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# Expropriation and Inventions: Appropriable Rents in the Absence of Property Rights

By JAMES J. ANTON AND DENNIS A. YAO\*

*We analyze the problem faced by a financially weak independent inventor when selling a valuable, but easily imitated, invention for which no property rights exist. The inventor can protect his or her intellectual property by negotiating a contingent contract (with a buyer) prior to revealing the invention or, alternatively, the inventor can reveal the invention and then negotiate with the newly informed buyer. Despite the risk of expropriation, we find that, in equilibrium, an inventor with little wealth can expect to appropriate a sizable share of the market value of the invention by adopting the latter approach. (JEL L13, O31, D23)*

Most independent inventors cannot successfully create an organization to take commercial advantage of their invention and, therefore, must rely on another party. The ensuing relationship may involve a production contract, a licensing arrangement, or the outright sale of the invention. With all of these forms, the inventor's ability to capture rents depends on the marketplace value of the invention, the means by which the invention is taken to market, and the property rights and information of the inventor.

When an inventor can rely on patents or other forms of property rights to protect his

intellectual property, theory suggests that the inventor can appropriate a substantial fraction of the invention's value. If property rights are weak or nonexistent, as is often the case, the inventor's ability to capture rents would seem to be substantially circumscribed. Under patent law, for example, many inventions are considered to be too closely related to "prior art" to justify a patent, and even if patents are granted "many...would be held invalid if ever litigated" (Phillip Areeda and Louis Kaplow, 1988 p. 177).<sup>1</sup> Reliance on trade-secret law (law pertaining to the use of confidentially disclosed, commercially useful information) to protect against the theft of ideas is often problematic because of the strategies that buyers employ to avoid legal challenges and

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<sup>1</sup>Consider, for example, the case of the ballpoint pen. Although L. J. Biro invented and patented the ballpoint pen, the first ballpoint pens were marketed in the United States by Milton Reynolds, who developed a pen (after seeing a Biro pen in Argentina) using "prior art" that did not infringe on Biro's patents (John Jewkes et al., 1969 pp. 234–35). Eric von Hippel's (1982) study of court records shows that, when litigation occurs, the likelihood of a patent being held valid and infringed is about 3 to 1 against the patent-holder.

the difficulty of establishing legal proof.<sup>2</sup> Finally, some forms of intellectual property, such as new product concepts and management-systems ideas, are just inherently difficult to protect.

In this paper we focus on the inventor's problem when no legal mechanism provides effective protection for the invention.<sup>3</sup> Our stylized version of the problem addresses the following concern. Suppose an inventor cannot individually bring an invention to the market and is concerned about disclosing key aspects of the invention to a potential buyer or partner. Sight unseen, a buyer may be hesitant to buy or contract for an unknown commodity, but if the inventor first reveals information regarding the invention, a lack of property rights makes it possible for the newly informed party to "steal" or "expropriate" the invention. Expecting that firms are likely to pay very little for an invention they have not seen, the inventor must decide if they would pay anything at all once they have a clear avenue to take the invention to market without the inventor.<sup>4</sup>

<sup>2</sup>Steven N. S. Cheung (1982), for example, notes that almost all U.S. firms require outside inventors to sign a waiver form acknowledging that no confidential relationship is established, thereby undermining a trade-secret remedy for idea theft. See also the opinions in *Burten v. Milton Bradley Co.* (592 F. Supp. 1021 [D.R.I. 1984], rev'd 763 F.2d 461 [1st Cir. 1985]) a case in which an electronic board game submitted to Milton Bradley from two inventors was allegedly "stolen" from the inventors. In addition, under trade-secret law (see J. H. A. Pooley, 1987) there is no violation if the invention was independently discovered or reverse-engineered. This is the basis of Kentucky Fried Chicken's defense against an inventor who claims that KFC stole his pressurized frying cooker (*Business Week*, 7 May 1990, p. 41).

<sup>3</sup>By analyzing the no-property-rights case, we adopt a different perspective from that of the R&D and innovation literature that assumes patent protection (see e.g., Partha Dasgupta and Joseph Stiglitz, 1980; Nancy T. Gallini, 1984; Gallini and Ralph A. Winter, 1985; Morton I. Kamien and Yair Tauman, 1986; Michael L. Katz and Carl Shapiro, 1986).

<sup>4</sup>David J. Teece (1986) argues, for example, that when imitation is easy the profits from innovation accrue to owners of complementary assets such as manufacturing capability rather than to the developers of the intellectual property. Gallini and Brian D. Wright

We model a setting with an inventor and two manufacturing firms that are currently competing in a duopoly market. The inventor may possess a valuable process invention that reduces the costs of production of the manufacturers. Initially, only the inventor knows whether the invention is valuable. A useless invention has no incremental value, while a valuable invention results in incremental profit increases to the manufacturers, the sizes of which depend on whether the other firm has the invention. The invention also has the property that, once revealed to a manufacturer by the inventor, it can be perfectly reproduced without cost or threat of legal action. Firms can also independently develop the invention, and a third party cannot verify the source of a valuable invention.<sup>5</sup>

Suppose that an inventor attempts to sell the invention while avoiding the risk of expropriation. One way to do this is to negotiate a contract before revealing the invention to any of the firms. When the inventor has large financial resources, it is straightforward to show that an inventor can credibly signal the value of the invention by agreeing to part with assets if the invention turns out to be useless. In this case, the inventor can obtain the full value of the invention to a "monopolist" firm. When, however, an inventor's wealth is small, this *ex ante* signal comes at the expense of inventor rents; when invention is difficult *ex ante* and the inventor's wealth goes to zero, the inventor's rents vanish.

Our primary result is that an inventor without property rights and with virtually no wealth can still appropriate a sizable share of the ultimate value of the invention. To obtain these rents the inventor chooses to reveal the invention prior to any agreement.

(1990) identify when an inventor can capture rents by signaling the value of an innovation via licensing contracts.

<sup>5</sup>The amount of payment that the inventor can obtain from the firms is conditioned on the firms' beliefs about the usefulness of the invention. Thus, the model addresses adverse-selection problems but not moral-hazard issues.

This strategy allows the inventor to negotiate with the firm on the basis of full, rather than incomplete, information about the value of the invention. The manufacturer voluntarily negotiates a contract with the inventor because the manufacturer is concerned about the possible loss of its "monopoly" in the use of the invention. The equilibrium contract creates incentives that prevent the inventor from profiting by selling the invention to the other firm and undermining the first firm's monopoly. We also find that, when bargaining power lies with the firms, the inventor's share of the rents increases as the inventor's *ex ante* wealth decreases. This result derives from the fully informed firm's strategic use of the inventor's wealth (within the structure of the contract) to limit the potential contracts an inventor will accept from the other firm.

The results in our paper address the general issue of selling information, which has been emphasized by Kenneth J. Arrow and others (see Arrow, 1970). As the inventor chooses, in equilibrium, to reveal the invention prior to receiving a contract offer, our analysis is also related to the recent work on strategic information revelation. For example, see Masahiro Okuno-Fujiwara et al. (1990), which examines revelation via public disclosure. In contrast, we focus on a setting where information is privately revealed to only one of two firms in the market, and the only way the inventor can convince the firm that the invention is valuable involves transferring the necessary "how-to" knowledge to the firm. Thus, in terms of certifiable information, the inventor is unable to mitigate the adverse-selection problem without also opening the door for the firm to expropriate the invention via imitation.

The paper proceeds as follows. Section I describes the model and extensive form. Section II presents our main result. We characterize an equilibrium that exhibits *ex post* contracting on the equilibrium path: the inventor first reveals the invention to one of the firms and then receives and accepts an *ex post* contract offer for payment. Section III, which provides a benchmark for the main result, characterizes an equilibrium that exhibits *ex ante* contracting and

derives a general bound on the payoff to an inventor in any *ex ante* allocation. We present our conclusions in Section IV. All proofs are in the Appendix.

## I. The Model

We are interested in the extent to which an inventor can obtain rents from a useful invention when another party is needed to realize the value of the invention (i.e., put the invention to use), there are no property rights regarding the invention, and the inventor has small assets relative to the economic value of the invention. The essential features of this problem can be captured with a relatively simple model. Consider an industry in which there is the potential for a discovery that represents a discrete improvement over the status quo.<sup>6</sup> The industry consists of two firms or manufacturers,  $i = 1, 2$ , and there is a single inventor,  $I$ , who is outside of the industry. The inventor can make the discovery (a "good" invention) or fail to make the discovery (a "bad" invention). All parties are risk-neutral and maximize expected profits.

The model incorporates the following elements. *Ex ante*, neither manufacturer knows whether the inventor has a good invention; this is private information of the inventor. The inventor has the strategic option of "showing" or "revealing" a good invention to a manufacturer, which may be done before or after contracting. Thus, a good inventor can choose whether contracting is conducted on an *ex post* basis with an "informed" firm (the inventor reveals the invention prior to a contract offer) or on an *ex ante* basis with an "uninformed" firm (the inventor seeks a contract offer prior to revealing the invention). When the inventor reveals a good invention prior to a contract

<sup>6</sup>The discovery could, for instance, involve a process innovation that reduces production costs for an existing product. The model also applies if the discovery relates to a product innovation. To the extent that "reverse engineering" is possible, the benefit from innovating is the head start in bringing the product to market (see e.g., Jean-Pierre Benoit, 1985).

offer, the manufacturer is affected in two ways. In addition to learning that the inventor has a valuable invention, the manufacturer also gains the ability to reproduce and use the invention (imitate) without relying further on the inventor and without encountering any legal obstacles associated with expropriating the inventor's intellectual property.<sup>7</sup> We refer to this act of imitation as "expropriation."

We also allow for the possibility that a manufacturer may discover the invention independently of the inventor. Thus, the inventor or the firm may be the underlying source of a valuable invention, and this allows us to capture the lack of property rights as a structural feature of the analysis. We now turn to the formal specification of these elements and, with these in place, we present the extensive form of the model.

The profits of the manufacturers, gross of any payments to the inventor, are determined by which of the firms, if any, has a good invention. For simplicity, we specify these profits in reduced form.<sup>8</sup> There are four possible states of the world. When firm  $i$  has the (good) invention but firm  $j$  does not, then  $i$  earns a profit of  $\pi_M$  while  $j$  earns  $\pi_L$ , where M stands for "monopoly" and L for "low" profits. We use "monopoly" to refer to the case in which only one firm has the invention (the other firm is not necessarily driven from the market). If both firms have the invention, then each firm earns  $\pi_D$  where D stands for "duopoly" profits. Finally, profits are  $\pi_0$  for each firm when neither has the invention. Assume that  $\pi_M$  exceeds  $\pi_D$ , and  $\pi_L$  and  $\pi_0$  are each less than  $\pi_D$ . More importantly, we make the standard assumption that  $\pi_M +$

$\pi_L > 2\pi_D$  (industry profits are largest when one firm uses the invention).

