

# Long Term Contracting with Private Information\*

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## Abstract

This paper explores the possibility for efficient long term contracts among traders with changing and privately known incentives for exchange. We analyze a negotiation process that enables parties to adapt the default rules of exchange to changes in their preferences for trade. The selection of control rights and default options is delegated to the parties themselves, who collectively are best informed as to which investments and exchanges are efficient. The paper demonstrates how contracts with flexible and endogenous default options are tailored to induce efficient investment and optimal exchange. Applications of our findings for contract theory, the design of commercial contracts, and the need for legal support are discussed.

## 1 Introduction.

### 1.1 The Problem

A common view holds that efficiency is difficult to realize in contracting environments that extend through time and in which much of the parties' information is private.<sup>1</sup> The incentives for strategic behavior are great and

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<sup>1</sup>See Williamson (1979), Akerlof (1979) and Stiglitz (2002)

are difficult to remedy at law: courts cannot observe what parties cannot observe and the rules are unfriendly as well. There also are technical difficulties, such as making dynamic contracting arrangements self financing.

Against these concerns, much contracting in long term, private information environments takes place. The arrangements are called “hybrid”, and commonly involve joint arrangements to develop a drug, a software program or some other piece of intellectual property. Thus, there are two questions: Positively, how do parties structure hybrid arrangements to encourage efficient investment and trade? Normatively, can the law give more help to the parties than it now does?

These questions are our subject. In the model below, two parties attempt to exploit a possibly profitable opportunity. The parties can invest to acquire information about how to exploit the opportunity, what their private gains would be were the opportunity pursued and how technical production problems are best solved. The parties also expect ultimately to trade the right to exploit the opportunity. The parties are symmetrically informed at the beginning, but not so later. Neither party, in the model, can observe the other’s investment scope and level, nor observe the results that investment yields. Efficiency requires the parties to invest efficiently and to allocate the opportunity to the party who turns out to have the highest value for it.

The model thus poses the canonical contracting problem: to motivate efficient investment, truthful information revelation and efficient trade while satisfying the standard IR, IC and budget balance constraints. Our approach is to construct a framework agreement that provides instructions and creates incentives for the parties at the various stages of their relationship. The parties’ equilibrium best responses are to comply with the agreement but, we will see, inefficient out of equilibrium behavior may occur.

## **1.2 The agreement and results**

The parties’ task, in the model, is ultimately to allocate the right to exploit a production facility that they have come to own jointly. The agreement that guides them (herein "the Agreement") has two main sections, corresponding to the two main tasks the parties must accomplish. The first section regulates the investment phase. It instructs each of them to invest in the opportunity, to report to each other their demands for the facility, as investment has revealed or created it, and to create default control rights should the venture end. The second section regulates the allocation stage. It directs the transfers

the parties must make to finance trade, structures the revelation game the parties play when uncertainty is resolved and allocates the facility, for a period, to the party with the highest realized valuation.

We show, beginning at the allocation stage, how the Agreement solves the contracting problems that the parties, and parties like them, face. At the last stage, when uncertainty about the world is resolved, the Agreement's allocation section directs the parties to report their realized valuations for the facility. Party valuations are private, so parties have discretion regarding the value to report. The party who reports the highest valuation is awarded the right to exploit the facility. The other party receives a transfer that equals the high reporter's expected surplus conditional on that party's report, less a constant "participation payment". Hence, each party is made the residual claimant of the exchange surplus; the parties then cannot do better than reveal their true values. In this way, the contract ensures efficient trade; surplus is maximized because the party that can generate the highest return from the facility is allocated the right to operate it.

The Agreement's allocation section also provides for the later transfers that induce efficient revelation. Turning to the penultimate stage, before parties learn their valuations, each party commits to make a "deposit". Each deposit equals the expected (maximum) surplus the parties expect from the allocation stage less the expected value of the party's default outside option. Put another way, the deposits equal the net expected continuation surplus from participating in the scheme. This analysis leads to one of the model's principal results. The Agreement maximizes the expected continuation surpluses in order to ensure that the deposits at least cover the later required transfers. These surpluses are maximized, in turn, by minimizing each party's default outside option. This implies that the party who would do best were he to walk is allocated the lowest valued default option. We show that the deposits this financing method creates exceed the later required transfers.

The Agreement's investment section regulates the parties' earlier interactions. Each party knows its own demand for the facility at the last stage of the investment phase. The demands are a function of the parties' earlier investments, in the sense either that investment revealed information about exploitation opportunities or investment helped to create those opportunities by developing sales opportunities or the like. The demands are private information but the parties must be induced to report them truthfully. The demands permit the parties to calculate the expected continuation surpluses that play the financing role later.

Again, truthful revelation is induced by transfers the parties expect to make and receive. Each party expects to receive a transfer, at this stage, that equals the expected demand of his partner for the facility, which a party can infer from knowing his own demand and the other party's report. The parties also are promised the expected continuation surplus less the expected next stage continuation payments each is to make. As the transfers are set equal to the next stage payments, each party actually is promised the continuation surplus. This surplus can only be maximized if the parties report truthfully, for the reasons given above. Hence, the parties report their demands truthfully.

The Agreement's investment stage has another function: to create the default control rights that determine the deposits that the parties later make. Here, the Agreement takes the value of a party's default option as given, and affects its value through discounting the option by the probability that a party is given control should the relationship end. For example, a party is given control with probability two thirds, so that the other party is given control with probability one third. This analysis leads to another of the model's important results. Our conception of control rights implies that complete control is represented by the probability one. Control with this probability, however, maximizes the value of a party's outside option, and thus minimizes the party's continuation value of staying in the relationship. Many inefficient contracts in the literature assume that one or the other party has complete control in the default case but our analysis shows, in contrast, that efficiency is better obtained with divided control rights.

Turning now to the investment stage, though investment is unobservable, each party anticipates both truthful reporting at the later stages and being the residual claimant of the expected surplus the relationship creates. Hence, each party has an incentive to invest efficiently. The investments themselves are funded by promised transfers that split the expected surplus from the relationship.

To summarize, we have constructed an agreement that yields efficient investment and efficient trade in an environment where parties' demands, realized valuations and investment behavior are private information. The Agreement also satisfies budget balance and the IR and IC constraints. We recognize that, at this stage, the Agreement is only a "possibility result"; that is, it shows only that efficient long term contracting is theoretically possible in the complex contexts we model. Nevertheless, we later argue that the results are consistent with recent thick descriptions of hybrid arrangements

in apparently similar contexts.

The Agreement yields efficient investment and trade when the parties play equilibrium best responses to each other's choices and reports. Contract law, however, is frequently asked to constrain or deter out of equilibrium behavior. The law is effective in the many contexts in which parties conclude a final contract that one of them later breaches. In contrast, we show, current law is an ineffective regulator of defections in the contexts we model, in which parties make investments and reports in order to develop an opportunity that their final contract is to govern. As an example, early defections in our context would be deterred by penalties but contract law does not enforce penalty terms.

