right)\right] \frac{de^{B*}}{d\alpha} \tag{52}
$$

using the first order conditions (12) and $\frac{de^{A*}}{d\alpha} = \frac{de^{B*}}{d\alpha}$ from Lemma 2.

Using (39), we know that $0 \leq r_B^B(.) \leq 2$. Given any value of θ^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 θ^A is negative. Similarly, given θ^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 θ^A is positive. Since $r_B^B(.)$ decreases monotonously in θ^B, there exist θ^B such that $\frac{dTS^*}{d\alpha} = 0$.

Also

$$
\begin{aligned}
\frac{d^2TS^*}{d\alpha^2} &= \frac{d}{d\alpha}\left[\frac{dTS^*}{d\alpha}\right] = R_{\alpha\alpha} + 4R_{e\alpha}\frac{de^*}{d\alpha} + 2R_{ee}\left(\frac{de^*}{d\alpha}\right)^2 \\
&= R_{\alpha\alpha} + 2\frac{de^*}{d\alpha}\left[\frac{R_{ee}R_{e\alpha} + 2R_{e\alpha}r_{ee} - R_{ee}r_{e\alpha}}{R_{ee} + r_{ee}}\right] < 0
\end{aligned} \tag{53}
$$

where the second step uses (5) and the negative sign follows from (40).

$$
\Rightarrow \frac{d^2TS^*}{d\alpha^2} < 0 \tag{54}
$$

Hence there exist interior solutions for α.

Now

$$\frac{d^2TS^*}{d\alpha d\theta^B} = \frac{d}{d\theta^B}\left[\frac{dTS^*}{d\alpha}\right] = R_{BB}\frac{de^{B*}}{d\alpha}\frac{de^{B*}}{d\theta^B} \tag{55}$$

Differentiating the first order condition for e^{B*} w.r.t. θ^B, it follows 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

$$\frac{d^2TS^*}{d\alpha d\theta^B} < 0 \tag{56}$$

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

$$\frac{d^2TS^*}{d\alpha d\theta^A} < 0 \tag{57}$$

$$\frac{dTS\left(\alpha,\theta^1_A,\theta^1_B\right)}{d\alpha} - \frac{dTS\left(\alpha,\theta^2_A,\theta^2_B\right)}{d\alpha} = \frac{d^2TS}{d\alpha d\theta^A}\left(\theta^1_A-\theta^2_A\right) + \frac{d^2TS}{d\alpha d\theta^B}\left(\theta^1_B-\theta^2_B\right) \tag{58}$$

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 $\theta^1_B > \theta^2_B \Rightarrow$

$$\frac{dTS\left(\alpha,\theta^1_A,\theta^1_B\right)}{d\alpha} < \frac{dTS\left(\alpha,\theta^2_A,\theta^2_B\right)}{d\alpha}\ \forall\alpha \tag{59}$$

Therefore, from $\frac{d^2TS}{d\alpha^2} < 0$, it follows that $\alpha^*\left(\theta^2_A,\theta^2_B\right) > \alpha^*\left(\theta^1_A,\theta^1_B\right)$. Since the boundary solutions $\alpha^* = 0$ and $\alpha^* = 1$ also exist (see proof of corollary below), it follows that $\alpha^*\left(\theta^2_A,\theta^2_B\right) \geq \alpha^*\left(\theta^1_A,\theta^1_B\right)$.

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

$$\frac{dTS^*\left(\delta,\theta^A,\theta^B\right)}{d\delta} = \left[R_A\left(e^{A*},e^{B*}\right)-1\right]\frac{de^{A*}}{d\delta} + \left[R_B\left(e^{A*},e^{B*}\right)-1\right]\frac{de^{B*}}{d\delta} \tag{60}$$

$$\frac{d^2TS^*}{d\delta^2} = \frac{d}{d\delta}\left[\frac{dTS^*}{d\delta}\right] = R_{AA}\left(\frac{de^{A*}}{d\delta}\right)^2 + R_{BB}\left(\frac{de^{B*}}{d\delta}\right)^2 < 0 \text{ since } R_{AA} = R_{BB} < 0 \tag{61}$$

$$\frac{d^2TS^*}{d\delta d\theta^B} = \frac{d}{d\theta^B}\left[\frac{dTS^*}{d\delta}\right] = R_{BB}\frac{de^{B*}}{d\delta}\frac{de^{B*}}{d\theta^B} > 0 \text{ since } R_{BB} < 0, \frac{de^{B*}}{d\delta} < 0, \frac{de^{B*}}{d\theta^B} > 0 \tag{62}$$

$$\frac{d^2TS^*}{d\delta d\theta^A} = \frac{d}{d\theta^A}\left[\frac{dTS^*}{d\delta}\right] = R_{AA}\frac{de^{A*}}{d\delta}\frac{de^{A*}}{d\theta^A} < 0 \text{ since } R_{AA} < 0, \frac{de^{A*}}{d\delta} > 0, \frac{de^{A*}}{d\theta^A} > 0 \tag{63}$$

Now

$$\frac{dTS\left(\delta,\theta^1_A,\theta^1_B\right)}{d\delta} - \frac{dTS\left(\delta,\theta^2_A,\theta^2_B\right)}{d\delta} = \frac{d^2TS}{d\delta d\theta^A}\left(\theta^1_A-\theta^2_A\right) + \frac{d^2TS}{d\delta d\theta^B}\left(\theta^1_B-\theta^2_B\right) \tag{64}$$

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

$$\frac{dTS\left(\delta,\theta^1_A,\theta^1_B\right)}{d\delta} < \frac{dTS\left(\delta,\theta^2_A,\theta^2_B\right)}{d\delta}\ \forall\delta \tag{65}$$

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