The source of a good invention can be the inventor or a manufacturer. At the start of the game,  $I$  discovers a good or bad invention; neither is of direct value to  $I$ . The manufacturers do not observe this outcome. *Ex ante*, they believe  $I$  discovers a good invention with probability  $q \in (0, 1)$ . Independently of each other and the inventor, each firm discovers the good invention with probability  $\alpha \in (0, 1)$ ; this occurs just before gross profits are realized.<sup>9</sup>

A good inventor can reveal the invention to a firm. In this event, the firm is able to make full use of the invention and earn a gross profit of  $\pi_M$  or  $\pi_D$ , depending on whether the other firm also possesses the invention. In our analysis, the ability of the inventor to appropriate rents is related to the rents available to the firms and the inventor collectively (the gross profit levels). These gross profits should be interpreted as including any downstream effects of imitation. If the invention involves process innovation, the invention may remain hidden from a competing firm when one firm adopts the invention in production. In contrast, for a product innovation in a market without a substantial first-mover advantage, the collective rents are likely to be smaller when a previously uninformed competitor can imitate the invention shortly after it is brought to market.

Now consider the specification of contracting within this framework. We assume that legally enforceable contracts take the form of payments that are contingent on the gross profit levels of the two firms. That is, we assume that *ex post* the gross profit levels are observable and verifiable. A contract between  $I$  and a firm is therefore a vector  $\mathbf{R} = (R_0, R_i, R_j, R_D)$  where  $R_x$  is the payment by the firm to  $I$  in the event state  $x$  occurs and 0,  $i$ ,  $j$ , and D correspond,

<sup>7</sup>One interpretation of this is that, once the invention is revealed, all relevant information regarding the invention (design, manufacture, etc.) becomes known to the firm, and the inventor cannot provide additional value with respect to the use of the invention by the firm.

<sup>8</sup>It is possible to derive the gross profits from an underlying model of duopoly competition. An example is provided by Cournot quantity competition, extended to include asymmetric cost information between the manufacturers.

<sup>9</sup>This allows us to explore expropriation without creating an added source of private information, as would be the case if firms had earlier discovery dates. The basic incentive for contracting is robust to this variation.

respectively, to gross profit outcomes when neither firm, only firm  $i$ , only firm  $j$ , and both firms have the invention.

Contracting on gross profits reflects the lack of property rights regarding the invention. In essence, we assume that a third party can observe only events that are consequences of using the invention. While a third party may conclude that the invention is being used, the third party cannot verify the source of the invention (as  $\alpha > 0$  and  $q > 0$ , the source may be the inventor or the firms). For example, a payment of  $R_i$  in the event of a monopoly for firm  $i$  must be made whenever  $i$  earns  $\pi_M$ , independently of whether  $I$  revealed the invention to firm  $i$  or firm  $i$  discovered the invention.

Finally, we assume that the inventor has a limited liability equal to  $L > 0$ . We are particularly interested in the case of  $L$  approaching zero, which corresponds to a setting in which the inventor cannot pursue a self-use strategy (or a self-manufacture strategy in the case of product innovations), perhaps due to limited wealth or capital-market access. By assumption, then, a net payment by the inventor in excess of  $L$  in any state is not feasible. For simplicity, we assume that the value of  $L$  is common knowledge among the parties. Thus, if a contract  $\mathbf{R}$  is agreed to and, subsequently, an additional contract  $\mathbf{S}$  is agreed to, then we require

$$(1) \quad R_x \geq -L \text{ and } R_x + S_x \geq -L$$

$$x \in \{0, i, j, D\}.$$

Note that (1) constrains each step in a sequence of contracts so that an initial contract payment is not allowed to violate (1) based on an expectation that a subsequent contract will resolve the violation.

The next step is to embed these elements in an extensive-form game of incomplete information. Figure 1 provides a schematic of the extensive form. It is a sequential process in which firms make contract offers and bargaining with one firm must be concluded prior to bargaining with the other firm.

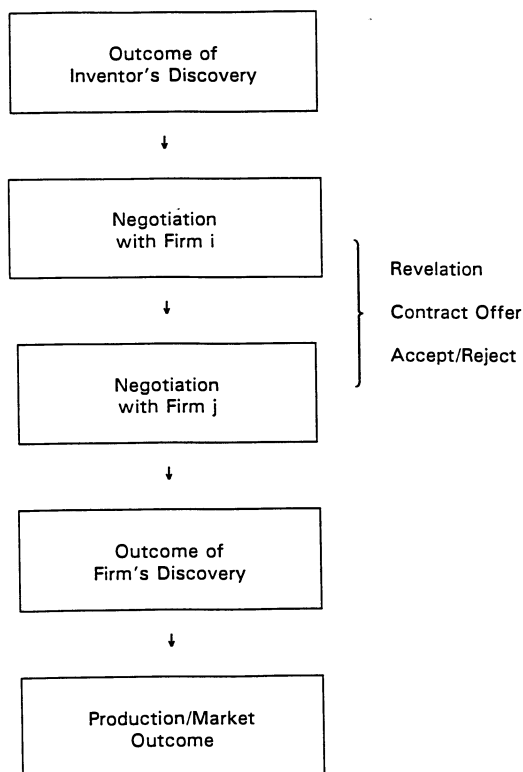


FIGURE 1. STRUCTURE OF THE GAME

The extensive form begins with  $I$  learning privately whether the invention is good or bad; we refer to this as a good  $I$  and a bad  $I$ , respectively. Next,  $I$  can choose to approach either firm for a contract offer or choose not to approach.  $I$  approaches a firm by (privately) sending one of two messages. If  $I$  reveals (only a good  $I$  can reveal), then the firm simultaneously learns that  $I$  is good and also acquires all necessary "how-to" knowledge (the ability to imitate the invention and, hence, to expropriate). Alternatively,  $I$  can choose not to reveal the invention. In response to the message, the firm chooses what contract, if any, to offer. Then,  $I$  chooses whether to accept the offer and whether to reveal (unless revelation has already occurred). This process is then repeated with the other firm.

There is only one bargaining round with each firm so that, at most, a firm makes one

offer to the inventor. Thus, we employ a simple take-it-or-leave-it bargaining structure for contracting; this is conservative with respect to the payoffs of the inventor, as the firms will offer contracts that push the inventor to indifference with respect to accepting.

Consider now the information available to a firm when formulating a contract offer. If  $I$  approached firm  $k$  by revealing, then we refer to  $k$  as an "informed" firm and refer to an offer from  $k$  as an "*ex post*" contract offer. If  $I$  did not reveal, then  $k$  is "uninformed," and we refer to the offer as an "*ex ante*" contract offer. We assume that a signed contract between an inventor and a firm is observable to the other firm, but one firm cannot observe whether a good inventor reveals the invention to the other firm. Thus, an element of the set {informed, uninformed}  $\times$   $\{\mathbf{R} | R_x \geq -L, x = 0, 1, 2, D\}$  describes the information available to a firm, where an observation of  $\mathbf{R} = (0, 0, 0, 0)$  denotes no prior contract observed, and the contract offer,  $\mathbf{S}$ , must satisfy  $S_x + R_x \geq -L$ . A strategy for the firm maps observed information to a contract offer. Thus, a firm makes an offer based on whether a good invention has been revealed to it and on the observed contract, if any, between  $I$  and the other firm.

We now turn to the beliefs of the firms. Due to incomplete information, a firm cannot be sure of precisely where it is in the extensive form when it makes a contract offer. Rather, the firm has beliefs about its position which are based on available information. Suppose firm  $k$  observes that a signed contract is in place between  $I$  and firm  $\sim k$ . Then beliefs for  $k$  must specify probabilities for the events (a)  $I$  is bad, (b)  $I$  is good and has revealed the invention to the other firm, and (c)  $I$  is good and has not revealed to the other firm. If, in addition,  $k$  is informed, then the probability that  $I$  is bad must be zero. If  $k$  observes no signed contract between  $I$  and  $\sim k$ , then firm  $k$  is unsure whether it is the first or second firm to have been approached and, hence, whether  $\sim k$  will have a subsequent opportunity to make an offer; in addition to (a)–(c) above, the beliefs must also specify proba-

bilities for no approach, no offer, and a rejected offer as regards  $I$  and the other firm.

A strategy for the inventor is a plan for bargaining with the firms. An inventor has complete but imperfect information (as  $\alpha > 0$ ) regarding position in the extensive form. First, immediately after discovering the invention, the inventor may choose one of the firms, denoted by  $i$ , to approach for a contract offer by revealing or not revealing the invention to firm  $i$ . If  $i$  makes an offer, then  $I$  chooses whether to accept or reject, and then whether to reveal to  $i$  or not. Next,  $I$  may approach the other firm, denoted by  $j$ , and choose whether to reveal. This is followed by the choice to accept or reject an offer from  $j$  and then a final decision to reveal to  $j$  and  $i$ .

We solve for a perfect Bayesian equilibrium. In this game, such an equilibrium is a triple of strategies and a pair of belief functions that satisfy three conditions: given the firm's available information and beliefs, and given the strategies of the inventor and the other firm, the firm's strategy specifies a contract offer that maximizes the firm's expected payoff; given an inventor type (good or bad), the strategies of the firms, and a decision node of the inventor, the inventor's strategy maximizes the inventor's expected payoff; and, whenever possible, beliefs are derived from Bayes' rule and the strategies of the other players.

## II. The Structure of an *Ex Post* Contracting Equilibrium

In this section we develop our main result that an inventor who has made a difficult but valuable discovery can expect a significant payoff in equilibrium by freely revealing the invention prior to receiving a contract offer. This result emerges from the analysis of an equilibrium path with the following features: a good inventor "reveals" the invention to a randomly chosen firm, denoted by  $i$ , prior to any contractual relationship with either firm; firm  $i$ , which is now "informed," offers the "*ex post*" contract,  $\mathbf{R}^*$ ;  $\mathbf{R}^*$  is accepted by the inventor; and no other contracts are signed, and the

good inventor does not reveal the invention to the other firm,  $j$ .

First, we develop necessary conditions for this "ex post" contracting equilibrium and pin down the payoffs and structure. Later, we present sufficient conditions and discuss how the equilibrium is supported.