### 1.3 Plan for the the remainder of the paper.

Part 2 below summarizes current theory regarding the case we analyze. Part 3 sets out the model. We then describe and analyze the efficient development of the production facility. Figure 1 represents schematically the investment and allocation sections of the Agreement, and then describes them formally. Part 4 constructs the Agreement's allocation section, exhibits its efficiency properties and shows that the Agreement satisfies budget balance and voluntary participation. This Part also describes, and adapts to the model, Coasian bargaining under complete and private information. Part 5 models the Agreement's investment section and shows how it induces efficient investment. This Part also summarizes the results and discusses how the current legal rules poorly constrain strategic out of equilibrium behavior. Part 6 considers extensions [to be written] and Part 7 concludes.

## 2 Recent Developments in the Theory

In this section, we review the principal contributions to the theory of efficient contracting with private information, and indicate how our findings relate to and extend recent developments in this area.

**The Coase Theorem:** To achieve efficient exchange, property rights should be clearly assigned, and the parties permitted to bargain. The Theorem may not hold when parties are asymmetrically informed<sup>2</sup>, but

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<sup>2</sup>See Farrell (1987).

it provides a useful guide to efficient contracting when only one party is asymmetrically informed.

Vickrey (1961), Clark (1971 ) and Groves (1973) extended the theory of efficient contracting to the private information setting.

**VCG Mechanisms:** Efficient trade among privately informed traders is possible only if each trader pays or receives the value lost or gained by the other traders. This condition requires that, in bilateral exchange, the buyer pays the seller's cost of supply or the seller receives a payment equal to the buyer's value from trade. Each party to the exchange, that is, must be the residual claimant of the net surplus that trade creates.

Later, d'Aspremont and Varet (1979) and Myerson and Satterthwaite (1983) showed that VCG mechanisms cannot be implemented under many standard contracts.

**Impossibility of Efficient Exchange with Budget Balancing and Voluntary Participation:** Private contracting requires the parties' consent and voluntary participation. Contracts also must be self financing, which requires transfers between the parties to balance. Neither voluntary participation nor budget balance is ensured under VCG when property rights are vested with one trader. The payment that this owner demands to reveal her value for trade exceeds the potential gains from trade. Efficient trade is then impossible unless a third party, such as the government, subsidizes it. This seldom is possible in decentralized markets.

In an attempt to restore efficient contracting, Cramton, Gibbons and Klemperer CGK(1987) demonstrated how privately informed members can efficiently dissolve a partnership.<sup>3</sup>

**CGK: Possibility of Efficient Exchange with Shared Ownership of Assets:** Members of a partnership who are uncertain whether they will later be the buyer or the seller of partnership assets demand less to reveal their value of trade. Consequently, it is possible to restore efficient exchange along with voluntary participation and balanced transfers when the ownership allocation among the partners creates this uncertainty.

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<sup>3</sup>See also Ayres and Talley (1995), Edlin and Reichelstein (1996), Lewis and Sappington (1989), Schweizer (2006) and Segal and Whinston (2009) for related results.

The contract theory just reviewed shares the assumption that default property rights are set exogenously or are determined prior to contracting.<sup>4</sup> The success of a relationship, in this theory, thus depends on whether the default is set correctly in the beginning and whether the parties' incentives to bargain over time remain aligned. When parties are attempting to create a product, design a service, or sustain an evolving relationship, their preferences as between continuance and exit may change over time, however. If those preference changes are unobservable, the parties' time zero default property right allocations may induce incentives to invest or to trade that are misaligned.<sup>5</sup> Default control rights thus must be adjusted "along the way" to induce the parties to continue to support their relationship.<sup>6</sup>

**Forming Firms:** Our analysis has implications for when firms form. Hart and Holmstrom (2010) argues that firms are formed when market contracting cannot efficiently allocate residual control rights. In their model, parties do not renegotiate because renegotiation, under the contracts they assume, would create opportunities for strategic behavior. More relevant here, Hart and Holmstrom apparently assume that decision right allocations do not adjust to current information but rather are fixed at the outset. In contrast, decision rights in our model are a function of information that the parties develop. Comparing our analysis with theirs raises two empirical questions: (i) In which contexts are the Hart and Holmstrom assumptions or our assumptions the more plausible? (ii) How do actual agents behave in those contexts? The theory developed below, we hope, permits these questions to be put more precisely.

### 3 Model

Firms  $x$  and  $y$  form a joint venture to acquire and develop a production facility. The firms plan to share the facility, which has a normalized manu-

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<sup>4</sup>Some notable exceptions are Ayres (2004), Matuschek (2004) and Kuribko and Lewis (2010)

<sup>5</sup>If the preferences of the traders are common knowledge at each stage, it is possible to set initial default rights so the parties can efficiently renegotiate to their mutual advantage. See Edlin and Reichelstein(1996)

<sup>6</sup>Dynamic mechanisms with unchanging control rights cannot achieve efficiency, except in special cases. See Athey and Seigel (2007).

facturing capacity of 1 unit, to produce materials for their customers. The sharing arrangement is to be made pursuant to a multi-stage Agreement that is described below. Each firm  $i$  derives a benefit  $b_i$  from employing the capacity, that varies in the interval  $[0, \bar{b}]$  and is distributed by the cumulative density function  $F_i^{k_i}(b_i)$ , with a strictly positive and continuous density, that depends on the firm's demand state  $k_i$ . The demand state  $k_i$  is either  $h$  (high) or  $l$  (low). The likelihood that a firm's realized demand for capacity is high is greater in the high demand state  $h$ ; hence, we assume that  $F_i^h(b_i) \leq F_i^l(b_i)$  for  $b_i \in [0, \bar{b}]$ .<sup>7</sup>

The goal is to allocate capacity efficiently to the user that has the highest demand. For any given pair of realized firm demands  $\mathbf{b} = (b_x, b_y)$ , the maximum surplus derived from production capacity, denoted by  $W^A(\mathbf{b})$ , is achieved with the optimal allocation,  $\alpha^*(\mathbf{b}) = (\alpha_x^*(\mathbf{b}), \alpha_y^*(\mathbf{b}))$ , such that,

$$W^A(\mathbf{b}) = \sum_{i=x,y} \alpha_i^*(\mathbf{b}) b_i = \max[b_x, b_y]$$

The value of capacity is greater when it is shared between firms  $x$  and  $y$ . The expected surplus derived from efficient utilization of capacity, given the expected demand state  $\mathbf{k} = (k_x, k_y)$ , denoted by  $W^A(\mathbf{k})$ , is

$$W^A(\mathbf{k}) = E^{\mathbf{k}} W^A(\mathbf{b}) = E^{\mathbf{k}} \max[b_x, b_y]$$

where  $E^{\mathbf{k}}$  is the expectation over demands  $(b_x, b_y)$  given the state  $\mathbf{k}$ .

The demand state for each firm is partly a function of the firm's investment. Investment is multifaceted: it can directly increase the factory's production capacity, or yield information about production or sale opportunities, or increase expected sales. In the model, the firms' investments,  $\mathbf{I} = (I_x, I_y)$ , affect the probability  $\lambda(\mathbf{k} | \mathbf{I})$  of various demand states  $\mathbf{k}$  arising. The efficient investment profile  $\mathbf{I}^* = (I_x^*, I_y^*)$  maximizes expected surplus from the facility, such that

$$W(I^*) = \max_{\mathbf{I}} \sum_{\mathbf{k}} \lambda(\mathbf{k} | \mathbf{I}) W^A(\mathbf{k}) - \sum_{i=x,y} I_i$$

We focus on the obstacles to efficient contracting that arise because the firms' actions, demands and preferences for exchange are private information.

