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INTELLECTUAL PROPERTY DISCLOSURE AS "THREAT"

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Abstract

This paper models the disclosure of knowledge as a "threat", useful in ensuring firms keep their commitments. We show that firms holding knowledge are better able to enforce agreements than firms that don't. In markets requiring innovation to make a product, disclosure is a more powerful threat than entry by the punishing firm alone. Occasionally, the punishing firm won't be able to innovate, making it impossible for it to enter the cheating firm's market and punish. The punishing firm, however, can through disclosure credibly ensure that one, if not many, firms enter the cheating firm's market. In the model, firms contract explicitly to exchange knowledge and tacitly to coordinate the introduction of innovations to the marketplace. We find conditions under which firms can self-enforce both agreements. The enforcement conditions are weaker when (1) firms possess knowledge and (2) knowledge is easily transferable to other firms. The disclosure threat has implication for antitrust law generally, which are considered.

1 Introduction

Once released, information is the quintessential public good. It is non-rival – my use of information does not prevent others from using that same information. It is non-exclusive. Absent some legal rights or expensive self-help, one can't easily exclude someone else from using information. The familiar argument is that intellectual property rights respond to the unique character of information. Patent, copyright, and trade secret all give information-creators some ex post control over their creation. The assumption is that, without some control, the eventual appropriation of the information will stunt its development. Yet the non-rival and non-exclusive nature of information leads to another consequence not appreciated in the academic literature or intellectual property policy debates. The same characteristics that make information-creation problematic also render the disclosure of information an effective weapon for self-policing agreements. Once revealed, information can flow to every firm in the market. It can be disclosed or licensed to a 100 firms or a 1000 firms. With the information in hand, any one of these firms might be able to build competing products and enter the market. The fear of facing massive induced entry, then, provides an incentive for each firm to keep its word. Intellectual property disclosure, in other words, works as a big and effective hammer.

The usually response to a renegade firm, one who doesn't comply with its obligations in, say, a price-fixing agreement, is for the other firms to punish the deviation (Friedman [1971]). The punishing firms might cut prices or expand output in subsequent periods. We show that the punishing firms who possess information can do better than that. By disclosing information, the punishing firms invite in a host of competitors to the renegade firm. This will be especially important if the punishing firms' threat of expanding output or cutting prices lack credibility for some reason. Consider, for example, a punishing firm that is capacity constrained. In this case, the threat to expand output in subsequent periods won't deter cheating on a price fixing agreement. But the threat of intellectual property disclosure will. The punishing firm doesn't have to have the capacity itself so long as (1) some other firm in the market has the capacity and (2) all that firm requires is some knowledge to get going. Unleashed, the information serves as the catalyst to production by other firms.

This paper models information disclosure as threat. We show how disclosure threats can effectively enforce explicit and tacit agreements between firms. We also show that firms holding intellectual property are better able to enforce agreements than firms who don't. As to welfare, better enforcement works for good and ill. On the plus side, the threat of disclosure means that joint ventures where firms exchange knowledge are self-executing. Firms don't need the courts (Posner, R. [2006] and Shavell [1980]) or reputational sanctions (Bernstein [1992], Posner, E. [1998] and Klein and Leffler [1981]) to generate compliance with contractual obligations to share know-how. The end result is more joint ventures, more knowledge sharing, and more new products. On the minus side, tacit agreements to divide up markets are also self-executing. As a result, there is an increased risk of collusion where firms have information that could be leaked upon observing a deviation from any tacit agreement.

To highlight the role of information disclosure, the model considers two R&D firms ahead of the competition in two innovation markets. The firms form an R&D joint venture. In this venture, they write an explicit contract to share knowledge. If possible, the firms would also like to tacitly divvy-up the two markets. That is, each firm wants to focus on developing one of the two possible innovations. Two mechanisms sustain both the explicit joint venture contract and the tacit market coordination agreement. If a firm observes its rival failing to comply with its obligations it either (1) enters and competes in the renegade's market in all the subsequent periods or (2) releases information into the market. The first threat is a variant on the classic grim trigger strategy in repeated games (Friedman [1971]). Whether the threat controls deviations depends on the relationship between the gain to a one time deviation and the firm's discount rate. The more interesting second strategy – IP disclosure – is credible because it is only carried out when the punishing firm is unable to innovate on its own in the renegade's market. In that case, the punishing firm doesn't care how many other firms use the disclosure as a gateway into the renegade's market. The disclosure threat controls deviations if disclosure is sufficiently likely to induce innovation by other firms. The model's upshot is this: adding an IP disclosure threat to the more tradition entry threat makes it easier for firms to maintain agreements without resorting to court enforcement.

Disclosure is a key feature of the model. Firms could disclose explicitly by publishing information in a scientific journal or a company publication, like the IBM technical journal.[1] Alternatively, firms might disclose by having

[1] For example, a number of results from the human genome project have been "dis-

employees present papers describing the information at conferences. Finally, firms might disclose their technology through a public sale, thereby making the technology ineligible for patent or trade secret protection (see 35 U.S.C. § 102(b)). To focus on disclosure threats and the self-enforcement of agreements, we abstract away from court enforcement. Without judicial enforcement, firms in the model won't disclose information to other firms via licensing arrangements. Although helpful in illustrating the results, that simplification is largely irrelevant. Disclosure via licensing works the same as broad public disclosures – it induces entry into a market the punishing firm otherwise could not enter. In so doing, the license-disclosure threat provides another enforcement lever, useful in sustaining agreements.

Our paper relates to a large literature on the strategic transfer of knowledge. The paper closest to ours is Anton and Yao [1994]. They study the problem facing an inventor who wants to transfer knowledge in the absence of property rights. Without IP rights, contracts don't work. Any knowledge transfer will be snapped up and then the purchaser won't pay. They show that the inventor will be nonetheless able to protect his property rights by credibly threatening the buyer to disclose information to a potential market rival. We extend their work to show that threats of knowledge leakage can ensure compliance with any agreement between firms. Like in Anton and Yao [1994], courts don't do any enforcement here. But we take a few steps forward. First, our model focuses on public disclosures, rather than disclosures directed to a rival. We demonstrate that the broader the disclosure is, the higher its value as an enforcement mechanism. Second, and not surprisingly, we show that the value of greater enforcement by disclosure threats depends on whether the underlying agreement enhances or detracts from social welfare.