In equilibrium, the expected payoff to a good  $I$  is  $(1 - \alpha)R_i^* + \alpha R_D^* \equiv \Pi_I^*$ , since firm  $i$  has the invention and firm  $j$  independently discovers the invention with probability  $\alpha$ . A bad  $I$  enters no contracts and thus earns zero. Upon becoming informed,  $(1 - \alpha)(\pi_M - R_i^*) + \alpha(\pi_D - R_D^*)$  is the expected payoff for firm  $i$ . Firm  $j$ , upon observing  $R^*$  between  $I$  and  $i$ , expects a payoff of  $(1 - \alpha)\pi_L + \alpha\pi_D$ .

The first necessary condition for an ex post equilibrium derives from the need to structure  $R^*$  to remove any possible gains to trade between the inventor and firm  $j$ . That is, once a good  $I$  has accepted  $R^*$  it must not be possible for both  $I$  and  $j$  to benefit from an additional contract. Upon observing  $R^*$ , firm  $j$  anticipates a monopoly outcome for firm  $i$  (with probability  $1 - \alpha$ ). Thus, to avoid receiving  $\pi_L$ , firm  $j$  can try to induce  $I$  to reveal to  $j$  as well, thus guaranteeing the duopoly outcome. To do so,  $j$  must find a contract,  $S$ , that provides an incentive for  $I$  to reveal to  $j$  and is mutually profitable for  $I$  and  $j$ . Since the inventor has already revealed to firm  $i$ , this revelation incentive requires that  $R_D^* + S_D > R_i^* + S_i$ , so that the inventor earns more in state  $D$  than in state  $i$ .

The inventor will accept  $S$  if by doing so profits are increased, and this entails  $R_D^* + S_D > (1 - \alpha)R_i^* + \alpha R_D^*$ . For  $j$  to benefit from offering  $S$ , we need  $\pi_D - S_D > (1 - \alpha)\pi_L + \alpha\pi_D$ . Mutual profitability thus requires

$$(2) \quad (1 - \alpha)(\pi_D - \pi_L) > S_D$$

$$> (1 - \alpha)(R_i^* - R_D^*).$$

If this condition holds, then  $j$  can upset the equilibrium by offering a contract  $S$  such as  $S_D = (1 - \alpha)(\pi_D - \pi_L) - \varepsilon$  and  $S_x = -(R_x^* + L)$  for states  $x = 0, i, j$ . This contract satisfies limited liability, induces a good  $I$  to reveal to firm  $j$  given that firm  $i$  is

informed, and is mutually profitable for  $I$  and  $j$  given  $R^*$ . To eliminate this possibility, condition (2) must fail, and thus,  $I$  must offer  $R^*$  such that

$$(3) \quad R_i^* - R_D^* \geq \pi_D - \pi_L.$$

That is,  $j$ 's benefit from having the invention when  $j$  knows  $i$  has it (the most  $j$  is willing to pay) is less than  $I$ 's loss under  $R^*$  if  $I$  reveals to  $j$ .

The second necessary condition concerns expropriation by firm  $i$ . Since  $I$  reveals to firm  $i$  without any prior contract, firm  $i$  has the option of expropriating the invention (a zero offer) rather than offering  $R^*$ . The choice depends on what firm  $i$  expects  $I$  to do if no contract is offered. If  $i$  expects that  $I$  will end up revealing the invention to  $j$ , then expropriation is unprofitable for  $i$  when

$$(4) \quad (1 - \alpha)(\pi_M - R_i^*) + \alpha(\pi_D - R_D^*) \geq \pi_D.$$

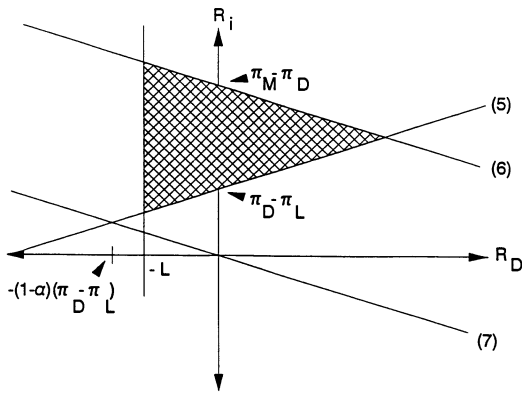
Intuitively, condition (4) reveals that firm  $i$  would always expropriate if the inventor were to receive too large a share of the rents from monopoly use of the invention. To see this, simply rearrange (4) by solving for the equilibrium payoff of the inventor to find  $(1 - \alpha)R_i^* + \alpha R_D^* \leq (1 - \alpha)(\pi_M - \pi_D)$ .

To build intuition for why expropriation leads to the duopoly outcome, note first that expropriation is a zero-payment contract offer. Given the above analysis of condition (2), from  $R_i = R_D = 0$  we see that gains to trade exist between the inventor and firm  $j$ . This intuition underlies  $i$ 's expectation that expropriation results in the duopoly outcome (we consider the equilibrium beliefs and contract offer of firm  $j$  later in this section).

We now examine the implications of these two necessary conditions and limited liability.<sup>10</sup> Begin by rearranging conditions (3)

<sup>10</sup>One potential interaction that we ignore is contracting between firms over the invention. In a duopoly context, contracting could be difficult because of anti-trust considerations. It is easy, however, to expand the model to include this interaction, thus adding  $\pi_M + \pi_L - 2\pi_D \geq R_i^* - R_D^*$  as an additional necessary condition.



FIGURE 2.  $L < (1 - \alpha)(\pi_D - \pi_L)$ 

and (4) so that  $R_i$  is on the left side of the inequality, thus facilitating a comparison when  $R_i$  is graphed against  $R_D$ :

$$(5) \quad R_i^* \geq (\pi_D - \pi_L) + R_D^*$$

$$(6) \quad R_i^* \leq (\pi_M - \pi_D) + \alpha(1 - \alpha)^{-1} R_D^*.$$

Figure 2 graphs these inequalities, including the lower bound set by limited liability, condition (1). By the direction of the inequalities, potential  $R_i^*$  and  $R_D^*$  equilibrium payments lie in the shaded area. Because the slopes in (5) and (6) are opposite in sign, the standard assumption that monopoly use of the invention leads to the greatest industry profits,  $\pi_M + \pi_L > 2\pi_D$ , implies that the shaded region exists. The inventor prefers contract payments to the northeast while firm  $i$  prefers those to the southwest. Because expected gross profits are constant at  $(1 - \alpha)\pi_M + \alpha\pi_D$  over the shaded region, movement from one contract to another has a zero-sum flavor: increases in profits to one party equal the decrease in the profits to the other party.

In equilibrium an inventor must earn nonnegative profits by accepting  $R^*$ :

$$(7) \quad \Pi_I^* \geq 0.$$

Define isoprofit lines for the inventor by  $\Pi_I \equiv (1 - \alpha)R_i + \alpha R_D$ . In Figure 2, these lines are parallel to the boundary line of

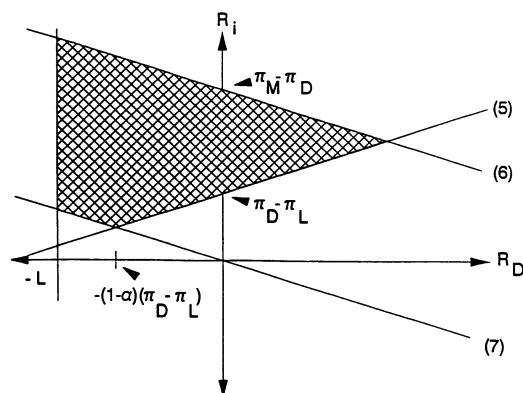
condition (6), and the zero isoprofit line passes through the origin. When  $L$  becomes small, the zero isoprofit line does not intersect the crosshatched region. As  $L$  approaches zero, the minimum expected payoff to a good inventor from accepting  $R^*$  approaches  $(1 - \alpha)(\pi_D - \pi_L)$ , obtained from the contract at the intersection of the  $R_i$  axis and lower bound (5) in Figure 2.

This result reveals an important property of *ex post* equilibria involving low-probability discoveries: an inventor with little or no liability can expect a contract offer with a significant payoff. The reason is as follows. To prevent firm  $j$  from upsetting the equilibrium by offering a contract that leads to a duopoly outcome,  $R^*$  must establish a sufficiently large wedge between  $R_i^*$  and  $R_D^*$ , namely,  $\pi_D - \pi_L$ . For firm  $i$ , an attractive way of doing this would be to set  $R_D^*$  to a large negative value and thereby hold down the value of  $R_i^*$ . Since small liability prevents  $R_D^*$  from being a large negative amount, the wedge implies that the inventor must receive a large payment in the event of a monopoly for firm  $i$ . Thus, the positive expected payoff for a good inventor is a consequence of limited liability and incentives required to maintain a monopoly in the invention.

By the same logic, with a larger  $L$  firm  $i$  can maintain the wedge with a smaller monopoly state payment,  $R_i^*$ , by taking advantage of the larger liability level to reduce the duopoly state payment,  $R_D^*$ . Thus, the lower bound on the equilibrium payoff to  $I$  decreases as  $L$  rises. As shown in Figure 3, for  $L \geq (1 - \alpha)(\pi_D - \pi_L)$  the zero isoprofit line,  $\Pi_I = 0$ , intersects the crosshatched region, and the lower bound of  $\Pi_I^* = 0$  is potentially binding.

In the extensive form, firms make take-it-or-leave-it offers, and in equilibrium, this allows firm  $i$  to push the payoff of the inventor to the lower bounds described above. Proposition 1 describes the equilibrium contract.

**PROPOSITION 1:** Consider an equilibrium, for the extensive form, in which the equilibrium path exhibits *ex post* contracting, and let  $R^*$  denote an equilibrium contract. Then  $R^*$

FIGURE 3.  $L \geq (1 - \alpha)(\pi_D - \pi_L)$ 

satisfies:

- (a) when liability is small, that is,  $L < (1 - \alpha)(\pi_D - \pi_L)$ , we have

$$R_i^* = \pi_D - \pi_L - L \quad \text{and} \quad R_D^* = -L$$

- (b) when liability is large, that is,  $L \geq (1 - \alpha)(\pi_D - \pi_L)$ , we have

$$R_i^* = \alpha(1 - \alpha)^{-1} R_D^*$$

$$\text{for } -L \leq R_D^* \leq -(1 - \alpha)(\pi_D - \pi_L).$$

(All proofs are in the Appendix.) To develop an understanding of Proposition 1, begin with the case of large liability. Direct calculations reveal that the inventor receives an equilibrium payoff of  $\Pi_i^* = 0$ . The inventor would reject any such contract if the next best alternative, bargaining with firm  $j$ , yielded a positive expected payoff. With take-it-or-leave-it offers, however, firm  $j$  is able to capture all of the gains to trade that exist when the inventor has rejected the offer from firm  $i$  (this is demonstrated below in the proof of Proposition 2).