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<sup>7</sup>More formally, the high state and low state distributions are stochastically ordered. There is a greater likelihood demand will turn out to be high in the  $h$  (high) demand state than in the  $l$  (low) demand state.

The issue is whether a contracting procedure exists that induces the firms to invest efficiently to develop the manufacturing facility, and then to allocate capacity to the firm that turns out to have the greatest demand for it.

### 3.1 The Agreement's investment and allocation section

At time  $t_0$ , immediately after acquiring the facility, the firms agree to an investment and allocation agreement denoted respectively by  $(\mathbf{I}^*, \tau(\mathbf{I}^*, \mathbf{k}))$  and  $\langle \mathbf{r}(\mathbf{k}), \boldsymbol{\alpha}^*(\mathbf{b}), \boldsymbol{\tau}^*(\mathbf{k}, \mathbf{b}) \rangle$ . The first set of terms governs investment and the second set governs allocation. The sequence of actions that the contracts govern is illustrated in Figure 1. The Agreement directs the firms, at time  $t_1$ , to make investments  $\mathbf{I}^* = (I_x^*, I_y^*)$  to develop the capacity for their individual uses. The investments are designed to maximize the expected commercial use from the manufacturing facility. Whether a firm invests efficiently, however, is voluntary because its investment behavior is unobservable. Each firm therefore must believe that it is in its best interest to invest as the agreement directs.<sup>8</sup> At time  $t_2$ , after the investments are complete, each firm privately learns how investment affected the firm's expected demand:  $k_i \in (h, l)$ . This demand information indicates whether the firm is likely to be a heavy or a light user of the production capacity in subsequent periods.

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<sup>8</sup>Another way to put the point in text is that the Agreement here functions as a planning device rather than as the basis for a possible legal enforcement action.

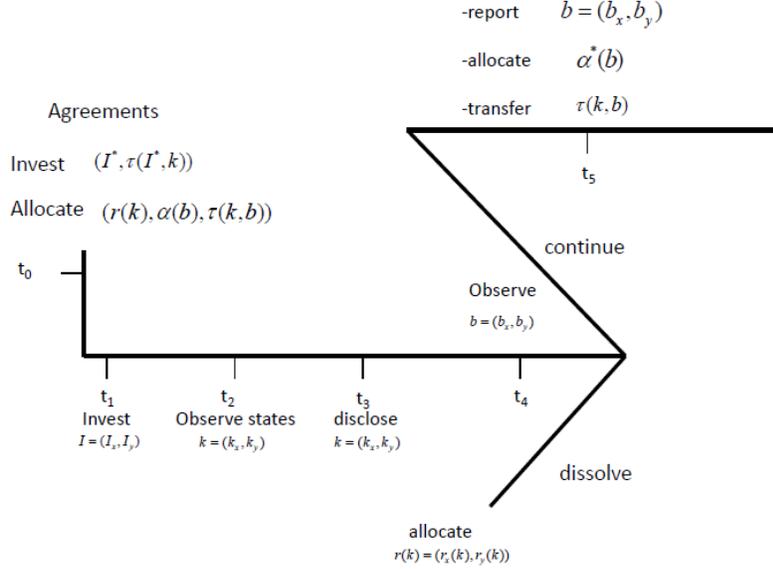


Figure 1: Investment and Capacity Allocation Agreement

The agreement creates two requirements for time  $t_3$ , when firms have learned their demand states  $\mathbf{k} = (k_x, k_y)$ : to disclose these demands and to exchange transfers  $\tau(\mathbf{I}^*, \mathbf{k})$  that compensate each of them for their investments in developing the manufacturing facility. The disclosure of demand states also allows the firms to pin down the later allocations that the agreement requires to govern the assignment of production in subsequent periods.

At time  $t_4$ , the firms privately observe the realized benefits,  $\mathbf{b} = (b_x, b_y)$ , each would derive from employing the capacity. The firms then decide whether to *continue* or to *dissolve* the agreement. The agreement allocates shares of the capacity to each party,  $\mathbf{r}(\mathbf{k}) = (r_x(\mathbf{k}), r_y(\mathbf{k}))$ , upon dissolution; a party may unilaterally use its share. We discuss below how share allocations are made and implemented. Although dissolving the agreement is an option, on the equilibrium path the firms choose to continue with the agreement to time  $t_5$ . The firms then disclose their realized demands  $\mathbf{b} = (b_x, b_y)$ , whereupon the optimal allocation  $\alpha^*(\mathbf{b})$  based on the reported demands is made and the firms make transfer payments to each other,  $\tau(\mathbf{k}, \mathbf{b}) = (\tau_x(\mathbf{k}, \mathbf{b}), \tau_y(\mathbf{k}, \mathbf{b}))$

## 4 Contracting for Allocation

As is customary in multistage contracting analysis, it is instructive to work backwards from the last stage of contracting to the beginning stages. We thus begin at time  $t_5$  when the firms are negotiating over access to the capacity after the initial investments  $\mathbf{I}$  have been made, the firms have disclosed their states  $\mathbf{k} = (k_x, k_y)$ , the Agreement's allocation terms have therefore been fixed, and the firms have observed their private demands  $\mathbf{b} = (b_x, b_y)$ .

### 4.1 Allocating capacity efficiently:

#### 4.1.1 An efficient allocation with complete information

It is instructive to begin with the simplest setting, in which there is complete information about the firms' capacity demands. Coase (1960) discovered the optimal contract for such well informed parties. One party, say firm  $x$ , purchases the right to all of the capacity from firm  $y$ . When the parties learn the values  $b_x$  and  $b_y$ , firm  $x$  sells the right to capacity to firm  $y$  for  $b_y$ , firm  $y$ 's value for capacity, if  $y$  has the higher value. Otherwise,  $x$  enforces his contract right to the factory. This contract is efficient: it allocates capacity to the firm with the highest valuation, and the parties' transfers balance the budget because they sum to zero. Efficiency is achieved in this context because firm  $x$  is the residual claimant; it has the right to receive the surplus from allocating capacity, whatever the surplus turns out to be. Firm  $x$  therefore chooses the surplus maximizing outcome. The example teaches that making the "chooser" the residual claimant to a contract's surplus is necessary and sufficient for an efficient decision.