Anton and Yao [2002] and [2003] provide another justification for IP disclosure. They teach us that expropriable partial disclosure can be used to credibly signal the quality of an inventor's innovation. Gans and Stern [2000] study bargaining over the licensing terms between an incumbent and a potential entrant with a technological innovation. In their model, knowledge exogenously spills over from the innovator to the incumbent during bargaining. d'Aspremont et al. [2000] study the sharing of interim research knowledge between two firms engaged in a patent race. Anton and Yao [2004], Denicolò and Franzoni [2004], and Friedman et al. [1991] all study the trade-off be-

closed" by R&D firms to the general public, Eisenburg [2000].

tween protecting innovation via patenting – with the accompanying public disclosure – and trade secrecy.

Another line of related research considers strategic disclosure by firms involved in a patent race. Parmonsky [2000] demonstrates that firms can use disclosure defensively to stop the issuance of a patent to a competing firm. Lichtman et al.[2000] show how a firm leading in a patent race can, through disclosure, so reduce a laggard's firm expected payoff from the patent that the laggard quits. Baker and Mezzetti [2005] show how disclosures targeted to the patent office can usefully alter the prior art and thereby help extend the patent race.

Finally, our paper connects with the literature on multimarket contact. Bernhemin and Whinston [1990] were among the first to explore the effect of multimarket contact on collusive behavior. They showed that multimarket contact may enhance the firms' ability to collude when the firms or the markets are asymmetric. We focus on symmetric firms and markets, and show that multimarket contact and the ability to disclose information to the market facilitate knowledge sharing and market division among firms.

The paper is organized as follows. Section 2 develops the model. Section 3 presents the benchmark case, i.e., the situation where the threat of intellectual property disclosure is unavailable. In the absence of a disclosure threat, section 3 studies the conditions under which the two firms can nonetheless sustain both knowledge-sharing and market coordination. There, as noted above, the threat of entry by one firm into the other's market does all the work. Section 4 allows for IP disclosure. Equilibrium is defined for three cases: (1) where firms use the threat of disclosure to enforce knowledge sharing, but not market coordination; (2) where firms use the threat of disclosure to enforce market coordination, but not knowledge sharing and (3) where firms use the threat of disclosure to enforce knowledge sharing and market coordination. In each case, the parameter restrictions necessary to sustain agreement are less severe if firms hold disclosable intellectual property. As a result, an equilibrium involving any kind of coordination is more likely when the firms could, if cheated upon, reveal intellectual property to other firms in the market. Section 5 examines some of the legal implications and welfare effects of the IP disclosure threat. Section 6 concludes. Proofs are relegated to the appendix.

2 The Model

There are two firms ($i \in \{1, 2\}$) competing in two innovation markets ($j \in \{A, B\}$). Each firm may be able to introduce an innovation in each of the two markets. Thus, there are four potential innovations or products. The two innovations in a market are substitutes. One can think of firms 1 and 2 as the leading firms in two particular research and development markets. There also exist potential start-up firms which may be able to enter either market A or B. The precise notion of the start-up firms and entry will be formalized later. Let m_j be the total number of innovations introduced in market j and denote with $V_i^j(m_j)$ the value to firm i, in each of an infinite number of periods, of introducing an innovation in market j as a function of the total number of innovations. Thus, letting δ be the common discount factor, the discounted payoff to firm i of introducing an innovation in a market with m_j innovations is $V(m_j)/(1-\delta)$. To simplify the exposition, assume symmetry of the two markets and the firms' payoff functions: $V_i^j(m_j) = V(m_j)$ for all i and all j.

The timing of the game is as follows: First, firms decide whether to form a joint venture and privately share their knowledge about technology in the two markets. A firm's knowledge determines the probability with which it can innovate in a market. Second, each firm learns whether it actually can bring a product to market. For simplicity we assume that whether a firm can bring a product to market is publicly known.[2] Third, each firm decides whether to disclose any knowledge to the market. The choice of whether to disclose will be addressed in detail in Section 4. Fourth, firms play a market entry game.

In our setup, if each firm always enters any market where it can introduce an innovation, then the two firms are subject to a coordination failure. If each firm is able to introduce an innovation in both markets, then the firms benefit from coordinating and each entering one market. Coordination may be sustained because firms have the opportunity to enter repeatedly over time. More precisely, we assume that in each time period $t \geq 1$ of the entry game, firms decide simultaneously whether to enter an innovation market that they have not entered before and whether to disclose any of their knowledge to the market.

[2] This assumption could be relaxed at the cost of complicating the analysis with little change in the main economic insights.

2.1 Development Probability and the Value of Innovations

In each innovation market j, assume that the two leading firms' knowledge level k can take on two values, low or high, $k \in \{l, h\}$. Without any knowledge transfer from the leading firms, no other firm can innovate and enter either of the two markets. Naturally, firms with more knowledge have a greater probability of being able to innovate. To capture this idea in the simplest possible way, we assume that a leading firm with a low amount of knowledge can develop an innovation with probability p_l, while a leading firm with a high knowledge level is able to develop the innovation with probability p_h, where $p_l < p_h$.

In any market, each firm's innovation or product is a substitute for the other firms' innovation. With more firms in a market, there are more substitute innovations competing for consumer demand. The increased competition lowers each firm's profit in that market. Formally, let $V(m) > V(m+1)$. We will also assume that there exists $m^E \geq 2$ such that $V(m^E) > 0 > V(m^E+1)$; m^E is the maximum number of firms that could profitably enter the market. Finally, we assume that the total payoff to all firms in the market decreases with the number of firms, $mV(m) > (m+1)V(m+1)$. To make our analysis more concrete consider, as an example, firms introducing identical innovations into two symmetric Cournot oligopoly markets. Then our reduced form assumptions on V hold. For example, with linear demand and constant marginal cost we have $V(m) = (A-c)^2/b(m+1)^2$, where A is the vertical intercept and b is the slope of the demand function, while c is marginal cost.

Before getting to the details of disclosure in Section 4, the next section examines the benchmark case where IP disclosure threats are unavailable. Take, for example, two lumber firms who want to enforce (1) a tacit agreement to divide markets by geography and (2) an explicit agreement to share customer lists, protected as trade secrets. In the tacit market division agreement, one firm agrees to serve the Eastern United States. The other firm agrees to serve the Western United States. The logging industry requires substantial upfront investments in equipment. As a result, simple disclosure of the customer lists won't induce entry into either logging market. IP disclosure is thus ineffective and unavailable. As is well known, occasionally these firms can still enforce both agreements. The crux of the paper is that the number of circumstances where firms without easily transferrable intellectual property can enforce agreements is smaller than the number of circumstances

(1) Firm 1 and Firm 2 can innovate in both markets.
(2) Firm 1 and Firm 2 can only innovate in the same one market.
(3) Firm 1 can innovate in one market only; Firm 2 can innovate in one market only; Firm 2's market is different from Firm 1's.
(4) Firm 1 can innovate in one market only; Firm 2 can innovate in both markets.
(5) Firm 1 can innovate in both markets; Firm 2 can innovate in one market only.
(6) Neither Firm 1 nor Firm 2 can innovate in either market.