When  $L$  is sufficiently large, firm  $i$  can structure  $\mathbf{R}^*$  so that gains to trade between the inventor and firm  $j$  are eliminated and the payoff to the inventor under  $\mathbf{R}^*$  is forced to zero, the threshold level at which the inventor is just willing to accept the contract.

More important is the case of small liability in which the inventor receives

$$\Pi_i^* = (1 - \alpha)(\pi_D - \pi_L) - L > 0.$$

Although the inventor can expect only a zero payoff from bargaining with  $j$ , this acceptance threshold is not binding. The reason, as discussed above, is that a small  $L$  makes it impossible for firm  $i$  to structure an  $\mathbf{R}^*$  that eliminates gains to trade with firm  $j$  and also has a zero payoff for the inventor. To preserve a monopoly in the invention, firm  $i$  must respect the gains-to-trade condition, and so the inventor receives a positive expected payoff from  $\mathbf{R}^*$ .

The payoffs in Proposition 1 apply to equilibrium in our extensive form. Under this bargaining structure, where firms make take-it-or-leave-it offers, the payoff to the inventor declines as  $L$  rises, reflecting the role of  $L$  in setting the  $(R_i^* - R_D^*)$  wedge. Under alternative assumptions where bargaining power is less concentrated, this negative relationship between  $L$  and the equilibrium share of rents appropriated by  $I$  may not hold. Referring back to Figure 2, note that the lower bound on the payoff to  $I$  declines with  $L$  while the upper bound is independent of  $L$ . Under any bargaining structure, increases in  $L$  have this adverse effect on feasible payoffs and, in this sense, put the inventor at a strategic disadvantage.<sup>11</sup>

In each case, the firm structures  $\mathbf{R}^*$  to take strategic advantage of the liability of the inventor. An interpretation of  $\mathbf{R}^*$  which illustrates this point is the following. As a condition of the contract, firm  $i$  "requires" that the inventor "post a bond" equal to  $R_D^*$ . This bond is forfeited if the duopoly state occurs, but it is returned with a bonus of  $(R_i^* - R_D^*)$  if the monopoly state for  $i$  occurs. By necessity, this bond is small when the liability of the inventor is small. The bonus, however, must remain sufficient to eliminate gains to trade with the other firm.

<sup>11</sup>Accounting for an initial wealth of  $L$ , we see that the net wealth to the inventor remains constant at  $(1 - \alpha)(\pi_D - \pi_L)$  over the small  $L$  range. Thus, while there is no net advantage to reducing  $L$ , or burning money, the inventor could benefit by hiding assets. An interesting extension would involve allowing for private information regarding the size of  $L$ .

Thus, small liability reduces the strategic advantage of firm  $i$ , eliminating it as  $L$  approaches zero, and leads to a positive payoff for the inventor.

With the necessary structure of an *ex post* contracting equilibrium established in Proposition 1, we are ready to consider existence. Sufficient conditions for existence of this equilibrium are given in Proposition 2.

**PROPOSITION 2:** *Suppose that  $\pi_M + \pi_L > 2\pi_D$ . Then there exists an equilibrium with ex post contracting.*

As described above, on the equilibrium path a good  $I$  approaches one of the firms (randomly chosen) by revealing the invention, and then  $R^*$  is offered by this firm and accepted by  $I$ ; a bad  $I$  chooses (optimally) not to approach either firm.<sup>12</sup> This path must be supported by the decisions of firms and the inventor “off the equilibrium path,” and furthermore, these decisions must be optimal for a specified set of beliefs. The formal proof is deferred to the Appendix. For the present, we concentrate on developing the intuition behind the critical element in supporting the equilibrium, namely, the reason an informed firm finds it optimal to offer  $R^*$  to the inventor.

The reason is that if the informed firm does not offer  $R^*$ , then the inventor will end up revealing the invention to the other firm. Thus, the monopoly in the invention will be lost, and the duopoly state will prevail. The exact way in which this occurs will depend on the nature of the deviation from  $R^*$ . To illustrate the basic idea behind the supporting beliefs and strategies, we focus on the case of “expropriation” in which the informed firm deviates by making no contract offer.

Given expropriation,  $I$  has the option of approaching the other firm. If  $I$  were to reveal the invention before receiving an offer, then state D would occur. The monopoly in the invention for the expropriating firm would then be lost, and by the existence

condition ( $\pi_M + \pi_L > 2\pi_D$ ), offering  $R^*$  would yield higher profits.

If, on the other hand,  $I$  were to seek an *ex ante* contract, then the beliefs of an uninformed firm who observes no prior contract would come into play. These beliefs are specified as

$$(8) \quad \left\{ \begin{array}{l} \rho = \text{probability } I \text{ is good} \\ \text{and has revealed} \\ \text{to the other firm} \\ 1 - \rho = \text{probability } I \text{ is bad} \\ 0 = \text{probability } I \text{ is good} \\ \text{and has not revealed} \\ \text{to the other firm} \end{array} \right.$$

where  $\rho$  satisfies  $0 < \rho < 1$ , and where  $I$  approached the other firm with probability 1. Under these beliefs, an uninformed firm discounts completely the prospect of contracting for monopoly use of the invention and, instead, anticipates that *ex ante* contracting with a good  $I$  takes place only after the invention has been revealed to the other firm. In short, the belief is that a good  $I$  has been expropriated after revealing to the other firm.

These beliefs lead to a simple optimal contract offer. By offering a small positive payment in the duopoly state,  $R_D = \varepsilon$ , and a (negative) payment of  $-L$  in all other states, the uninformed firm can screen a bad  $I$  while attracting a good  $I$  who then reveals.<sup>13</sup> As this results in the duopoly state, the monopoly in the invention for the expropriating firm would again be lost, and thus, the equilibrium-path offer of  $R^*$  is preferred to expropriation.

Of course, the complete analysis of the full range of deviations from equilibrium and the supporting beliefs and strategies involves a number of additional considerations. The essential idea for the overall supporting belief structure, however, is captured by this informal consideration of expropriation. Whenever an uninformed firm

<sup>12</sup>We avoid unnecessary complications off the equilibrium path with a random choice of firm by  $I$ , as a nonrandom choice would force one firm to treat revelation as a surprise. Specifying no approach also keeps matters simpler.

<sup>13</sup>Whenever contract payments push the inventor to indifference with respect to revealing the invention, the “tie” is broken in favor of the firm making the last offer, as this firm could always offer a slightly larger payment.

considers a contract offer and observes that  $\mathbf{R}^*$  is not already in place, it believes that if  $I$  is good then  $I$  has previously revealed to the other firm. Consequently, as  $\mathbf{R}^*$  is not in place, the uninformed firm and a good  $I$  can both benefit from a contract that leads a good  $I$  to reveal to the uninformed firm, thus resulting in the duopoly state. In turn, this supports the equilibrium-path offer of  $\mathbf{R}^*$  by an informed firm.

### III. *Ex Ante* Contracts and Limited Liability

Thus far we have focused on equilibrium behavior involving *ex post* contracting. We now consider equilibrium behavior when the inventor approaches a firm for a contract without revealing the invention. The fundamental difference between contracting on an *ex post* versus an *ex ante* basis is the information position of the firms. In the *ex post* case, the invention has been revealed to the firm, whereas in the *ex ante* case the firm remains unsure whether the inventor is good or bad.

We begin by examining equilibrium behavior (in the extensive form) involving *ex ante* contracting when the inventor has significant resources (large  $L$ ). Afterwards, we turn to the general properties of *ex ante* contracting. We derive an upper bound on the size of the inventor's rents, which is valid for a wide range of extensive forms, and show that these rents must vanish as  $L$  and  $q$  go to zero. We conclude the section with a summary of *ex ante* and *ex post* contracting, focusing on the roles of  $L$ ,  $\alpha$ ,  $q$ , and gross profit levels.

#### A. *Ex Ante* Contracting in Equilibrium

We will show that when  $L$  is sufficiently large, there exists an equilibrium involving *ex ante* contracting in which the inventor captures all of the rents. First, consider the maximum payoff an inventor could obtain when it is common knowledge that the inventor is good. The largest payoff possible for a firm is  $(1 - \alpha)\pi_M + \alpha\pi_D$ , which occurs when a good inventor reveals only to this firm. Similarly, a firm can never be forced to a payoff below  $(1 - \alpha)\pi_L + \alpha\pi_D$ . The

difference between these extremes,  $\Pi_j^* \equiv (1 - \alpha)(\pi_M - \pi_L)$ , is the largest payment an inventor could receive.

An equilibrium with *ex ante* contracting that supports a payoff of  $\Pi_j^*$  for  $I$  has a straightforward structure. The first feature is monopoly contracting: given that a good  $I$  accepts the equilibrium contract  $\mathbf{R}^*$ , the incentive structure of  $\mathbf{R}^*$  ensures that the invention is revealed only to  $i$ , the contracting firm. As with the earlier analysis, this requires that, given  $\mathbf{R}^*$ , there are no remaining gains to trade between  $I$  and  $j$ ; this reduces to setting sufficiently large payment wedges in  $\mathbf{R}^*$ , namely,  $\pi_D - \pi_L < R_i^* - R_D^*$  and  $\pi_M - \pi_L < R_i^* - R_j^*$ .

The second feature is separation: a good  $I$  accepts and a bad  $I$  rejects the offer of  $\mathbf{R}^*$ . If

$$0 > E_{\alpha, \alpha}\{\mathbf{R}^*\}$$

$$\equiv (1 - \alpha)^2 R_0^* + \alpha(1 - \alpha)(R_i^* + R_j^*) + \alpha^2 R_D^*$$

so that the expected value of  $\mathbf{R}^*$  (over independent discovery by the firms) is negative, then a bad  $I$  rejects  $\mathbf{R}^*$ . The intuitive structure of  $\mathbf{R}^*$  is then simple. Set  $R_0^* = R_j^* = R_D^* = -L$  and then set  $R_i^*$  to achieve the payoff of  $\Pi_j^*$  for  $I$ . This simultaneously makes the two wedges as large as possible and also minimizes the value of  $\mathbf{R}^*$  to a bad  $I$ . The formal properties of this *ex ante* contract and the equilibrium are reported below.