#### 4.1.2 Contracting between privately informed firms

Contracting for efficient capacity allocation is more difficult when the firms are privately informed. To see why, let both firms privately observe their expected demand for capacity,  $k_x$  and  $k_y$ , before the parties negotiate to allocate capacity. The Coase contract now cannot work because neither party knows both capacity values; hence, neither party, were it to have control, would invariably offer to sell or to buy so as to achieve efficiency. The issue, then, is whether efficiency is achievable when contracts must delegate allocation to the privately informed parties. An efficient contract turns out

to exist, and it is implemented with residual claim transfers, as described below:

The Agreement requires each firm at,  $t_5$ , after it privately observes its demand, to report demand to the other. Disclosures need not be truthful because demand information is private. After disclosure, a firm knows its own demand for capacity and the other firm's *reported* demand. The agreement rewards each firm, in return for its disclosure, with the capacity allocation,

$$\bar{\alpha}_i^*(b_i) = E_{b_{-i}}(\alpha_i^*(\mathbf{b}))$$

This expression reflects the likelihood that a particular firm's demand,  $b_i$ , is greater than the other firm's demand,  $b_{-i}$ .<sup>9</sup> In addition, firm  $i$  expects to receive the transfer,

$$\bar{\tau}_i(\mathbf{k}, b_i) = E_{b_{-i}}(a_{-i}^*(\mathbf{b}) b_{-i} - d_i(\mathbf{k}))$$

The transfer to firm  $i$  equals the expected value of capacity to the firm's contract partner – the first *RHS* term – less the deposit firm  $i$  itself must commit to make in order to fund the arrangement – the second *RHS* term.<sup>10</sup> We refer to this as a *residual claim transfer*, because it makes each firm the residual claimant of the expected surplus from exchange. To understand how the transfers function, note that firm  $i$  with private demand  $b_i$ , who discloses that its demand is  $b_i$ , expects to receive surplus,

$$\begin{aligned} W_i^A(\mathbf{k}, b_i) &= \bar{\alpha}_i^*(b_i) b_i + \bar{\tau}_i(\mathbf{k}, b_i) \\ &= \bar{\alpha}_i^*(b_i) b_i + E_{b_{-i}}^{\mathbf{k}}(a_{-i}^*(\mathbf{b}) b_{-i} - d_i(\mathbf{k})) \\ &= E_{b_{-i}}^{\mathbf{k}}(W_i^A(\mathbf{k}, \mathbf{b}) - d_i(\mathbf{k})) \end{aligned} \tag{1}$$

The *RHS* of the top line equation is the expected value to firm  $i$  of capacity plus the transfer to firm  $i$ . Substituting from prior equations yields the last *RHS* line, which is the expected surplus from exchange, except for a constant  $d_i(\mathbf{k})$  that does not depend on firm  $i$ 's report. Each party thus is the residual claimant to the expected surplus that flows from his report. *Note* that a firm computes the expected surplus using its knowledge of its own demand

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<sup>9</sup>The notation  $b_{-i}$  refers to the benefits to the other firm besides  $i$ ; we shall occasionally adopt this notation for convenience where no confusion exists.

<sup>10</sup>We define the deposits that are required to ensure that parties participate under the agreement – the  $d(\mathbf{k})$  terms – in the section below.

and its partner's expected demand report. Firm  $i$  cannot improve its payoff by reporting untruthfully because it is the residual claimant of the surplus the relationship creates (except for  $d_i(\mathbf{k})$ ). Hence, in equilibrium each firm truthfully reports its demand and capacity is allocated to the firm with the highest valuation; consequently, the parties optimize the facility's capacity. This leads to our first result:

**PROPOSITION 1:** *Corresponding to each state  $\mathbf{k}$ , there exists a set of contractually mandated transfers  $\{\bar{\tau}_i(\mathbf{k}, b_i)\}_{i=x,y}$  that make each firm the residual claimant, induce truthful disclosure of demand and therefore ensure efficient allocation of capacity.*

## 4.2 Ensuring voluntary participation

We now move back one stage in the allocation agreement, to  $t_4$ . The firms then have observed their private demands and must decide whether to *continue* or to *dissolve* the agreement. To ensure that it is individually rational for each firm to continue to the  $t_5$  exchange stage, each firm at  $t_4$  must expect to receive greater surplus from continuing than from dissolving the agreement for all possible private demands. Formally, this condition is written,

$$W_i^A(\mathbf{k}, b_i) - r_i(\mathbf{k}) b_i \geq 0 \text{ for all } b_i \in [0, \bar{b}]$$

The first *LHS* term is firm  $i$ 's expected continuation surplus. The second *LHS* term is the firm's expected value from dissolving the agreement. Regarding this second term,  $r_i(\mathbf{k})$  is the *probability* that the agreement allocates control to a party upon dissolution, and  $b_i$  is the party's dissolution payoff. A sufficient condition for voluntary participation is,

$$\min_{b_i} W_i^A(\mathbf{k}, b_i) - r_i(\mathbf{k}) b_i = W_i^A(\mathbf{k}, b_{iw}) - r_i(\mathbf{k}) b_{iw} \geq 0 \quad (2)$$

Here  $b_{iw}$  is the *worst off firm  $i$  type*, who gains the least from continuing rather than dissolving the agreement; Equation (2) thus recites that continuation must be profitable for the worst off types. Then, it will be profitable for all types. Substituting the expression for  $W_i^A(\mathbf{k}, b_i)$  from (1) into (2), simplifying and rearranging terms allows us to solve for the maximum value of  $d_i(\mathbf{k})$  that ensures that voluntary participation holds for all  $b_i$  types,

$$d_i(\mathbf{k}) = E_{b_{-i}} W_i^A(\mathbf{k}, b_{iw}) - r_i(\mathbf{k}) b_{iw}$$

The deposit  $d_i(\mathbf{k})$  should be interpreted as the maximum *concession* or *participation payment* that each party can extract from its partner, while ensuring that the partner continues with the arrangement for any demand realization. Parties anticipate that their later payoffs will be reduced by these concession payments. Before observing its realized demand, each firm thus expects to receive the surplus  $W_i^A(\mathbf{k}) = W^A(\mathbf{k}) - d_i(\mathbf{k})$  if it participates in the exchange. The Agreement cannot promise to provide more surplus to the firms than the exchange itself creates. This constraint implies that the sum of concessions must cover the net surplus the Agreement promises to the firms. Put another way, the expected surplus must equal or exceed the promised concession payments, a requirement that is defined as

$$\begin{aligned}
B(\mathbf{r}(\mathbf{k})) &= \sum_i d_i(\mathbf{k}) - W^A(\mathbf{k}) \\
&= \sum_i (W^A(\mathbf{k}) - W_i^A(\mathbf{k})) - W^A(\mathbf{k}) \\
&= W^A(\mathbf{k}) - \sum_i W_i^A(\mathbf{k}) \\
&\geq 0
\end{aligned}$$

The first term on the top equation's *RHS* is the sum of the concession payments; the second term is the expected surplus from trade: efficiently allocating the facility. The concession payments importantly turn on the party's property rights, the  $r(\mathbf{k})$  terms. Hence, the Agreement must allocate those rights so as to produce a positive budget surplus.