Figure 1: Possible Subgame Configurations

where firms with easily transferrable intellectual property can do so. And the most extreme case of firms without easily transferrable intellectual property are firms who don't hold any intellectual property whatsoever. Like our lumber firms – where simple revelation of customer lists won't induce entry – firms without any intellectual property have a more difficult time sustaining agreements than firms with intellectual property.

3 Benchmark Case: No Intellectual Property Disclosure Threat is Available

Before turning to the equilibrium in this benchmark case, it is useful to delineate the behavior in the market entry game subgames. Figure 1 lists the possible subgame configurations.

Subgame configuration (2) and (3) have a unique subgame perfect equilibria in which each firm enters a market at time $t = 1$ if it is able to develop the innovation in that market. (Recall that a firm cannot enter a market unless it is able to develop an innovation.) Absent the threat of disclosure, subgame configurations (4) and (5) also have a unique subgame perfect equilibria. In those equilibria, every firm enters every market in which it can develop an innovation. In these subgames, the firms can't coordinate – one entering market A and the other entering market B. The reason is that the entry threat needed to maintain agreement is not credible. Suppose that firm 1 can only develop in market A, while firm 2 can develop in markets A and B. Can the firms agree that firm 1 will introduce its innovation in market A and firm B will introduce its innovation in market B only? No. Firm 2 will always deviate and enter market A, too. It faces no retribution from doing so. Firm 1 can't punish firm 2's behavior because it is unable to innovate and enter market B. That all changes with the threat of IP disclosure.

Coordination is only possible in subgame configuration (1). There, both firms are able to develop an innovation in both markets. In this case there are two different types of subgame perfect equilibria with no entry delay.[3] In the first type of equilibrium, both firms enter both markets immediately. In the second type of equilibrium, firms coordinate: One firm enters market A immediately and the other enters market B immediately. This second type of equilibrium, however, only exists if the discount rate δ is sufficiently high. Before formalizing this result in the next proposition, define:

$$\delta_1 = \frac{V(2)}{V(1) - V(2)}. \tag{1}$$

Proposition 1 *When each leading firm can develop an innovation in both markets, the entry game has two types of subgame perfect equilibrium outcomes with immediate entry. In the first equilibrium outcome, both firms enter both markets. This type of equilibrium always exists. In the second equilibrium outcome, each leading firm enters a different market. This type of equilibrium exists if and only if $\delta \geq \delta_1$.*

Proof. See the Appendix.

This result is standard. If the discount factor is low (below δ_1), there does not exist any equilibrium of the market entry subgame where firms can successfully enforce an agreement to coordinate market entry decisions. The impatient firm values the one-time bump in profits from deviating on the market division agreement more than the stream of losses from competing in both markets in every future period. On the other hand, when the firms are sufficiently patient, enforcement of the tacit agreement is possible.

Of the six possible market entry subgame configurations, cooperation is possible in just one, and then only if the firms are sufficiently patient. Returning to the lumber company example, the only time the geographic market division agreement works is when (1) both firms are sufficiently patient and

[3] An equilibrium has no entry delay if all entry in the innovation markets takes place at $t = 1$. For our purposes, these are the most interesting and plausible equilibria and we focus on them in this paper.

(2) both firms have the capacity to deliver lumber to both the Eastern and Western United States. Otherwise any tacit agreement falls apart.

Now consider knowledge-sharing between the firms. Suppose that at the beginning of the game each leading firm i only has low knowledge in both markets. For simplicity, assume that by sharing its knowledge a firm enables the other firm to have high knowledge in both markets.[4] In the first stage of the game, firms simultaneously decide whether to share their knowledge. They have made a joint venture agreement and now must make sure that they benefit from it. In the second stage, nature determines whether each firm is able to develop the innovations with probability p_l or p_h, depending on the firm's knowledge level. We will look for the subgame perfect equilibria of the game.

The following threshold value of p_l will be used in the next proposition, defining the equilibrium without disclosure:

$$p_l^* = p_h - \frac{p_h^3 \left[V(1) - 2V(2)\right]}{2\left[V(1) - V(2)\right]}.$$

Proposition 2 *Without IP disclosure, there is no subgame perfect equilibrium of the game in which the leading firms share knowledge if $p_l < p_l^*$, or if $\delta < \delta_1$. If, on the other hand, $p_l \geq p_l^*$ and $\delta \geq \delta_1$, then there is an equilibrium in which the firms share knowledge and each firm enters a different market when both firms can innovate in both markets.*

Proof. See the Appendix.

To sustain the knowledge sharing agreement each firm credibly threatens to enter each market where it can develop an innovation if the rival firm fails to share knowledge. For this threat to serve its purpose, a firm must be able to innovate with sufficiently high probability, even if its rival does not share knowledge. That is to say, it must be $p_l \geq p_l^*$, where p_l^* is less than the probability that the firm with high knowledge is able to innovate.[5] The restrictions on p_l makes it is sufficiently likely the firms will end up in a market entry subgame where both firms can enter both markets. Only in this subgame can coordination occur and, accordingly, only then can firms use threats to deviate from the coordinated scheme to punish a failure to

[4] We would obtain similar qualitative results if we just assumed that knowledge sharing leads to high knowledge with a sufficiently high probability.

[5] Note that $p_l^* < p_h$, since $V(1) > 2V(2)$ by assumption.

share knowledge. In all other subgames, the firms can't coordinate entry. If these other subgames are sufficiently likely, knowledge-sharing cannot be self-enforced, no matter how patient the firms are. The chance of a firm hurting itself by sharing knowledge is simply too high. Since a coordinated equilibrium is unlikely, by sharing knowledge a firm just increases the likelihood that its rival will eventually enter more markets. The restriction, $\delta \geq \delta_1$, means that, once in the subgame where both firms can enter both markets, the firms are sufficiently patient to facilitate coordination.

When $p_l < p_l^*$ or $\delta < \delta_1$ firms face a standard prisoner's dilemma. Both firms would be better off if they could commit to share knowledge and coordinate their entries in the markets. Nevertheless, this sort of cooperation is unobtainable. In equilibrium, each firm has an incentive to take the knowledge shared by its rival, fail to return the favor, and then enter every innovation market it can.