**PROPOSITION 3:** *Necessary conditions for an equilibrium with ex ante contracting involving a monopoly contract and separation are*

$$(a) \quad L > \alpha(\pi_M - \pi_L)$$

$$(b) \quad \Pi_j^* = (1 - \alpha)(\pi_M - \pi_L)$$

where  $\Pi_j^*$  is the equilibrium payoff to a good inventor. This equilibrium exists if

$$L > \alpha(\pi_M - \pi_L).$$

The equilibrium contract,  $\mathbf{R}^*$ , is given by

$$(c) \quad R_i^* = \pi_M - \pi_L + \alpha(1 - \alpha)^{-1}L$$

$$R_x^* = -L \quad \text{for } x = 0, j, D.$$

On the equilibrium path, a good  $I$  ap-

proaches one of the two firms, denoted by  $i$  (randomly chosen), accepts the offer of  $R^*$  from  $i$ , and then reveals the invention to  $i$ ; a bad  $I$  approaches neither firm. From (b) above, a good  $I$  captures all of the rents while the firms earn equal profits. The existence condition,  $L > \alpha(\pi_M - \pi_L)$ , which is also necessary for the equilibrium, is the pivotal part of Proposition 3. To develop intuition, note that separation is achieved by requiring a payment of  $L$  from  $I$  whenever the monopoly state does not occur. Calculation then reveals that  $E_{\alpha, \alpha}\{R^*\} = (1 - \alpha)[\alpha(\pi_M - \pi_L) - L] < 0$ . Thus, it is the existence condition which ensures that separation is possible. By contrast, sufficiently large payment wedges under  $R^*$  require only that  $L > 0$ . Consequently, the key to the equilibrium is that liability,  $L$ , is large relative to the increment from low to monopoly profits,  $\pi_M - \pi_L$ , weighted by the probability of independent discovery by a firm,  $\alpha$ .<sup>14</sup>

Intuitively, then, the firms can screen a bad  $I$  in this case, and they are led to "compete away" their profits as they attempt to structure the *ex ante* contract offer,  $R^*$ , so that a good  $I$  will choose one firm over the other.<sup>15</sup>

### B. The Limits of Ex Ante Contracting

In contrast to the case when  $L$  is relatively large, separation is problematic when

$L$  is small. Consider, for example, the monopoly contract of Proposition 3 and let  $L \rightarrow 0$ . The payment  $R_i^*$  goes to  $\pi_M - \pi_L$  while all other payments go to zero, and consequently, a bad  $I$  is no longer screened.<sup>16</sup> This example reflects a general limitation of *ex ante* contracts when the inventor has limited resources.

A bad  $I$  can mimic the actions of a good  $I$  with respect to entering into *ex ante* contracts since, by definition, any revelation of the invention does not occur until after the contract(s) are signed. Thus, any allocation involving *ex ante* contracting must present a good and bad  $I$  with the same options for entering into contracts. While the expected payoff for a bad  $I$  is generated by the firm discovery lottery of  $\{(1 - \alpha)^2, \alpha(1 - \alpha), (1 - \alpha)\alpha, \alpha^2\}$  over the states  $\{0, 1, 2, D\}$ , a good inventor accounts for the contractual benefits that derive from revealing the invention after contracts are signed.

The problem for a good inventor is that high payments in the monopoly or duopoly states are also attractive to a bad inventor. The value of  $q$ , the probability that  $I$  is good, then becomes important. Firms perceiving that attracting bad inventors will lead to negative expected profits will then be unwilling to enter into such contracts. As illustrated by the monopoly contract of Proposition 3, this problem can be avoided when  $L$  is large via contracts that require large payments from the inventor in the undesired states. As the resources of the inventor decline, however, the size of the payment an inventor can make is restricted, and consequently, contracts with large payments in a monopoly state will necessarily offer positive expected profits to bad inventors. In turn, negative expected profits for

<sup>14</sup>A simple benchmark may help to interpret what it means for  $L$  to be large relative to  $\alpha(\pi_M - \pi_L)$ . Ignore all strategic issues and suppose that a firm can pursue R&D which, if successful, will increase profits to  $\pi_M$  from a status quo of  $\pi_L$ . With  $\alpha$  as the probability of success, the expected value to the firm of discovering the invention is just  $\alpha(\pi_M - \pi_L)$ , and the firm would be willing to invest in R&D an amount approaching this value. Relating back to Proposition 3, the equilibrium will not exist when the resources of the inventor are less than an amount that is of the same magnitude as such a firm's R&D budget (for this invention).

<sup>15</sup>This equilibrium-path behavior is analogous to the bidding incentives in an auction setting. A "monopoly" contract will emerge in equilibrium for a variety of contract models and extensive forms when  $L$  is large. One example is a sealed-bid auction where firms bid for a contract offered by the inventor (see e.g., Michael H. Riordan and David E. M. Sappington, 1987). Also, see Gallini and Wright (1990).

<sup>16</sup>There is also the possibility of an *ex ante* pooling equilibrium. One can show that such an equilibrium does not exist when  $L > \alpha(\pi_M - \pi_L)$  or when  $L$  is below a (smaller) threshold value. Further, for  $L$  near the threshold, existence requires that  $q$  is bounded away from zero. This latter feature is troubling in that, if a bad inventor can earn positive expected profits, then an infinite number of "speculators" may be attracted to enter the industry.

firms create an incentive to reduce monopoly-state payments.

This intuition suggests that *ex ante* contracting does not allow a good inventor with small liability to obtain sizable rents. The formal statement of the result is given below.

**PROPOSITION 4:** *Suppose that (a) firms and the inventor enter into contracts voluntarily and (b) a good inventor makes an optimal choice regarding revelation of the invention only after entering into contracts. Then, as the liability of the inventor becomes small ( $L \rightarrow 0$ ) and the adverse-selection problem becomes acute ( $q \rightarrow 0$ ), the payoff to a good inventor goes to zero.*

Thus, contracting on an *ex ante* basis necessarily leads to a vanishingly small payoff for the inventor as  $L$  and  $q$  go to zero. Note that it is  $q$ , the probability that the inventor has a good invention, rather than  $\alpha$ , the probability of independent invention by a manufacturer, that is important for adverse selection in *ex ante* contracting and limits the payoff to the inventor.

### C. The Structure of Ex Ante and Ex Post Contracts

Propositions 3 and 4 provide useful benchmarks, and together with our earlier results, we can employ them to examine the structure of *ex ante* and *ex post* contracting in relation to the underlying environment. In particular, we are interested in how  $L$ ,  $\alpha$ ,  $q$ , and gross profit levels relate to our primary question: can a financially weak independent inventor without property rights appropriate rents from a valuable invention? We begin with equilibrium payoffs and then turn to existence.

Payoffs to the inventor are  $\Pi_I^* = (1 - \alpha)(\pi_M - \pi_L)$  in the equilibrium with *ex ante* contracting (Proposition 3) and  $\Pi_I^* = (1 - \alpha)(\pi_D - \pi_L) - L$  in the equilibrium with *ex post* contracting (Proposition 1, small- $L$  case; we are not focusing on the large- $L$  case as it has  $\Pi_I^* = 0$ ). Setting aside existence issues for the moment, it is clear that the *ex ante* payoff is always larger than

the *ex post* payoff (as monopoly profits exceed duopoly,  $\pi_M > \pi_D$ ). In both cases, decreases in  $\alpha$  lead to larger payoffs for the inventor. Intuitively, as  $\alpha$  declines and firms are less likely to discover the invention independently of the inventor, the firms are willing to pay more to acquire the invention. In contrast to the payoff in the *ex post* case (in Proposition 1), the payoff in the *ex ante* case (in Proposition 3) is not affected by  $L$ , as the inventor's resources are employed only to screen a bad inventor.

The crucial differences between *ex ante* and *ex post* contracting turn on the issue of existence. Recall that the existence condition in the *ex ante* case is

$$L > \alpha(\pi_M - \pi_L)$$

and for the *ex post* case it is

$$L < (1 - \alpha)(\pi_D - \pi_L)$$

Each condition becomes easier to satisfy as  $\alpha$  declines.<sup>17</sup> Now consider the role of liability ( $L$ ) and adverse selection ( $q$ ). For *ex ante* contracting, large  $L$  and small  $\alpha$  function as substitutes with respect to existence: the less likely independent invention by the firms or the larger the liability of the inventor, the easier it is to screen a bad inventor. For a given  $\alpha > 0$ , however, as  $L$  declines the *ex ante* existence condition will eventually fail. Furthermore, from Proposition 4, we know that, in general, the payoff to the inventor in any *ex ante* contracting allocation will go to zero with  $L$  and  $q$  (screening

<sup>17</sup>The limiting case of  $\alpha = 0$  highlights the importance of property rights. In this case the only possible gross profit outcome is  $\pi_0$  when the inventor is bad and, consequently, screening becomes costless. Moreover, the outcomes  $\pi_M$  and  $\pi_D$  correspond one-to-one with the decision of a good inventor to reveal the invention to the firm(s). Consequently, the effect of  $\alpha = 0$  is that the potential for contracting on gross profits essentially confers property rights for the invention on the inventor. In general, independent discovery is one of many factors that contribute to a stochastic relationship between gross profits and the revelation decision of a good inventor. In our analysis, the key assumption regarding the relationship is first-order stochastic dominance: revealing the invention to a firm makes higher profits more likely.

becomes more costly as  $q$  declines). In contrast, the existence condition for the *ex post* case necessarily holds as  $L$  declines. In addition, existence in the *ex post* case is independent of adverse selection (via  $q$ ) since the inventor reveals prior to contracting with the firms.

Our primary focus is on a financially weak independent inventor who lacks property rights. For this case, our results imply that it will not be possible to appropriate significant rents through *ex ante* contracting. The *ex ante* equilibrium will not exist ( $L < \alpha[\pi_M - \pi_L]$ ), and when combined with adverse-selection problems ( $q \rightarrow 0$ ), rents via *ex ante* contracts are vanishingly small. In contrast, the *ex post* equilibrium will exist (when  $L < (1 - \alpha)[\pi_D - \pi_L]$ ), it is independent of adverse-selection problems, and the inventor captures a significant fraction of the available rents.