Only particular property right allocations yield efficient allocations. For example, the Coasian assignment of a strong property right to either party violates budget balance in this private information environment. To see why, let firm  $x$  have the exclusive right to capacity upon dissolution, as provided for in the Coase contract described above. Using our notation, and remembering that the  $\mathbf{r}$  terms are probabilities,  $\mathbf{r}(\mathbf{k}) = (r_x(\mathbf{k}) = 1, r_y(\mathbf{k}) = 0)$ . Now let both firms' private values be uniformly distributed in the interval  $[0, \bar{b}]$ . (The following arguments apply to any pair of distributions.) When firm  $x$  has the exclusive right to capacity, his *worst off type* turns out to be the maximum value:  $b_{iw} = \bar{b}$ .<sup>11</sup> Therefore, the maximum surplus firm  $x$  can be forced to concede in order to ensure that it will continue in the arrangement is  $d_x(\mathbf{k}) = 0$ . Firm  $x$  cannot do better in the relationship than it can do outside; hence, it is indifferent to participating. In contrast, firm  $y$ , which

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<sup>11</sup>Upon dissolution, firm  $x$  has the right to the entire capacity, which is its best possible outcome.

has no control rights, gains least from participating when his demand type is  $b_{yw} = 0$ . Firm  $y$  thus expects a surplus of  $\bar{b}/2$  from participating (recall that the benefit distribution is uniform from 0 to  $b$ ). Firm  $y$ 's maximum concession for the right to participate is therefore  $d_y(\mathbf{k}) = \bar{b}/2$ .

The firms combined participation payments under Coasian property rights thus sum to  $d_x(\mathbf{k}) + d_y(\mathbf{k}) = \frac{\bar{b}}{2}$ . This sum is below the required transfer  $W^A(\mathbf{k}) = \frac{2\bar{b}}{3}$  that the parties must finance; the budget is not balanced.<sup>12</sup> Hence, efficient allocation is not implementable when firm  $x$  is given sole control of the replacement decision. The same result would obtain were the contract to award  $y$  sole control.<sup>13</sup>

In this environment, the firms must shift their focus from assigning, or recognizing, pre-existing property rights to selecting default control rights that maximize the budget surplus, and hence maximize the likelihood that a contract is self financing. The control right allocation that maximizes the budget surplus in state  $\mathbf{k}$  is characterized by the following,

**PROPOSITION 2:** *The control rights  $\mathbf{r}^*(\mathbf{k})$  that maximize the budget surplus  $B(\mathbf{r}(\mathbf{k}))$  minimize the sum of the parties outside options,  $r_x^*(\mathbf{k})b_{xw} + r_y^*(\mathbf{k})b_{yw}$ .<sup>14</sup>*

**PROOF:** *In the appendix.*

Minimizing the sum of the parties' outside options maximizes their continuation surpluses; hence, it maximizes their willingness to participate in and thus to finance the capacity allocation part of the Agreement.

Before continuing the analysis, we note that parties cannot precisely implement probabilistic control rights: i.e, the buyer has one third control if

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<sup>12</sup>To understand this result, realize that the transfer is the surplus from trade. When both parties' values are uniformly distributed on the same distribution, as is assumed above, the expected exchange surplus is computed as follows (using 0 to 100 for example):

$$\begin{aligned} E \max[x, y] &= \int_0^{100} \left(1 - \left(\frac{z}{100}\right)^2\right) dz \\ &= \left(z - \frac{z^3}{3(100)^2}\right)_{z=0}^{z=100} \\ &= 66.67 = \frac{2}{3}(100) \end{aligned}$$

<sup>13</sup>The text thus replicates the Myerson and Satterthwaite (1983)'s result, noted in Part 2, that efficient exchange between privately informed agents cannot be sustained under strong property rights.

<sup>14</sup>Schweizer (2006) also suggests this method for selecting property right assignments.

the agreement ends prematurely. Parties can, however, affect the relative values of their default options. As examples, a party that is to create major intellectual property during a venture may be discouraged from defection by having to forfeit much of that property upon exit. The right to market existing venture property may rest with, or shift to, the party who is least able to market outside the venture. In the example here, a party that is allocated control may be required to delegate a portion of production to its partner for a specified time. The value of a party's exit option is reduced if the controlling party must wait to deal with another producer. The relative values of these contractually restricted outside options may be interpreted as probabilistic control rights because they affect the parties' continuation values in the same ways. How real these control right possibilities are is a question that awaits further research. Our claim here is only that impressionistic data and analysis suggest that party ability to affect the value of exit options in efficient ways possibly exists.<sup>15</sup>

Returning to the model, the sum of the deposits collected when default control rights are set optimally always exceeds the required transfers,  $W^A(\mathbf{k})$ , thus resulting in a strictly positive budget surplus,  $B(\mathbf{r}^*(\mathbf{k})) > 0$ .

**PROPOSITION 3:** *The control rights  $\mathbf{r}^*(\mathbf{k})$  that maximize the concession payments parties make yield a strictly positive budget surplus,  $B(\mathbf{r}^*(\mathbf{k})) > 0$ . The firms' transfers balance with  $\sum_i \tau_i(\mathbf{k}, \mathbf{b}) = 0$*

**PROOF:** *In the Appendix.*

Intuitively, a party's gross continuation payoff – the surplus it expects to receive – reflects the possibility that the party turns out to have the higher demand; that is, of having a value for the facility that exceeds the average demand. The parties default control rights, on the other hand, are evaluated at each party's minimum type. The concession payment is the difference between the gross payoff and the control right payoff. The expected surplus from the agreement itself, on the other hand, is calculated on the basis of average demands. It follows that when the concession payments are summed, they yield a total that exceeds the expected gain the relationship yields. The Agreement contains a mechanism for rebating the surplus to the parties. See

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<sup>15</sup>See Gilson, et al (2009), (2010) for a description of actual party efforts differentially to affect exit options in hybrid arrangements to develop drugs and software.

Appendix. In essence, each party's required payment is reduced by half the overage. Importantly, the amounts rebated do not depend on the parties' reports. Therefore, the parties do not have an incentive to report strategically to increase the rebated sums.

- To illustrate how these Propositions function in the allocation example here, deposits are maximized by stipulating equal control rights:  $r_x^*(\mathbf{k}) = \frac{1}{2}, r_y^*(\mathbf{k}) = \frac{1}{2}$ . Under this assignment, and continuing with the uniform benefit example,  $x$  and  $y$  each make concession payments  $d_x^k(\mathbf{k}) = d_y^k(\mathbf{k}) = \frac{3\bar{b}}{8}$  for a total of  $\frac{3\bar{b}}{4}$ , which exceeds the required transfer  $W^A(\mathbf{k}) = \frac{2\bar{b}}{3}$ .<sup>16</sup> There is a strictly positive budget surplus of  $\frac{b}{12}$ .