To fix ideas, consider again the two lumber firms. The agreement to share customer lists is the analog to the knowledge sharing agreement among the R&D firms. Like the knowledge sharing agreement, the two lumber firms can self-enforce this sharing contract. But enforcement hinges on the likelihood that both firms will be able to deliver to both parts of the United States in every future period. And this is only one of many possibilities. In all other cases, the lumber firms cannot use threats of market entry to sustain the sharing agreement. The analysis easily extends to any input-sharing agreement between firms lacking intellectual property. With no intellectual property – and hence no possibility of IP disclosure – these firms can self-enforce an input-sharing agreement only when if there is a good chance both firms will eventually be able to serve both markets. Again, that all changes when we add intellectual property to the mix. Note also that, without IP disclosure, the equilibrium path always involves, whenever possible, market entry coordination. .

4 Intellectual Property Disclosure as an Enforcement Device

This section allows one or both firms to disclose intellectual property to the market. The market initially has zero knowledge about both technologies, and thus no new firms can develop either innovation. If, however, knowledge is readily transferable to the market, then this inability can be overcome. If some knowledge is disclosed about technology A, B, or both, a new firm may be able to develop either innovation and thus may decide to enter into either innovation market. Intuitively, intellectual property revelation allows other R&D firms to "get up to speed." In turn, the revelation facilitates entry into the various innovation markets. We suppose that each of the start-up firms focuses on only one market. Each new firm will enter its focused-upon market if one of the leading firms publicly discloses knowledge in that market, and if the new firm succeeds in developing the innovation. Hence, all we need to specify is the probability that $\ell \geq 0$ firms will enter, as a function of the knowledge level disclosed by a leading firm. Suppose, for example, that firm 1 (or 2) reveals a knowledge level $k \in \{l, h\}$ in a market. Then, the probability that exactly ℓ new firms will be able to innovate in that market is $g_k(\ell)$.

Intuitively, if a leading firm discloses a low knowledge level in a market, then the new firms in that market will be able to innovate with a lower probability than if the leading firm had disclosed a high level of knowledge. We could formalize this by assuming that the probability distribution G_h first order stochastically dominates G_l; that is, $G_h(\ell) = \sum_{q=0}^{\ell} g_h(q) \leq G_l(\ell) = \sum_{q=0}^{\ell} g_l(q)$ for all ℓ. However, we will not make any use of this assumption because, in all the equilibria we will study, a leading firm will disclose information to the market only when its knowledge level is low.

Let knowledge disclosure take place after the leading firms have learned whether they are able to innovate and both before and during the entry game.

There is no judicial enforcement of agreements, either between the leading firms or between a leading firm and a new firm. Without court enforcement, licensing agreements are not possible. Firms have trouble selling information, but they can give it away. As a result, they don't care how many firms get the information. So, they disclose to the entire market, inducing entry by the maximum number of firms into the renegade's market.

Even if we allow court enforcement of a licensing contract between a new firm and a leading firm, the assumption makes sense if (1) the identity of the new firms is not known until after a leading firm has disclosed knowledge to the market; (2) the new firms are so numerous and the probability that each one of them be able to develop is so small that the new firms are unwilling to pay the transaction costs associated with entering into a licensing agreement; or (3) the relevant knowledge is not protected by patent or trade secret, so there are no IP rights over which to barter. That said, the assumption of no-licensing is just an abstraction, helpful in fixing ideas. In Section 5, we discuss how licensing would affect the results.

After acquiring knowledge, and then discovering whether it can develop an innovation, a new firm participates in the entry game with the two leading firms.

Suppose that firm i is the only leading firm that is able to innovate in market j. Suppose also that the other leading firm has disclosed knowledge $k \in \{l, h\}$ to the market. Since any new firms that are able to innovate, up to m^E, enter market j, firm i's expected profit from this market is

$$\pi_k = \sum_{\ell=0}^{m^E-1} g_k(\ell)[V(\ell+1)]. \tag{2}$$

We are now ready to derive our main results. First, we show the positive social value of being able to threaten to disclose intellectual property. With disclosure, firms can credibly agree to share knowledge, even without colluding in the market entry game. This equilibrium is sustained by the threat of disclosing to the market any time a firm cannot develop an innovation.

Define p_l^{**} as follows

$$p_l^{**} = p_h - \frac{(1-p_h)\left[V(1) - \pi_l\right]}{\pi_l - V(2)}.$$

Proposition 3 *Suppose disclosure of information is possible. When $V(1) \geq \pi_l > V(2)$, if $p_l \geq p_l^{**}$, then there is a subgame perfect equilibrium in which the leading firms share knowledge and all enter each market in which they can develop an innovation. When $\pi_l \leq V(2)$, then there is always a subgame perfect equilibrium in which the leading firms share knowledge and all enter each market in which they can develop an innovation.*

Proof. See the Appendix.

The equilibrium described in this proposition is the best equilibrium from the consumers' point of view. The leading firms share knowledge, but do not coordinate their entry decisions; each leading firm enters all markets in which it can develop an innovation.

Several points are worth making here. First, this equilibrium is not possible for firms without the threat of IP disclosure. In other words, firms who lack intellectual property can only self-enforce input-sharing agreements if they can also agree to and maintain a market division agreement. In contrast, R&D firms can enforce knowledge sharing, while still competing in each and every market.

Second, in equilibrium, knowledge sharing occurs no matter how patient the firms are. Impatient firms, without intellectual property to disclose, can't sustain agreements. Impatient firms with intellectual property can since any deviation from knowledge sharing is punished immediately by either disclosure or the rival's market entry.

Third, this equilibrium shows that the circumstances where firms can enforce knowledge sharing are greater with a disclosure threat. If disclosure facilitates a ton of effective new firm entry ($\pi_l \leq V(2)$), firms can maintain knowledge sharing, even if they think chances are slim that with low knowledge the rival firm will be able to innovate. If, on the other hand, there are no new firms that can enter and develop an innovation, $g_l(0) = 1$, then $\pi_l = V(1)$, $p_l^{**} = p_h$, and this equilibrium does not exist. Simply put, the more numerous and better able to develop an innovation are the firms "waiting in the wings" - ready to enter either innovation market if given the right amount of knowledge - the better the disclosure threat works.

Our next result highlights the potential negative social value of the disclosure threat; that is, tacit collusion is more likely. Define the following discount factor:

$$\delta_2 = \frac{V(2)}{V(1) - \pi_l}. \tag{3}$$

Proposition 4 *Suppose disclosure of information is possible. If and only if $\delta \geq \max\{\delta_1, \delta_2\}$, there is a subgame perfect equilibrium in which: (1) the leading firms do not share information and (2) when each firm can develop at least one innovation and in all markets at least one firm can develop an innovation, the firms coordinate market entry (i.e., each enters a different market).*

Proof. See the Appendix.