#### IV. Conclusion

In this paper we examined the problem confronting a financially weak, independent inventor whose only access to the market involves selling the invention to a firm. The fundamental problem facing an inventor with a good invention is how to convince the prospective buyer that the invention is good while also obtaining a significant share of rents. We focused on the polar case of perfect expropriability in which the inventor has no property rights with respect to the invention.

The inventor can choose an "*ex post* contracting" approach in which the inventor reveals the invention and then negotiates a contract or, alternatively, an "*ex ante* contracting" approach in which the parties try to mitigate adverse selection regarding the invention by employing an appropriately structured *ex ante* contract. In equilibrium, *ex post* contracting allows an inventor with limited resources to capture a sizable share of the market value of the invention.

This conclusion holds despite our conservative assumption regarding bargaining: firms make take-it-or-leave-it offers. Such an assumption is consistent with our view of the inventor as the "weaker" party in con-

tract negotiations. An analysis of the other extreme, in which the inventor makes take-it-or-leave-it offers, leads to greater equilibrium expected profits for the inventor. For example, in Figure 2 the inventor would offer a contract in the extreme northeast corner and earn  $(1 - \alpha)(\pi_M - \pi_D)$ .

With large financial resources, an inventor prefers the *ex ante* approach. This suggests the use of an intermediary, such as a venture capitalist (VC), to provide the resources a financially weak inventor needs in order to signal a valuable invention (see e.g., Raphael Amit et al., 1990). Such an arrangement could be structured so that the VC contracts with the inventor over the outcome states and then uses its financial resources (big  $L$ ) to obtain the *ex ante* "monopoly" contract from a firm. Such an arrangement is attractive to the inventor as long as the VC market is competitive, verification of the value of the invention is inexpensive, and the VC cannot, itself, expropriate the invention.

Casual empiricism suggests that there are many problems that arise in the relationships between financial intermediaries and inventors.<sup>18</sup> Expropriation appears to be a problem that is endemic to all settings in which intellectual property can be stolen.<sup>19</sup> Thus, in our view, intermediaries do not undermine the importance of the expropriation issue.

Our analysis, which has focused on the case in which an inventor has no property

<sup>18</sup>There are many examples of inventors and entrepreneurs who have been unable to work deals with financial intermediaries or banks and have dealt directly with manufacturers. For example, Conner Peripherals, developers of a new 3.5-inch hard drive for laptop computers, "had trouble finding venture capitalists to finance the company, so went to Compaq Computer... (which) provided \$12 million." In its first year of shipments Conner sold 90 percent to Compaq (*New York Times*, 27 May 1990, p. F-6). Similarly, the Gleasman Corporation, inventors of various automotive components, have had little luck with venture capitalists and have focused instead on selling their inventions to manufacturers (based on conversation with the CEO of Gleasman Corporation).

<sup>19</sup>For example, a VC could expropriate an invention by employing contracts with other inventors.

rights, may also be applicable for cases in which property rights, such as patents, are available. Patents have two problems: they are sometimes unenforceable, and they reveal underlying knowledge that may be useful for future inventions. For these reasons, firms often eschew patent protection in favor of relying on secrecy (Eli Lederman, 1989).

From the viewpoint of the inventor, this implies that the joint benefits associated with keeping an idea secret could exceed the benefits of a patented invention. Thus, because an inventor without property rights can appropriate a sizable share of the value of the invention, when joint benefits under secrecy are significantly greater than under patent protection, some inventors may choose to forgo patent protection.

#### APPENDIX

##### PROOF OF PROPOSITION 1:

Let  $\Sigma \equiv \{(R_i, R_D) \mid \text{conditions (1), (5), and (6) hold}\}$ . To begin, we find the payments in  $\Sigma$  with the lowest payoff to the inventor,

$$\begin{aligned}\Pi_I &\equiv (1 - \alpha)R_i + \alpha R_D \\ &\geq (1 - \alpha)[\pi_D - \pi_L + R_D] + \alpha R_D \\ &\geq (1 - \alpha)(\pi_D - \pi_L) - L\end{aligned}$$

[by (5) and (1)], must hold for any  $(R_i, R_D) \in \Sigma$ . When  $L < (1 - \alpha)(\pi_D - \pi_L)$ , this lower bound is positive, and the payments  $R_D = -L$  and  $R_i = \pi_D - \pi_L - L$  are in  $\Sigma$  and achieve the lower bound. When  $L > (1 - \alpha)(\pi_D - \pi_L)$ , this lower bound is negative. In this case the zero isoprofit line of  $0 = \Pi_I = (1 - \alpha)R_i + \alpha R_D$  intersects  $\Sigma$ . By condition (7),  $\Pi_I^* \geq 0$  is necessary, in equilibrium, for the inventor to accept  $\mathbf{R}^*$ . Payments  $(R_i, R_D) \in \Sigma$  with  $0 = (1 - \alpha)R_i + \alpha R_D$  then achieve  $\Pi_I = 0$ .

The following accounting identity relates payoffs to  $I$  and  $i$  at  $(R_i, R_D) \in \Sigma$ :

$$\begin{aligned}\Pi_i &\equiv (1 - \alpha)(\pi_M - R_i) + \alpha(\pi_D - R_D) \\ &= (1 - \alpha)\pi_M + \alpha\pi_D - \Pi_I.\end{aligned}$$

Thus, over  $\Sigma$ ,  $\Pi_i$  is at a maximum when  $\Pi_I$  is at a minimum.

The contracts in (a) and (b) of Proposition 1 imply that the payoff to  $I$  equals the lower bound developed above for each of the  $L$  cases. By the accounting identity, it is optimal for firm  $i$  to offer this  $\mathbf{R}^*$  if  $I$  is expected to accept. In the proof of Proposition 2 we show that  $I$  expects a payoff of zero from bargaining with firm  $j$  following a rejection of a firm- $i$  offer. Thus, when  $L < (1 - \alpha)(\pi_D - \pi_L)$ ,  $\mathbf{R}^*$  is accepted by the inventor. When  $L \geq (1 - \alpha)(\pi_D - \pi_L)$ ,  $I$  necessarily accepts any offer from  $i$  with a positive payoff. The only possible equilibrium is for  $i$  to offer an  $\mathbf{R}^*$  with  $\Pi_I^* = 0$ , thus leaving the inventor indifferent between acceptance and rejection.

##### PROOF OF PROPOSITION 2:

To establish Proposition 2, we must exhibit strategies and beliefs that support the equilibrium path described at the beginning of Section III. To begin, we construct the beliefs and solve for the strategy choice (contract offer) for the cases of an uninformed firm and an informed firm. Analysis of the inventor's strategy is then straightforward.

*Case 1: Uninformed Firm.*—Suppose that  $I$  has approached a firm for a contract without revealing the invention. Begin with the expropriation-branch case in which no prior contract is observed. Consider an optimal contract offer for the firm with beliefs as specified in (8) in the text. A bad  $I$  rejects an offer of  $\mathbf{S}$  if

$$\begin{aligned}E_{\alpha, \alpha}\{S_x\} \\ \equiv (1 - \alpha)^2 S_0 + \alpha(1 - \alpha)(S_i + S_j) + \alpha^2 S_D < 0.\end{aligned}$$

Thus, the maximum possible payoff for the firm is

$$\begin{aligned}E_{\alpha, \alpha}\{\pi_x\} &\equiv (1 - \alpha)^2 \pi_0 \\ &\quad + \alpha(1 - \alpha)(\pi_M + \pi_L) + \alpha^2 \pi_D\end{aligned}$$

if  $I$  is bad.

If  $I$  is good, the firm believes it is the second firm to be approached (firm  $j$ ) and that the invention has been revealed to the other firm (firm  $i$ ). Gross of contract payments,  $j$  expects a profit of  $\pi_D$  if  $I$  reveals



to  $j$  and  $(1-\alpha)\pi_L + \alpha\pi_D$  if  $I$  does not. Thus, for a good  $I$  who has revealed to  $i$ , the maximum possible expected profit for  $j$  is  $\pi_D$ , which occurs if  $I$  reveals to  $j$  without any payment from  $j$ . Then,  $(1-\rho)E_{\alpha,\alpha}\{\pi_x\} + \rho\pi_D$  is an upper bound on the payoff to an uninformed firm when no prior contract is observed.

Suppose  $j$  offers  $I$  a contract,  $S$ , where  $S_x = -L$  for  $x=0, i, j$  and  $S_D = \varepsilon$ , where  $0 < \varepsilon < \alpha^{-2}(1-\alpha^2)L$ . Then,  $E_{\alpha,\alpha}\{S_x\} < 0$ , and a bad  $I$  rejects  $S$ . A good  $I$  who revealed to the other firm would optimally accept  $S$  and reveal to  $j$ . The payoff to  $j$  from this offer is arbitrarily close to the upper bound, and letting  $\varepsilon \rightarrow 0$  yields the optimal offer. The range of  $\varepsilon$  indexes a set of Pareto-improving contracts between a good  $I$  and an uninformed firm, and any contract in this set leads to the duopoly outcome.

When a prior contract,  $\mathbf{R} \neq \mathbf{0}$ , is observed, the uninformed firm can infer that it is firm  $j$  (the second firm). Beliefs are given by (8). Define a set of contracts  $\mathfrak{R}$  by  $\mathbf{R}' \in \mathfrak{R}$  if and only if  $\mathbf{R}' \neq \mathbf{0}$ ,  $\mathbf{R}'$  satisfies (1), and

$$(A1) \quad 0 \leq R'_i - R'_D < \pi_D - \pi_L.$$

The left-hand side of (A1) implies that, with  $i$  informed, a good  $I$  has no incentive under  $\mathbf{R}'$  to reveal to  $j$ . By the right-hand side,  $j$ 's incremental profit from becoming informed is greater than the incentive under  $\mathbf{R}'$  for a good  $I$  not to reveal to  $j$ . The lemma below is used to find  $j$ 's optimal offer.