Summarizing our results to this point we have

**PROPOSITION 4: Allocation Agreement:** *Corresponding to each state  $\mathbf{k}$  there exists an efficient exchange mechanism  $\langle \mathbf{r}^*, \boldsymbol{\alpha}^*, \boldsymbol{\tau} \rangle$  that is interim individually rational and balanced and has the following properties:*

(a) *Each member  $i$  receives expected residual claim transfers:*

$$\bar{\tau}_i(\mathbf{k}, b_i) = E_{b_{-i}} \alpha_{-i}^*(\mathbf{b}) b_{-i} - d_i(\mathbf{k})$$

(b) *Property right assignments minimize outside option value,*

$$\sum_i r_i^*(\mathbf{k}) b_{iw}$$

(c) *Expected surplus of each partner  $i$  is,*

$$\begin{aligned} W_i^A(\mathbf{k}) &= W^A(\mathbf{k}) - d_i(\mathbf{k}) \\ \sum_i W_i^A(\mathbf{k}) &= W^A(\mathbf{k}) \end{aligned}$$

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<sup>16</sup>With control rights of  $r_x^*(k) = \frac{1}{2}, r_y^*(k) = \frac{1}{2}$ , the deposit minimizing exchange values are  $b_{xw} = \frac{b}{2}$  and  $b_{yw} = \frac{b}{2}$ . The corresponding deposits for each firm  $i$  are

$$d_i = d = E_i \max(b_i, .5b) - .5(.5b) = \frac{3b}{8}$$

## 5 The investment part of the Agreement.

In the contracts modeled above, and in the literature in which similar contracts are addressed, relationships are short term, so that the parties' common information about value distributions and outside opportunities is unchanged. In CGK (1987), for example, the distribution of the partners' values is known and fixed when the partnership is dissolved. These models use common information to set default control rights and to develop the transfer payments needed to support efficient exchange. When a relationship lasts through time, however, it is implausible to suppose that the parties' future trade opportunities and the distribution of their preferences for exchange remain common knowledge. We next analyze a context in which private knowledge is partly a function of the parties' post-Agreement investments, and thus necessarily evolves over time. The investments themselves also are private and are partly cooperative (e.g. Che and Hausch (1999)); each firm's investment, that is, may affect the other firm's value for the facility.<sup>17</sup> The Agreement solicits updated information from the parties to create default control rights and to derive the transfer payments that govern later exchanges.

### 5.1 Implementation of the investment part

In this section, we ask how to implement the investment part of the Agreement  $(\mathbf{I}^*, \tau(\mathbf{I}^*, \mathbf{k}))$ . This part requires the parties to invest efficiently – to invest  $\mathbf{I}^* = (I_x^*, I_y^*)$  – to maximize the factory's value. The concern is that each firm knows that it cannot observe the other firm's investment choices or the resulting demand states. Initially, the Agreement directs each firm to invest  $\mathbf{I}^* = (I_i^*, I_{-i}^*)$ . We assume that  $\mathbf{I}^*$  is the unique interior efficient investment that maximizes the expected value of the factory.<sup>18</sup> The firms next report the demand states  $\mathbf{k} = (k_x, k_y)$  that their investments helped to

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<sup>17</sup>Regarding this assumption, recall that investment is multi-faceted. Hence, a firm's investment may promote demand for the general class of products that are produced at the manufacturing facility. Similarly, a firm's investment may indicate how best to produce from the facility. Party  $i$ 's investment therefore may affect party  $-i$ 's demand.

<sup>18</sup>Under weaker conditions there may be multiple local optimal investment profiles. In that case the desired investment can be implemented by the Agreement, but it is possible that other investment profiles may be implemented as well. Hence, implementation of the optimal investment profile, while possible, is not guaranteed.

create. The subsequent exchange of manufacturing capacity is governed by the Agreement's allocation part  $\langle \mathbf{r}^*(\mathbf{k}), \boldsymbol{\alpha}^*(\mathbf{b}), \boldsymbol{\tau}(\mathbf{k}, \mathbf{b}) \rangle$ .

We begin analysis with the last stage of the investment Agreement, at time  $t_3$ , after each firm  $i$  has invested  $I_i$  and observed its demand state,  $k_i$ . At that moment, the firms simultaneously report their demand state, and receive expected transfer payments,

$$\bar{\tau}_i((I_i, I_{-i}), k_i) = E_{k_{-i}} W_{-i}^A(\mathbf{k}) \mid (I_i, I_{-i}) - d_i(\mathbf{I}^*)$$

These transfers make each firm the residual claimant (except for the constant  $d_i(\mathbf{I}^*)$ ) of the expected surplus to follow,

$$W_i^A(k_i, (I_i, I_{-i})) = E_{k_{-i}} W_i^A(\mathbf{k}) \mid (I_i, I_{-i})$$

Therefore, firm  $i$  that reports state  $k_i$  and expects the other firm to report truthfully receives its expected continuation surplus plus a transfer that is equal to,

$$\begin{aligned} W_i^A(k_i, (I_i, I_{-i})) &= E_{k_{-i}} W_i^A(\mathbf{k}) \mid (I_i, I_{-i}) + \bar{\tau}_i((I_i, I_{-i}), k_i) \\ &= E_{k_{-i}} [W_i^A(\mathbf{k}) \mid (I_i, I_{-i}) + W_{-i}^A(\mathbf{k}) \mid (I_i, I_{-i})] - d_i(\mathbf{I}^*) \\ &= E_{k_{-i}} W^A(\mathbf{k}) \mid (I_i, I_{-i}) - d_i(\mathbf{I}^*) \\ &\geq E_{k_{-i}} W^A(\tilde{k}_i, k_{-i}) \mid (I_i, I_{-i}) - d_i(\mathbf{I}^*) \end{aligned}$$

The last line in the equation above indicates that  $i$  cannot increase its expected surplus by misreporting its state. This follows because  $i$  is the residual claimant to all the surplus created by its report. As such, firm  $i$  cannot improve its payoff by misrepresenting its demand state, provided that its partner reports truthfully as well. On this reasoning, both parties disclose the results of their investments truthfully. This disclosure, in turn, permits the parties to implement the later stage efficient allocation contract.

Turning now to the investment stage the Agreement  $(\mathbf{I}^*, \tau(\mathbf{I}^*, \mathbf{k}))$  induces an investment game between the partners. In that game, each firm selects an investment that, it believes, is a best response to its partner's expected investment. We are looking for the best response equilibrium to this game, to verify whether the efficient investment profile  $I^*$  is implemented in the equilibrium. When both firms assume that their partners invest efficiently,

each firm chooses investment  $I_i$  in order to,

$$\begin{aligned}
\max_{I_i} W^I(I_i, I_{-i}^*) &= \max_{I_i} EW_i^A(k_i | (I_i, I_{-i}^*)) - I_i \\
&= \max_{I_i} EW^A(\mathbf{k} | (I_i, I_{-i}^*)) - I_i - d_i(\mathbf{I}^*) \\
&= EW^A(\mathbf{k} | \mathbf{I}^* - I_i^* - d_i(\mathbf{I}^*))
\end{aligned}$$

The third line of the equation above follows because  $\mathbf{I}^*$  is the unique interior investment profile, so that  $I_i^*$  is the best investment response to  $I_{-i}^*$ . Regarding the intuition, each firm expects that its partner will report investment results truthfully at the later stage. The agreement uses the (truthful) demand revelations to structure the later capacity allocations such as to make each party the residual claimant of the factory's realized surplus. The parties thus invest efficiently at the earliest stage because each anticipates reaping the fruits of its and its partner's investment choices. This reasoning is summarized in :

**PROPOSITION 5:** *There exists an optimal investment Agreement  $\langle \mathbf{I}^*, \tau(\mathbf{I}, \mathbf{k}) \rangle$  that induces efficient ex ante investment  $\mathbf{I}^*$  with the following properties:*

(a) *Each member  $i$  receives expected residual claim transfers:*

$$\bar{\tau}_i(\mathbf{I}, k_i) = E_{\mathbf{k}_{-i}} W_{-i}^A(\mathbf{k} | \mathbf{I}^*) - d_i(\mathbf{I}^*)$$

(b) *Expected surplus of each member  $i$  is*

$$\begin{aligned}
W_i^I(I_i^*) &= EW^A(k | I_i^* - I_i^* - d_i(I_i^*)) \\
\sum_i W_i^I(I_i^*) &= EW^A(k | I^*) - \sum_i I_i^*
\end{aligned}$$

## 6 6. Discussion

### 6.1 6.1 The Economics

We construct a multi-stage Agreement that provides for efficient trade and investment in an environment where party valuations and investment behavior are private information. We stress the agreement's three key features.