As in the model without disclosure, collusion can still happen here when both firms can enter both markets. In addition, firms can collude when one of them can enter a single market, provided at least one firm can enter both markets. Returning to Figure 1, with disclosure, collusion is possible in subgame configurations (1), (4) and (5). Without disclosure, collusion is possible only in subgame configuration (1). This is because, besides the threat to enter their rival market, firms can now threaten to disclose. This latter threat is credible when a firm cannot enter that market on its own. Tacit collusion lowers consumers' surplus and often lowers social welfare (see the next section for a discussion of when market coordination does not lower welfare).

Our final result of this section shows that the socially "good" and the socially "bad" aspects of the market disclosure threat can be present at the same time. In the equilibrium that maximizes the sum of the firms' profits, firms share knowledge and collude in the market entry game, provided each firm can enter at least one market and one firm can enter both markets; that is, they collude in subgame configurations (1), (4) and (5). Define the following threshold value of p_l:

$$p_l^{***} = p_l^{**} - \frac{2\,(1-p_h)\,[\pi_l - V(2)] + p_h^2\,(2-p_h)\,[V(1) - 2V(2)]}{2\,[\pi_l - V(2)]}. \qquad (4)$$

Note that if $V(1) \geq \pi_l > V(2)$ then $p_l^{***} < p_l^{**} < p_h$.

Proposition 5 *Suppose market disclosure of information is possible and one of the following conditions hold: 1) $V(1) \geq \pi_l > V(2)$, $p_l \geq p_l^{***}$, and $\delta \geq \delta_2$; 2) $\pi_l \leq V(2)$, and $\delta \geq \delta_1$. Then there is a subgame perfect equilibrium in which the leading firms share knowledge and each firm enters a different market when both firms can develop at least one innovation and in all markets at least one firm can develop an innovation. If neither 1) nor 2) hold, such an equilibrium does not exist.*

Proof. See the Appendix.

In this equilibrium, knowledge sharing and market coordination are sustained by two threats: (1) the threat to disclose information when a firm cannot develop an innovation on its own, and (2) the threat to enter all markets where it can develop an innovation. To echo a common theme, note that, in this equilibrium, disclosure enlarges the set of circumstances where firms can successfully self-enforce agreements. If the pool of potential firms is rich and effective ($\pi_l \leq V(2)$), the leading firms don't have to anticipate being able to innovate on their own in both markets to maintain both agreements.

5 Legal and Welfare Implications

Viewing the disclosure of intellectual property as a "threat" leads to a number of legal and welfare implications. First, R&D knowledge sharing agreements raise enforcement concerns. Such agreements must detail the knowledge to be shared (even if it isn't created yet). Inartful and imprecise contractual drafting can make it difficult for courts to determine "breach," especially when the contract governs ever-evolving technology. Making enforcement more problematic is the presence of judges with little technology expertise or savvy. Our model shows that any enforcement concerns are potentially overstated. The threat of intellectual property disclosure can ensure compliance with knowledge-sharing commitments absent court intervention.

Second, antitrust officials worry about an increased chance of tacit collusion in evaluating mergers [1992 Horizontal Merger Guidelines]. According to the guidelines, "whether a merger is likely to diminish competition by enabling firms more likely, more successfully or more completely to engage in coordinated interaction depends on whether market conditions, on the whole, are conducive to reaching terms of coordination and detecting and punishing deviations from those terms." The model highlights a previously unrecognized factor in facilitating coordinated interaction: the presence of large amounts of leakable or disclosable intellectual property.

Third, the courts play no role in the analysis. Adding court enforcement of licensing arrangement with new firms wouldn't change much, however.[6] Upon observing a deviation from any agreement, a leading firm would license information to a competing third party firm. The third party firm with the best chance of innovating would pay the highest license fee. A renegade firm would still face entry if it defected from the knowledge-sharing or market division agreements, albeit by a single third-party firm rather than many fringe firms. And the punishment meted out would be more severe than if the punishing firm didn't hold any intellectual property whatsoever.

Indeed, the enforceability of third-party licensing arrangements and the ability of leading firms to self-execute agreements bear an interesting relationship: the less capable courts are at handling licensing arrangements, the better R&D firms are at self-enforcing their own agreements. The weaker

[6] There is a large literature on licensing and intellectual property transfer, for example see Katz and Shapiro [1985], [1988], Bhattacharya et al [1992], Anton and Yao [1994], [2002], d'Aspremont et al [2000], Bhattacharya and Guriev [2006] and Gans and Stern [2000].

court enforcement is, the less a new firm will pay for a license. After all, weak judicial enforcement means that the new firm may get less or different knowledge than the license guaranteed, with no available judicial remedy. If the transaction costs of finding the third-party firm are high enough, these search costs will swamp the benefit to the leading firm of the lower-priced licensing arrangement. It won't be in the punishing firm's interest to license; instead it will simply disclose. And, as we have seen, broad disclosure represents the most severe punishment available for deterring breach of agreements.

Fourth, the model sheds light on the proper antitrust treatment of R&D joint ventures. The welfare effects of any R&D joint venture reflect a balancing of interests. Knowledge sharing is always socially beneficial and should be encouraged, because it increases the chance of innovation in both markets. On the other hand, it is an open question whether the antitrust authority should prevent coordination in the entry decision. Typically market coordination reduces welfare, but the opposite is also possible. Welfare may increase if the reduction in consumers' surplus following market coordination is more than compensated by the increase in the firm's profits (e.g., this can happen if the fixed cost of entering a market is high).

Finally, it is important to note that allowing market coordination makes it easier for firms to share knowledge, and this has a positive effect on welfare. In light of this fact, how should the antitrust authority treat R&D joint ventures? Intuitively, if the probability that a leading firm is able to innovate when it has a low knowledge level is sufficiently high, and the fixed cost of entry sufficiently low, then preventing the formation of a joint venture is likely to enhance welfare. In such a case the social cost of collusion of entry decisions may not be worth the social benefit of facilitating information sharing.

6 Concluding Remarks

The model developed in this paper demonstrates how firms can use IP disclosure to enforce agreements to exchange knowledge and coordinate entry decisions. For some parameter configurations, the threat of disclosure deters the breach of the explicit knowledge sharing agreement and the tacit market division agreement arising out of an R&D joint venture. Some insights gained from the model follow: (1) Enforcing agreements – illegal and legal – is easier when the firms have intellectual property that can be easily released to the market. (2) If technology is difficult to transfer to other firms, firms don't have any technology to transfer, or there are few firms able to innovate when given the technology, firms will have greater difficulty self-policing their agreements. (3) If firms are in the process of developing similar innovations, then the case is stronger for antitrust officials to deter market entry coordination, even at the cost of banning the joint venture altogether and thereby impeding knowledge sharing.