**LEMMA:** Suppose firm  $j$  is uninformed and observes  $\mathbf{R} \in \mathfrak{R}$ . Conditional on beliefs in (8), the expected payoff to  $j$  from any contract offer is bounded above by

$$(1-\rho)E_{\alpha,\alpha}\{\pi_x\} + \rho[\pi_D - (1-\alpha)(R_i - R_D)].$$

**PROOF:**

Let  $S$  be a contract offer from  $j$ . With probability  $1-\rho$ ,  $I$  is bad, and with  $\mathbf{R}$  already in place, a bad  $I$  accepts  $S$  if  $E_{\alpha,\alpha}\{S_x\} > 0$ . Thus, if  $I$  is bad, the maximum possible expected profit for  $j$  is  $E_{\alpha,\alpha}\{\pi_x\}$ . With probability  $\rho$ ,  $I$  is good and firm  $i$  is informed. We establish the upper bound for

each possible case of contracting outcomes between firm  $j$  and a good  $I$ . (a) Firm  $j$  and a good  $I$  do not enter into a contract. Then  $j$  expects a payoff of  $(1-\alpha)\pi_L + \alpha\pi_D$ . Since  $\mathbf{R} \in \mathfrak{R}$  we rearrange (A1) to obtain the upper bound of

$$(1-\alpha)\pi_L + \alpha\pi_D < \pi_D - (1-\alpha)(R_i - R_D).$$

(b) Firm  $j$  and a good  $I$  enter into a contract,  $S$ , and  $I$  does not reveal to  $j$ . Then  $j$  expects a payoff of  $(1-\alpha)\pi_L + \alpha\pi_D - [(1-\alpha)S_i + \alpha S_D]$ . Without revelation,  $(1-\alpha)S_i + \alpha S_D \geq 0$  for a good  $I$  to accept  $S$ . Thus,  $j$ 's payoff is bounded above by  $(1-\alpha)\pi_L + \alpha\pi_D$ , and applying (A1) yields the desired upper bound. (c) Firm  $j$  and a good  $I$  enter into  $S$ , and  $I$  reveals to  $j$ . Then  $j$  expects  $\pi_D - S_D$ . With revelation,  $R_D + S_D \geq (1-\alpha)R_i + \alpha R_D$  for a good  $I$  to accept  $S$ . Hence,  $S_D \geq (1-\alpha)(R_i - R_D)$  and  $\pi_D - S_D \leq \pi_D - (1-\alpha)(R_i - R_D)$ . The lemma follows from the weights of  $1-\rho$  and  $\rho$  in  $j$ 's beliefs of a bad or a good  $I$ .

In order to achieve this payoff upper bound, firm  $j$  can employ an extension of the expropriation-branch contract which screens a bad  $I$  and provides incentives for a good  $I$  to reveal. For a given  $\mathbf{R} \in \mathfrak{R}$ , define a set  $\Psi(\mathbf{R})$  by  $S' \in \Psi(\mathbf{R})$  if and only if (1) holds and

$$(A2) \quad S'_D = -R_D + [(1-\alpha)R_i + \alpha R_D] + \varepsilon$$

$$(A3) \quad S'_x + R_x = -L \quad \text{for } x=0, i, j$$

where

$$0 < \varepsilon < \alpha^{-1}(1-\alpha)[L + (1-\alpha)R_i + \alpha R_D].$$

With  $\mathbf{R} \in \mathfrak{R}$  in place between  $I$  and  $i$ , firm  $j$  expects a bad  $I$  to reject  $S \in \Psi(\mathbf{R})$ , as  $E_{\alpha,\alpha}\{S_x\} < 0$ , and expects a good  $I$  to accept  $S \in \Psi(\mathbf{R})$  and reveal to  $j$ . Firm  $j$  thus expects  $(1-\rho)E_{\alpha,\alpha}\{\pi_x\} + \rho[\pi_D - S_D]$  as the payoff if it offers  $S$ . Substituting for  $S_D$  from (A2), this payoff is within  $\varepsilon$  of the upper bound in the lemma. Letting  $\varepsilon \rightarrow 0$  yields the optimal offer for firm  $j$ .

Finally, if the uninformed firm observes a prior contract,  $\mathbf{R} \notin \mathfrak{R}$ , so that (A1) fails, then no offer is optimal. If  $R_i < R_D$ , then a

good  $I$  is expected to reveal to  $j$  without any additional incentives;  $j$  can earn  $\pi_D$  by making no offer. Thus,  $j$  expects  $(1-\rho)E_{\alpha,\alpha}\{\pi_x\} + \rho\pi_D$  in this case, and by the same logic as in the lemma, this is the maximum possible payoff for  $j$ . Next, if  $R_i - R_D \geq \pi_D - \pi_L$ , then no Pareto-improving contracts exist between  $j$  and a good  $I$ . No offer yields  $(1-\rho)\pi_L + \alpha\pi_D$  for  $j$ , and again, this is  $j$ 's largest possible payoff.

*Case 2: Informed Firm.*—Suppose that  $I$  has approached a firm for a contract by revealing the invention. Where a prior contract between  $I$  and the other firm is observed, the informed firm need not fear any counteroffer from the other firm. We simplify matters by specifying that the informed firm believes  $I$  has revealed to the other firm with probability 1. Thus, no offer is optimal for the informed firm.

Now suppose that no prior contract is observed. This is consistent with the candidate equilibrium path; the updated beliefs are that  $I$  is good, that this firm is the first firm to be approached (denoted as firm  $i$ ), and hence that the other firm is uninformed. We sort  $i$ 's possible offers into four classes:

- Firm  $i$  makes no offer. Firm  $i$  expects an expropriation-branch response where  $I$  reveals to  $j$ , leading to a profit of  $\pi_D$  for  $i$ .
- Firm  $i$  offers  $\mathbf{R} \in \mathfrak{R}$ . If  $I$  refuses  $\mathbf{R}$ , then  $i$  expects  $\pi_D$  in profit as the expropriation branch ensues. If  $I$  accepts  $\mathbf{R}$ , then  $i$  expects  $j$  to counter with  $\mathbf{S} \in \Psi(\mathbf{R})$  and expects  $I$  to accept. Firm  $i$ 's profits will be  $\pi_D - R_D$ . From the above analysis of  $\mathbf{S} \in \Psi(\mathbf{R})$ ,  $(1-\alpha)R_i + \alpha R_D \geq 0$  is necessary for  $I$  to accept  $\mathbf{R}$ . Combining this with the definition of  $\mathfrak{R}$  then yields an upper bound on firm  $i$ 's payoff of
 
$$\pi_D - R_D \leq \pi_D + \min\{L, (1-\alpha)(\pi_D - \pi_L)\}$$
 from an offer  $\mathbf{R} \in \mathfrak{R}$ .
- Firm  $i$  offers  $\mathbf{R} \notin \mathfrak{R}$ , where  $\mathbf{R}$  fails to satisfy (A1) due to  $0 > R_i - R_D$ . If  $I$  rejects  $\mathbf{R}$ , then the expropriation branch

ensues, and  $i$  expects a payoff of  $\pi_D$ . Otherwise,  $j$  is expected to make no offer, and the duopoly state results. Thus,  $I$  will accept  $\mathbf{R}$  only if  $R_D \geq 0$ , and at most, firm  $i$  earns  $\pi_D$ . An upper bound on  $i$ 's payoff to an offer of  $\mathbf{R}$  in these three classes is

$$\pi_D + \min\{L, (1-\alpha)(\pi_D - \pi_L)\}.$$

- The fourth class, which includes the candidate equilibrium-path contract ( $\mathbf{R}^*$ ), involves an offer  $\mathbf{R} \notin \mathfrak{R}$  with  $R_i - R_D \geq \pi_D - \pi_L$ . Define  $\mathbf{R}^*$  by  $R_0^* = R_j^* = -L$ ,  $R_i^* = \pi_D - \pi_L - L$ , and  $R_D^* = -L$ , when  $L < (1-\alpha)(\pi_D - \pi_L)$ , and  $(1-\alpha)R_i^* + \alpha R_D^* = 0$  with  $R_D^* \in [-L, -(1-\alpha)(\pi_D - \pi_L)]$ , when  $L \geq (1-\alpha)(\pi_D - \pi_L)$ . For large  $L$ ,  $\mathbf{R}^*$  is unique up to the payoff to a good  $I$ .

We now show that  $\mathbf{R}^*$  is optimal for an informed firm when no prior contract is observed. Define a set of contracts by  $\Gamma \equiv \{\mathbf{R} | R_i - R_D \geq \pi_D - \pi_L\}$ . We first show that  $\mathbf{R}^*$  is optimal over  $\Gamma$ . To begin, suppose  $i$  offers  $\mathbf{R} \in \Gamma$  to  $I$ . Now suppose  $I$  rejects  $\mathbf{R}$ . If  $I$  approaches the other firm but does not reveal, then we have the expropriation branch and an overall payoff of zero to  $I$ . If  $I$  reveals to the other firm, then this other firm must make the equilibrium-path offer of  $\mathbf{R}^*$  as it is informed and observes no prior contract. In this case, the overall payoff is  $R_D^* < 0$  if  $I$  accepts and 0 if  $I$  rejects, since  $I$  has revealed to both firms. Thus, the largest possible payoff for  $I$  is zero if  $\mathbf{R}$  is rejected.

Now, suppose  $I$  accepts the offer of  $\mathbf{R} \in \Gamma$ . We know from the above analysis that  $I$  will not receive a second contract offer. As  $\mathbf{R} \in \Gamma \Rightarrow R_i > R_D$ ,  $I$  has no incentive under  $\mathbf{R}$  to reveal to the other firm. Thus,  $I$  will neither contract with nor reveal to the other firm if  $\mathbf{R} \in \Gamma$  is accepted.

We now show that  $\mathbf{R}^*$  is optimal for  $i$  in  $\Gamma$ . Begin with the case of  $L$  small:

$$L < (1-\alpha)(\pi_D - \pi_L).$$

Then any  $\mathbf{R} \in \Gamma$  has

$$(1 - \alpha)R_i + \alpha R_D \geq (1 - \alpha)(\pi_D - \pi_L) - L > 0.$$

From above, it is optimal for  $I$  to accept an offer of  $\mathbf{R} \in \Gamma$  from  $i$ , and as  $I$  will neither contract with nor reveal to the other firm, firm  $i$  expects  $\mathbf{R} \in \Gamma$  to yield a payoff of  $(1 - \alpha)\pi_M + \alpha\pi_D - [(1 - \alpha)R_i + \alpha R_D]$ . The optimal offer for  $i$  over  $\mathbf{R} \in \Gamma$  thus minimizes  $(1 - \alpha)R_i + \alpha R_D$  subject to  $R_i - R_D \geq \pi_D - \pi_L$  and  $R_x \geq -L$ . This yields

$$R_D^* = -L$$

$$R_i^* = \pi_D - \pi_L - L$$

and  $(1 - \alpha)(\pi_M + \pi_L) - (1 - 2\alpha)\pi_D + L$  is the resulting payoff to  $i$ . Now suppose  $L \geq (1 - \alpha)(\pi_D - \pi_L)$ . The only difference from the preceding case is that  $L$  is now large enough for firm  $i$  to capture all of the rents. Since there exists  $\mathbf{R} \in \Gamma$  with  $(1 - \alpha)R_i + \alpha R_D > 0$  in this case, it is easy to verify that  $\mathbf{R}^*$  as given in (b) of Proposition 1 is optimal over  $\Gamma$ .