First, there is efficient trade at the last stage because the parties truthfully report their values for exchange. The Agreement induces truthful reporting because it makes each party the residual claimant to the trading opportunity: each party, that is, either receives the trading opportunity, when its valuation for trade is highest, or receives a transfer that equals the other party's surplus from trade. The parties commit to fund the requisite last stage transfers at the prior stage. The Agreement's second key feature is to induce sufficient financing commitments by maximizing a party's continuation surplus within the agreement; and this, in turn, is accomplished by minimizing the value of the party's default outside option. Put another way, the Agreement selectively minimizes the value of the parties' control rights – the payoff a party could realize were it to dissolve the relationship. The party with the best outside option is given control with the lowest probability, which minimizes the value of its control right and thus encourages the party to stay with the arrangement.

The parties must know their demands for trade – the expected values that trade could yield for them – in order to compute the continuation surpluses, however. These demands, in turn, are a function of the parties' privately observed prior investments. The Agreement's third key feature, then, is to induce the parties to report their demands truthfully. The Agreement accomplishes this by providing for an earlier set of transfers that make each party the residual claimant to the arrangement's expected (rather than realized) surplus. The parties make their investment choices at the earliest stage. They then anticipate truthful reporting and sufficient financing at the later stages, so that each of them will be residual claimant to the arrangement's realized surplus, whatever it turns out to be. A party's best response is then to invest efficiently so as to maximize that surplus.

We develop these results using an example in which parties allocate capacity to a factory, the value of whose output is partly a function of the parties' investment behavior. Our story is a stand in for more complex arrangements: the logic applies whenever parties come together to develop and allocate an opportunity – a software program or a new drug – whose value is a function of the parties' investments. The investments are private and they partly influence the parties' preferences for trade. As a consequence of the evolving nature of private, payoff relevant information, the parties' initial control rights must be optimally adjusted "along the way". In these contexts, parties must solve the problems of inducing truthful disclosure of private information and creating efficient investment incentives. The analysis here thus is

an early step in understanding many real world arrangements that have been extensively described but less extensively theorized.

## 6.2 6.2 Legal Limitations

Each party's equilibrium best response is to perform under the Agreement at each stage. This feature characterizes many contracts, however, but law suits are common. Out of equilibrium behavior sometimes happens. As an example here, a party unexpectedly becomes liquidity constrained and would rather allocate suddenly scarce resources to avoid bankruptcy than to make a transfer payment the Agreement requires. The common contract law concern thus is how a court best responds to out of equilibrium behavior.

A party to the Agreement may engage in three possible types of strategic behavior, each of which may preclude the efficient outcome. There are three related contract law rules that limit the courts' ability to respond to these off the equilibrium path actions.

(i) First, contract law protects the expectation interest: that is, the law awards the non-breaching party the gain the party would have made under the contract, had it been carried out. Now consider parties who agree to investigate whether to exploit a possibly promising commercial opportunity. One of them defects from their arrangement by refusing to invest, say because it discovered a better opportunity.<sup>19</sup> Because investment behavior is private, the other party may not discover the defection until after it had invested. Contract law cannot award this party the standard expectation remedy because that remedy is the gain the party would have made from the developed opportunity. The parties never developed the opportunity. Contract law sometimes awards a party its reliance (i.e., investment) costs when its contract partner breached. The innocent party in this example could not recover its investment costs under this rule because the parties never made a final stage contract to allocate capacity to the factory. Rather, a party's claim to recover investment costs likely would run into the second rule, that contract law will not enforce penalties. A penalty is defined as a transfer that materially exceeds the gain a party would have made under its agreement. In the example here, the innocent party's expected contracting gain is zero

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<sup>19</sup>In the model, a party realizes a zero payoff if it chooses not to go forward. Parties sometimes defect when their disagreement payoffs unexpectedly improve.

– i.e., unknown – so any transfer above zero would be a penalty.<sup>20</sup>

(ii) Of probably greater relevance, investment under the Agreement is partly cooperative, in the sense that each party’s investment can convey information to the other. Now let a party that is supposed to invest instead delay until the other party reports the results of its investment. There is an incentive to delay: if the compliant party’s report is encouraging, the first party can then invest; if the other party’s report is discouraging, the first party can exit without incurring investment costs. If each party anticipates such strategic behavior, however, both will delay and the arrangement would unravel. The law could encourage compliance in the case of early defection or delayed investment by permitting the compliant party to recover its verifiable investment costs from the other. As we have seen, however, cost recoveries likely would be classified as penalties. In sum, contract law cannot help if a resource constrained party defects early on or materially delays.<sup>21</sup>

(iii) Contract law will not specifically enforce a promise to pay money. Because the non-breaching party can borrow elsewhere, the law makes him whole by permitting him to recover any difference in the interest rate from the breacher. A party to the Agreement may refuse to make a transfer that the agreement requires. The contractual transfers are parameter specific and to be made in the course of the parties’ relationship. Hence, the innocent party cannot borrow the withheld sum elsewhere. There is no contract law remedy for refusing to make transfer under the agreement.

To summarize, parties’ equilibrium best responses are to comply with the Agreement and many parties do comply in these legally unregulated contexts. Current contract law, however, is unhelpful in those cases, few in percent but possibly large in absolute number, where for exogenous reasons defection is more profitable to a party than compliance. Thus, our paper has a normative implication: Contract law, in addition to enforcing final arrangements parties manage to conclude, should facilitate parties’ ability to explore possibly efficient opportunities. These three rules should change.

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<sup>20</sup>Contract law restrictions on penalties are reviewed and criticized in Edlin and Schwartz (2003).

<sup>21</sup>Schwartz and Scott (2007) also suggests awarding a party verifiable investment cost to deter strategic behavior in the context of an agreement to develop a new machine or a new process.

## 7 Conclusion

We ask whether contract can induce efficient investment and trade when an economic relationship is expected to last for several periods, and when the parties are privately informed about investment levels and the costs and benefits of exchange. This question is addressed under the current institutional structure: today's contract law. Our principal contribution is to construct a contractual solution to the economic problem. A mechanism exists – the multi-stage Agreement – that induces parties to reveal their costs and benefits from exchange, and so to trade efficiently when they reach a trading stage. The parties must finance trade, however. The Agreement's crucial feature, at the penultimate stage, is to require financing transfers that are a function of the parties' outside options. The Agreement allocates default control rights so as to minimize the value of those options. This increases the parties' continuation payoffs from staying in the relationship. The greater are those payoffs, in turn, the more willing the parties are to finance the required later stage transfers. Finally, at the earliest investment stage the parties agree to finance demand creating investment out of expected surplus. The parties then anticipate that later trade will maximize whatever the surplus turns out to be. As a consequence, each party is motivated to invest efficiently; optimal investment maximizes expected surplus.