One final point is this: The joint venture antitrust analysis differs when innovations are complementary. In that case, the payoff to a leading firm that innovates in a market is higher if the other firm also innovates. As a result, it is mutually beneficial for both firms to develop their innovations in any given market. For example, the maker of an allergy medicine with side-effects prefers that a drug which mitigates those effects also comes to market. An extreme example of complementary innovations is provided by two goods that consumers only value as a bundle (for example, compatible DVD disk players and DVD disks). When innovations are complementary, it is a dominant strategy for each firm to share knowledge and enter any market where it can develop an innovation. There is no downside to sharing information; each firm prefers that the complementary innovation come to market. Because consumers are also better off when complementary innovations are produced, welfare increases under a joint venture. Thus there is no reason for the antitrust authority to prevent joint ventures to form when the leading firms are developing complementary products.

Appendix

Proof of Proposition 1

Consider the first type of equilibrium. The strategy of each firm is to enter both markets at any time t if it did not enter the markets before. Given the opponent's strategy, each firm's strategy is clearly sequentially rational.

Now consider the second type of equilibrium. Let's say that firm 1 enters market A, while firm 2 enters market B. Strategies that support this equilibrium are as follows. At time $t = 1$, firm 1 enters market A. At time $t > 1$, firm 1 stays in market A and enters market B if and only if firm 2 has entered market A in a previous period. Firm 2 follows a similar strategy, entering market B at $t = 1$. Discounted continuation equilibrium payoffs are $V(1)/(1-\delta)$ for both firms. If firm 1 deviates and enters both markets in the first stage (this is the best possible deviation), then it obtains a discounted continuation payoff equal to $[V(1) + V(2)] + 2V(2)\delta/(1-\delta)$. This deviation is not profitable if $\delta \geq \delta_1$. If, on the other hand, $\delta < \delta_1$, then this cooperative equilibrium cannot be sustained. It remains to be shown that there cannot be any other type of equilibrium with no entry delay.[7] This follows because the only reason why a firm may refrain from entering a market is that it coordinates with the other firm so that each firm enters a separate market. ■

Proof of Proposition 2

From Proposition 1 if $\delta < \delta_1$, no coordination will take place in the entry game, and thus it is a dominant strategy for a firm not to share knowledge (by benefiting the rival, knowledge sharing can only hurt a firm).

If $\delta \geq \delta_1$, information sharing can be part of an equilibrium if and only if coupled with coordination in the entry game. To sustain information sharing, each firm should follow the strategy of sharing knowledge and then entering one of the two markets at $t = 1$ if (1) the rival also shared knowledge and (2) the rival can develop innovations in both markets. (Assume, w.l.o.g., that firm 1 enters market A and firm 2 enters market B.) Subgame perfection requires that at $t = 1$ a firm enters all markets in which it can develop an innovation if the rival shared knowledge but cannot develop innovations in

[7] Depending on the discount factor, there an equilibria in which firms enter at a date t>1. If exiting and re-entering a market are possible, there may also be equilibria in which firms enter, then exit, then re-enter again a market. In this paper we focus on equilibria with no entry delay, which we find the most plausible.

both markets. If the rival fails to share, then the firm will enter any market where it can develop an innovation. Note that this is the most severe punishment that can be meted out to a firm that fails to share, and thus it gives us the best option to sustain knowledge sharing in equilibrium. This strategy gives the firm a discounted continuation equilibrium payoff U^E, where

$$\begin{aligned}
U^E(1-\delta) &= p_h^2\left\{p_h^2 V(1) + 2p_h(1-p_h)V(2)\right\} \\
&\quad +2p_h(1-p_h)\left\{p_h^2\left[V(1)+V(2)\right] + p_h(1-p_h)V(1) + p_h(1-p_h)V(2)\right\} \\
&\quad +(1-p_h)^2\left\{2p_h^2 V(1) + 2p_h(1-p_h)V(1)\right\} \\
&= \left[p_h^4 - 2p_h^2 + p_h\right]V(1) + \left[-2p_h^4 + 2p_h^2\right]V(2).
\end{aligned}$$

Failing to share knowledge yields the payoff U^D, where

$$\begin{aligned}
U^D(1-\delta) &= p_l^2\left\{2p_h^2 V(2) + 2p_h(1-p_h)V(2)\right\} \\
&\quad +2p_l(1-p_l)\{p_h^2\left[V(1)+V(2)\right] + p_h(1-p_h)V(1) + p_h(1-p_h)V(2)\} \\
&\quad +(1-p_l)^2\{2p_h^2 V(1) + 2p_h(1-p_h)V(1)\} \\
&= \left[p_h - 2p_l p_h\right]V(1) + 2p_l p_h V(2).
\end{aligned}$$

Simple algebra shows that $U^D \leq U^E$ if and only if $p_l \geq p_l^*$, where

$$p_l^* = \frac{(2p_h^2 - p_h^4)V(1) + 2(p_h^4 - p_h^2)V(2)}{2p_h\left[V(1)-V(2)\right]} = p_h - \frac{p_h^3\left[V(1)-2V(2)\right]}{2\left[V(1)-V(2)\right]}.$$

We know from Proposition 1 that if $\delta \geq \delta_1$, then cooperation can be sustained in the entry subgame. This concludes the proof. ■

Proof of Proposition 3

The following is an equilibrium strategy for firm 1 (firm 2's equilibrium strategy is similar).

- In the first stage of the game, firm 1 shares its knowledge with firm 2.
- In the second stage, there are two possibilities. If in the first stage firm 2 shared its knowledge, or if firm 2 did not share its knowledge, but firm 1 can still develop both innovations, then firm 1 does not disclose any information to the market. If in the first stage firm 2 did not share knowledge, and firm 1 cannot develop an innovation in a market, then firm 1 will publicly disclose its knowledge in that market.

- In the entry game firm 1 will enter any market where it can develop an innovation and only $m^E - 1$ other firms are able to innovate. Firm 1 never leaves a market it has entered.