Thus,  $\mathbf{R}^*$  is optimal for  $i$  over  $\Gamma$ . It is then straightforward to show that the existence condition,  $\pi_M + \pi_L > 2\pi_D$ , implies that the payoff to  $i$  from  $\mathbf{R}^*$  exceeds  $\pi_D + \min\{L, (1 - \alpha)(\pi_D - \pi_L)\}$  for each  $L$  case. Thus,  $\mathbf{R}^*$  is optimal for  $i$ .

*Case 3: Inventor.*—The strategy for  $I$  involves specifying (a) which firms, if any, to approach and, if an approach is made, which message to send (reveal or not reveal), and (b) the accept/reject choices in response to contract offers, for the inventor's decision nodes in the extensive form. It is straightforward to calculate optimal approach and accept/reject decisions for  $I$ . As many of these calculations were done above, we omit some of the details and focus on two main points.

First, a bad  $I$  cannot reveal a good invention and always evaluates contracts according to the  $E_{\alpha,\alpha}\{\cdot\}$  expectation. Thus, if  $\mathbf{R}$  has been accepted, then an offer of  $\mathbf{S}$  is accepted only if  $E_{\alpha,\alpha}\{S_x\} \geq 0$ . Let  $\mathbf{S}$  denote the offer of an uninformed firm when  $\mathbf{R}$  is observed and let  $\mathbf{S}'$  denote the offer if no

contract is observed. Then a bad  $I$  accepts  $\mathbf{R}$  only if  $E_{\alpha,\alpha}\{R_x\} + \max\{0, E_{\alpha,\alpha}\{S_x\}\} \geq \max\{0, E_{\alpha,\alpha}\{S'_x\}\}$ . Note that  $\mathbf{R}$  may be accepted even though  $E_{\alpha,\alpha}\{R_x\} < 0$  if accepting  $\mathbf{R}$  then allows a bad  $I$  to receive an offer  $\mathbf{S}$  that offsets the initial loss. From the above analysis it is easy to check that a bad  $I$  will reject all contract offers.

Now consider a good  $I$ . We focus on verifying that a good  $I$  is at a best response to the equilibrium contract offers. A good  $I$  can follow one of three strategic approaches. One, on the equilibrium path, is to reveal to one firm before accepting any contracts. This results in an offer of  $\mathbf{R}^*$  from the informed firm, and as shown above, it is optimal for  $I$  to accept  $\mathbf{R}^*$ . A second approach is to enter contracts only on an *ex ante* basis. When no prior contract is observed, an uninformed firm offers only the expropriation-branch contract. If  $I$  rejects, then the same offer would be made by the other uninformed firm; while if  $I$  accepts, then no offer would be made by the other firm. At best, a good  $I$  can net zero from this strategy. Finally, a good  $I$  can reveal at some intermediate point. Again, it is easy to show that  $I$  cannot benefit from this approach.

### PROOF OF PROPOSITION 3:

To prove (b), consider the offer from an uninformed firm when no prior contract is observed. In equilibrium, the offer from each firm must provide an identical payoff of  $(1 - \alpha)(\pi_M - \pi_L) = (1 - \alpha)R_i + \alpha R_D$  to a good inventor. Otherwise, one of the firms can profitably deviate by slightly raising the offered payment in the monopoly state. From (b), separation and (1) imply (a).

To demonstrate sufficiency, consider the contract  $\mathbf{R}^*$  defined by

$$R_i^* = \pi_M - \pi_L + \alpha(1 - \alpha)^{-1}L$$

$$R_x^* = -L \quad \text{for } x = 0, j, D.$$

It is straightforward to verify that  $E_{\alpha,\alpha}\{R_x^*\} < 0$ , that a good inventor under  $\mathbf{R}^*$  reveals only to firm  $i$ , and that no mutually profitable contracts exist between  $j$  and  $I$  given

$\mathbf{R}^*$  between  $i$  and  $I$ . Let  $\mathbf{R}^*$  be the offer from each firm when a firm is uninformed and no prior contract is observed. A wide range of beliefs can support the equilibrium. Verification is trivial with the following set of beliefs. When a prior contract  $\mathbf{R} \neq \mathbf{R}^*$  is observed, let an uninformed firm believe the inventor is bad with probability 1; thus, no offer is optimal. Let an informed firm believe that the other firm is informed with probability 1; thus, no offer is optimal for this firm.

#### PROOF OF PROPOSITION 4:

Allocations involving *ex ante* contracting are described with two pairs of contracts,  $\{(\mathbf{R}, \mathbf{S}), (\mathbf{R}', \mathbf{S}')\}$ , where  $\mathbf{R}$  and  $\mathbf{S}$  denote a contract between a good  $I$  and firm  $i$  and firm  $j$ , respectively, while  $\mathbf{R}'$  and  $\mathbf{S}'$  denote the corresponding contracts for a bad  $I$ . Special cases include separation (the contracts are different for a good and bad  $I$ ), pooling ( $\mathbf{R} = \mathbf{R}'$  and  $\mathbf{S} = \mathbf{S}'$ ), and no contracting ( $\mathbf{R} = \mathbf{S} = \mathbf{R}' = \mathbf{S}' = \mathbf{0}$ ). We assume that *ex ante* contracting satisfies three basic conditions:

- (a) A good  $I$  optimally reveals to firms  $i$  and  $j$  in response to the payoffs under  $(\mathbf{R} + \mathbf{S})$ . To describe this decision, let  $\mathbf{T} = (T_0, T_1, T_2, T_D)$  be a payoff vector and define

$$\Pi^g(\mathbf{T}) \equiv \max\{E_{\alpha, \alpha}\{T_x\}, (1 - \alpha)T_1 + \alpha T_D, (1 - \alpha)T_2 + \alpha T_D, T_D\}.$$

Thus,  $\Pi^g(\mathbf{T})$  is the maximum payoff for a good  $I$  under  $\mathbf{T}$  when  $I$  makes the optimal choice among revealing nothing, revealing to firm 1 but not 2, revealing to 2 but not 1, or revealing to both firms.

- (b) A good  $I$  and a bad  $I$  may enter into  $(\mathbf{R}, \mathbf{S})$  or  $(\mathbf{R}', \mathbf{S}')$ , or not enter into any contracts: revelation occurs after contracts are signed, so either type of  $I$  can mimic the behavior of the other. Hence, for a bad  $I$  we have  $E_{\alpha, \alpha}\{R'_x + S'_x\} \geq \max\{0, E_{\alpha, \alpha}\{R_x + S_x\}\}$ , and for a good  $I$   $\Pi^g(\mathbf{R} + \mathbf{S}) \geq \max\{0, \Pi^g(\mathbf{R}' + \mathbf{S}')\}$ .

- (c) Each firm prefers to enter into the contracts rather than refuse. If firm  $k$  refuses to enter any contracts, then  $k$  earns  $E_{\alpha, \alpha}\{\pi_x\}$  when  $I$  is bad and, at a minimum,  $(1 - \alpha)\pi_L + \alpha\pi_D$  when  $I$  is good, as the lowest possible payoff for  $k$  occurs when a monopoly for  $\sim k$  prevails. Thus, a firm can guarantee

$$\underline{\pi} \equiv (1 - q)E_{\alpha, \alpha}\{\pi_x\} + q[(1 - \alpha)\pi_L + \alpha\pi_D]$$

by refusing all contracts.

We employ (a)–(c) to derive an upper bound on a good  $I$ 's payoff,  $\Pi^g(\mathbf{R} + \mathbf{S})$ . There are three cases, depending on a good  $I$ 's revelation decision under  $\mathbf{R} + \mathbf{S}$ . For case 1, under  $\mathbf{R} + \mathbf{S}$ , a good  $I$  optimally reveals only to one firm, denoted by  $i$ . Then a good  $I$ 's expected payoff is

$$\begin{aligned} \Pi^g(\mathbf{R} + \mathbf{S}) &= (1 - \alpha)(R_i + S_i) + \alpha(R_D + S_D) \\ &\equiv \pi^g. \end{aligned}$$

Note that participation for a bad  $I$ , (b), implies that

$$\begin{aligned} E_{\alpha, \alpha}\{R'_x + S'_x\} &\geq E_{\alpha, \alpha}\{R_x + S_x\} \\ &\geq - (1 - \alpha)L + \alpha\pi^g \end{aligned}$$

as follows from limited liability and the definition of  $\pi^g$ . By (c),

$$\begin{aligned} (1 - q)E_{\alpha, \alpha}\{\pi_x - R'_x\} &+ q[(1 - \alpha)(\pi_M - R_i) + \alpha(\pi_D - R_D)] \\ &\geq \underline{\pi} \end{aligned}$$

and

$$\begin{aligned} (1 - q)E_{\alpha, \alpha}\{\pi_x - S'_x\} &+ q[(1 - \alpha)(\pi_L - S_i) + \alpha(\pi_D - S_D)] \\ &\geq \underline{\pi} \end{aligned}$$

hold for  $i$  and  $j$ . Adding the two conditions above, we find

$$\begin{aligned} q(1 - \alpha)(\pi_M - \pi_L) &\geq (1 - q)E_{\alpha, \alpha}\{R'_x + S'_x\} + q\pi^g \end{aligned}$$

upon combining with the definition of  $\pi$ . Then the desired upper bound is

$$\pi^g \leq (1 - \alpha)[(1 - q)L + q(\pi_M - \pi_L)] \\ \times [q + \alpha(1 - q)]^{-1}$$

as follows from the above participation constraint for a bad  $I$ .

By similar reasoning (for proofs, see the working-paper version of this article, available from the authors upon request), we arrive at the bounds

$$\pi^g \leq \{(1 - q)(1 - \alpha^2)L + 2q(1 - \alpha)(\pi_D - \pi_L)\} \\ \times [q + \alpha^2(1 - q)]^{-1} \\ \pi^g \leq 2q(1 - \alpha)[(1 - \alpha)(\pi_0 - \pi_L) \\ + \alpha(\pi_M - \pi_D)]$$

for the cases when a good  $I$  reveals to both firms and when a good  $I$  reveals to neither firm, respectively. For all three cases,  $\pi^g \rightarrow 0$  as  $L \rightarrow 0$  and  $q \rightarrow 0$ .

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