These results rest on two related economic assumptions: (a) control rights can be made sufficiently clear so that parties can alter them when needed; and (b) control rights can be made sufficiently precise – i.e., appropriately minimized – so that parties will finance efficient relationships. There is data that real parties do assign and modify control rights and attempt to affect their value, but the data is impressionistic.<sup>22</sup> When our two key assumptions fail to hold, efficiency may require parties to form firms. See Hart and Holmstrom (2010). Finally, because actual relationships likely are structured less precisely than in the model, there may be scope for strategic defections. For example, a party may refuse to make a financing deposit that the Agreement requires because its outside option has materially changed. Contract law, as it currently exists, functions poorly at deterring strategic defections because courts enforce contracts and parties have opportunities to defect before they agree on enforceable terms of trade. We argue that the law should advance, to intervene at stages prior to the trade stage. More particularly,

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<sup>22</sup>See Gilson, et al articles.

we suggest that efficiency would be enhanced if the law enforced contractual financing promises specifically and awarded the party that wants to continue an efficient relationship any verifiable investment costs it incurred.

## 8 Appendix

### 8.1 PROOF OF PROPOSITION 2

The optimal property rights  $\mathbf{r}^*(\mathbf{k})$  are determined by maximizing  $B(\mathbf{r}(\mathbf{k}))$ . This requires one to find a saddlepoint of the function<sup>23</sup>,

$$L(\mathbf{r}, \mathbf{b}, \boldsymbol{\mu}, \rho) = \max_{\mathbf{r}} \left( \sum_{i=x,y} \min_{b_i, \mu_i, \rho} [\bar{\alpha}_i^*(b_i) b_i + E_{b_{-i}} \alpha_{-i}^*(\mathbf{b}) b_{-i} - r_i b_i] + [\sum_i \mu_i r_i + \rho (1 - \sum_i r_i)] \right) \quad (\text{A1})$$

where  $\mu_i$  and  $\rho$  are Lagrange multipliers attached to the  $(r_i \geq 0)$  and the  $(1 - \sum_i r_i = 0)$  constraints. Our assumptions on  $F^{k_i}(\cdot)$  and  $\alpha_i^*(\cdot)$  ensure a solution to (A1) exists. The solution is characterized by the following necessary and sufficient first order conditions,

$$\bar{\alpha}_i^*(b_{iw}) + r_i^* \left\{ \begin{array}{l} \geq 0 \text{ as } b_{iw} = 0 \\ = 0 \text{ as } b_{iw} \in (0, \bar{b}) \\ \leq 0 \text{ as } b_{iw} = \bar{b} \end{array} \right\} \quad (\text{A2.a})$$

$$-b_{iw} + \mu_i - \rho = 0 \quad (\text{A2.b})$$

$$\mu_i r_i^* = 0, \quad \rho (1 - \sum_i r_i^*) = 0 \quad (\text{A2.c})$$

(A2.b) and (A2.c) imply,

$$r_i^*(\mathbf{k}) > 0, \text{ if } b_{iw} \leq \bar{b}_{-iw} \quad (\text{A3})$$

or that  $\sum_{i=x,y} r_i^*(\mathbf{k}) b_{iw}$  is minimized. ■

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<sup>23</sup>In the maximization of  $B(\mathbf{k})$  we ignore the term  $W^A(\mathbf{k})$  which is independent of the property right allocation  $\mathbf{r}(\mathbf{k})$ .

## 8.2 PROOF OF PROPOSITION 3

To verify  $\mathbf{r}^*(\mathbf{k})$  produces a strictly positive budget surplus,  $B(\mathbf{r}^*(\mathbf{k}))$  is shown to satisfy the following string of inequalities,

$$B(\mathbf{r}(\mathbf{k})) = \sum_i d_i(\mathbf{k}) - W^A(\mathbf{k}) \tag{A4.a}$$

$$\begin{aligned} &= \sum_i (\bar{\alpha}_i^*(b_{iw}) b_{iw} + \sum_{-i} E_{b_{-i}} \alpha_{-i}^*(b_{iw}, b_{-i}) b_{-i} - r_i^*(\mathbf{k}) b_{iw}) \\ &\quad - \sum_i \sum_{-i} E \alpha_{-i}^*(\mathbf{b}) b_{-i} \end{aligned} \tag{A4.b}$$

$$\begin{aligned} &> \sum_i (\bar{\alpha}_i^*(b_{iw}) b_{iw} + \sum_{-i} E \alpha_{-i}^*(\mathbf{b}) b_{-i} - r_i^*(\mathbf{k}) b_{iw}) \\ &\quad - \sum_i \sum_{-i} E \alpha_{-i}^*(\mathbf{b}) b_{-i} \end{aligned} \tag{A4.c}$$

$$= \sum_i (\bar{\alpha}_i^*(b_{iw}) - r_i^*(\mathbf{k})) b_{iw} \tag{A4.d}$$

$$= 0 \tag{A4.e}$$

(A4.c) follows from substituting allocation  $E_{b_{-i}}(\alpha_{-i}^*(\mathbf{b}))$  for  $E_{b_{-i}}(\alpha_{-i}^*(b_{iw}, b_{-i}))$  in (A4.b), and recognizing that  $E_{b_{-i}}(\alpha_{-i}^*(\mathbf{b}))$  is inefficient because it doesn't condition on  $b_{iw}$ . (A4.d) follows from (A4.c) after canceling and rearranging terms. (A4.d) leads to (A4.e) since  $-\bar{\alpha}_i^*(c_{iw}^t) + r_i^*(\mathbf{s}^t) = 0$  by (A2.a).

To complete our proof we now demonstrate the transfers are balanced. With a strictly positive budget surplus, the parties arrange a split of the surplus so that the transfers between  $x$  and  $y$  sum to zero. This adjustment should not affect their incentives to truthfully reveal the benefits and costs of allocating capacity. This requires the following modification to the original transfers  $\tilde{\tau}_i(\mathbf{k}, \mathbf{b})$  such that,

$$\begin{aligned} \tau_i(\mathbf{k}, \mathbf{b}) &\equiv E_{b_i} \tilde{\tau}_i(\mathbf{k}, \mathbf{b}) + E \tilde{\tau}_{-i}(\mathbf{k}, \mathbf{b}) - E_{b_i} \tilde{\tau}_{-i}(\mathbf{k}, \mathbf{b}) \\ &\quad + \frac{d_{-i}(\mathbf{r}^*(\mathbf{k})) - d_i(\mathbf{r}^*(\mathbf{k})) - E(\tilde{\tau}_i(\mathbf{k}, \mathbf{b}) + \tilde{\tau}_{-i}(\mathbf{k}, \mathbf{b}))}{2} \end{aligned}$$

Essentially, each party's required transfer is reduced by half the overage. Notice the overage refund does not depend on the parties' reports; hence incentives for truthful reporting are retained. It is straightforward to verify

that the modified transfers sum to zero and therefore balance the budget:  
 $\tau_i(\mathbf{k}, \mathbf{b}) + \tau_{-i}(\mathbf{k}, \mathbf{b}) = 0$  for all realizations of  $\mathbf{k}, \mathbf{b}$ . ■

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