The strategies in each entry subgame constitute an equilibrium. In the second stage, disclosure of a firm's knowledge in a market is optimal (it cannot hurt) if the firm cannot develop an innovation in that market. If the firm can develop an innovation in a market, then it cannot profit from disclosing information in that market. Given that firm 2 is following its equilibrium strategy, if in the first stage firm 1 follows the equilibrium strategy, it receives a discounted continuation payoff equal to U^E, where

$$\begin{aligned} U^E(1-\delta) &= 2p_h^2 p_h V(2) + 2p_h(1-p_h)\left[p_h V(2) + p_h V(1)\right] + 2(1-p_h)^2 p_h V(1) \\ &= 2\left(-p_h^2 + p_h\right) V(1) + 2p_h^2 V(2). \end{aligned}$$

If firm 1 does not share information, then its expected payoff is U^D, where

$$\begin{aligned} U^D(1-\delta) &= 2{p_l}^2 p_h V(2) + 2p_l(1-p_l)p_h\left[V(2) + \pi_l\right] + 2(1-p_l)^2 p_h \pi_l \\ &= 2\left(-p_l p_h + p_h\right)\pi_l + 2p_l p_h V(2). \end{aligned}$$

where π_l is given by equation (2). $U^E \geq U^D$ if and only if

$$PV(1)\left(1-p_h\right) + V(2)p_h \geq \pi_l\left(1-p_l\right) + V(2)p_l,$$

or, equivalently, if and only if

$$V(1) - \pi_l - p_h\left[V(1) - V(2)\right] \geq p_l\left[V(2) - \pi_l\right] \tag{5}$$

If $V(1) \geq \pi_l > V(2)$, then (5) is equivalent to

$$p_l \geq \frac{p_h\left[V(1) - V(2)\right] - \left[V(1) - \pi_l\right]}{\pi_l - V(2)} = p_l^{**}.$$

Thus, in this case, there is a subgame perfect equilibrium in which the leading firms share knowledge and each enters all markets in which they can develop an innovation, if $p_l \geq p_l^{**}$.

Second, if $\pi_l \leq V(2)$, then (5) is equivalent to

$$\left(1-p_h\right)\left[V(1) - \pi_l\right] + p_h\left[V(2) - \pi_l\right] \geq p_l\left[V(2) - \pi_l\right]$$

which is always satisfied. Thus, in this case there is always a subgame perfect equilibrium in which the leading firms share knowledge and all enter each market in which they can develop an innovation. ■

Proof of Proposition 4

We claim that the following is an equilibrium strategy for firm 1 (firm 2's equilibrium strategy is similar).

- In the first stage of the game, firm 1 does not share its knowledge with firm 2. Moreover, firm 1 does not disclose any information to the market before the entry game.

- In the second stage, firm 1 coordinates market entry with firm 2. When the firms can develop innovations in both markets with each firm being able to develop at least an innovation, then at $t = 1$ firm 1 enters only one market (a different market from firm 2); firm 1 enters any market in which it can develop an innovation at $t = 1$ if firm 2 cannot develop any innovations. At any subsequent time, firm 1 never leaves a market it has entered, and if firm 2 has entered the same market that firm 1 entered, then firm 1 enters any market in which it can develop an innovation and discloses its knowledge in any market in which it cannot develop an innovation.

We now prove that the specified strategies constitute an equilibrium. Consider the market entry subgame in which the firms can develop innovations in both markets with each firm being able to develop at least an innovation. Suppose the two firms follow the equilibrium strategies; that is, they enter different markets. Each firm's equilibrium discounted continuation equilibrium payoff is R^e, where

$$(1-\delta)R^e = p_l^2 V(1) + 2p_l(1-p_l)V(1) + 2(1-p_l)^2 V(1).$$

Only a firm that can develop an innovation in both markets may want to deviate. There are three different types of possible deviations. First, the firm may deviate and enter in both markets only when the other firm can innovate in both markets. In this case the deviating firms obtains a discounted continuation payoff R_1^d, where

$$
\begin{aligned}
R_1^d &= p_l^2\{[V(1)+V(2)]+2V(2)\delta/(1-\delta)\}+(1-p_l)^2[2V(1)/(1-\delta)] \\
&\quad +2p_l(1-p_l)\{V(1)/(1-\delta)\}.
\end{aligned}
$$

This deviation is not profitable if $\delta \geq \delta_1$, where δ_1 is defined by (1).

In the second type of deviation, the firm deviates by entering both markets when the other firm can only innovate in one market. This gives the deviating firm a payoff equals to R_2^d, where

$$
\begin{aligned}
R_2^d &= p_l^2[V(1)/(1-\delta)]+(1-p_l)^2[2V(1)/(1-\delta)] \\
&\quad +2p_l(1-p_l)\{V(1)+V(2)+[V(2)+\pi_l]\delta/(1-\delta)\}.
\end{aligned}
$$

This deviation is not profitable if $\delta \geq \delta_2$, where δ_2 is defined by (3).

In the last type of deviation, the deviating firm always enters both markets in the entry game. Then it obtains a discounted continuation payoff R_3^d, where

$$
\begin{aligned}
R_3^d &= p_l^2\{[V(1)+V(2)]+2V(2)\delta/(1-\delta)\}+(1-p_l)^2[2V(1)/(1-\delta)] \\
&\quad +2p_l(1-p_l)\{[V(1)+V(2)]+[V(2)+\pi_l]\delta/(1-\delta)\}.
\end{aligned}
$$

This deviation is not profitable if $\delta \geq \delta_3$, where

$$
\delta_3 = \frac{(2-p_l)\,V(2)}{(2-p_l)\,[V(1)-\pi_l]-p_l\,[V(2)-\pi_l]}. \tag{6}
$$

Note that if $V(2) > \pi_l$ then $\delta_1 > \max\{\delta_2, \delta_3\}$, while if $V(2) < \pi_l$ then $\delta_2 > \max\{\delta_1, \delta_3\}$. Thus, for $\delta \geq \max\{\delta_1, \delta_2\}$, there is a subgame perfect equilibrium in which the leading firms coordinate market entry, even though they did not share knowledge in the first stage of the game. ■

Proof of Proposition 5

We claim that the following is an equilibrium strategy for firm 1 (firm 2's equilibrium strategy is similar).

- In the first stage of the game, firm 1 shares its knowledge with firm 2.

- In the second stage, there are two possibilities. If in the first stage firm 2 shared its knowledge, or if firm 2 did not share its knowledge, but firm 1 can still develop both innovations, then firm 1 does not disclose any information to the market before the entry game. If in the first stage firm 2 did not share knowledge, and firm 1 cannot develop an innovation in a market, then firm 1 will publicly disclose its knowledge in that market.

- When information was shared in the first stage, no knowledge was disclosed to the market before the entry game, and the firms can develop innovations in both markets with each firm being able to develop at least an innovation, then at $t = 1$ firm 1 enters only one market (a different market from firm 2); firm 1 enters any market in which it can develop an innovation at $t = 1$ if firm 2 cannot develop any innovations. At any subsequent time, firm 1 never leaves a market it has entered, and if firm 2 has entered the same market that firm 1 entered, then firm 1 enters any market in which it can develop an innovation and discloses its knowledge in any market in which it cannot develop an innovation.

- If one of the two firms did not share information in the first stage, then at $t = 1$ firm 1 will enter any market where it can develop an innovation and only $m^E - 1$ other firms are able to innovate. Firm 1 never leaves a market it has entered.

We now prove that the specified strategies constitute an equilibrium. Suppose firms have shared knowledge, and consider the market entry subgame in which the firms can develop innovations in both markets with each firm being able to develop at least an innovation. Suppose the two firms follow the equilibrium strategies; that is, they enter different markets. Each firm's equilibrium discounted continuation equilibrium payoff is R^E, where

$$(1-\delta)R^E = p_h^2 V(1) + 2p_h(1-p_h)V(1) + 2(1-p_h)^2 V(1).$$

Only a firm that can develop an innovation in both markets may want to deviate. There are three different types of possible deviations. First, the firm may deviate and enter in both markets only when the other firm can innovate in both markets. In this case the deviating firms obtains a discounted continuation payoff R_1^D, where

$$\begin{aligned} R_1^D &= p_h^2\{[V(1)+V(2)] + 2V(2)\delta/(1-\delta)\} + (1-p_h)^2[2V(1)/(1-\delta)] \\ &\quad +2p_h(1-p_h)\{V(1)/(1-\delta)\}. \end{aligned}$$

This deviation is not profitable if $\delta \geq \delta_1$, where δ_1 is defined by (1).

In the second type of deviation, the firm deviates by entering both markets when the other firm can only innovate in one market. This gives the deviating firm a payoff equals to R_2^D, where

$$\begin{aligned} R_2^D &= p_h^2[V(1)/(1-\delta)] + (1-p_h)^2[2V(1)/(1-\delta)] \\ &\quad +2p_h(1-p_h)\{V(1)+V(2)+[V(2)+\pi_l]\delta/(1-\delta)\}. \end{aligned}$$

This deviation is not profitable if $\delta \geq \delta_2$, where δ_2 is defined by (3).

In the last type of deviation, the deviating firm always enters both markets in the entry game. Then it obtains a discounted continuation payoff R_3^D, where

$$\begin{aligned} R_3^D &= p_h^2\{[V(1)+V(2)] + 2V(2)\delta/(1-\delta)\} + (1-p_h)^2[2V(1)/(1-\delta)] \\ &\quad +2p_h(1-p_h)\{[V(1)+V(2)] + [V(2)+\pi_l]\delta/(1-\delta)\}. \end{aligned}$$

This deviation is not profitable if $\delta \geq \delta_3$, where δ_3 is defined in (6).

If $V(2) > \pi_l$ then $\delta_1 > \max\{\delta_2, \delta_3\}$, while if $V(2) < \pi_l$ then $\delta_2 > \max\{\delta_1, \delta_3\}$. Thus, if either $V(1) \geq \pi_l > V(2)$ and $\delta \geq \delta_2$, or if $\pi_l \leq V(2)$ and $\delta \geq \delta_1$, there is a subgame perfect equilibrium in which the leading firms coordinate market entry, given they both shared knowledge in the first stage of the game. On the other hand, if the leading firms did not share knowledge and punishment was implemented before the entry game, then there is no profitable deviation in the market entry game and firms enter all markets in which they can innovate.

Now consider the first stage, in which firms are supposed to share knowledge. Suppose that firm 2 is following its equilibrium strategy. If firm 1 also follows the equilibrium strategy, then it receives a discounted payoff equal to U^E, where

$$\begin{aligned} U^E(1-\delta) &= p_h^2\{p_h^2V(1) + 2p_h(1-p_h)V(1)\} \\ &\quad +2p_h(1-p_h)\{p_h^2V(1) + p_h(1-p_h)V(1) + p_h(1-p_h)V(2)\} \\ &\quad +(1-p_h)^2\{2p_h^2V(1) + 2p_h(1-p_h)V(1)\} \\ &= [-p_h^4 + 2p_h^3 - 2p_h^2 + 2p_h]V(1) + \left[2p_h^4 - 4p_h^3 + 2p_h^2\right]V(2). \end{aligned}$$

The best possible deviation for firm 1 is not to share information and enter any market in which it can develop innovation; with such a deviation its expected payoff is U^D, where

$$\begin{aligned} U^D(1-\delta) &= p_l^2\{2p_h^2V(2)+2p_h(1-p_h)V(2)\} \\ &\quad +2p_l(1-p_l)\{p_h^2[\pi_l+V(2)]+p_h(1-p_h)V(2)+p_h(1-p_h)\pi_l\} \\ &\quad +(1-p_l)^2\{2p_h^2\pi_l+2p_h(1-p_h)\pi_l\} \\ &= 2p_h(1-p_l)\pi_l+2p_lp_hV(2). \end{aligned}$$

where π_l is given by equation (2). $U^E \geq U^D$ if and only if

$$V(1)[-p_h^4+2p_h^3-2p_h^2+2p_h]+V(2)\left[2p_h^4-4p_h^3+2p_h^2\right] \geq 2\pi_lp_h(1-p_l)+2V(2)p_lp_h,$$

or, equivalently, if and only if

$$\left[-p_h^3+2p_h^2-2p_h+2\right]V(1)+\left[2p_h^3-4p_h^2+2p_h\right]V(2)-2\pi_l \geq 2p_l[V(2)-\pi_l] \tag{7}$$

There are two cases. First, if $V(1) \geq \pi_l > V(2)$, then (7) is equivalent to

$$p_l \geq \frac{(p_h^3-2p_h^2)[V(1)-2V(2)]+2p_h[V(1)-V(2)]-2[V(1)-\pi_l]}{2[\pi_l-V(2)]} = p_l^{***}.$$

Thus, in this case, there is a subgame perfect equilibrium in which the leading firms share knowledge and each enters a different market in the entry game, if $p_l \geq p_l^{***}$ and $\delta \geq \delta_2$ ($\pi_l > V(2)$ implies $\delta_2 > \max\{\delta_1, \delta_3\}$).

Second, if $\pi_l \leq V(2)$, then (7) is equivalent to

$$\left(-p_h^3+2p_h^2-2p_h+2\right)[V(1)-2V(2)]+2(1-p_h)V(2) \geq -2(1-p_l)[V(2)-\pi_l]$$

which is always satisfied, because the lhs is positive (recall $V(1) > 2V(2)$) and the rhs is negative. Thus, in this case, it is sufficient that $\delta \geq \delta_1$ for a subgame perfect equilibrium to exist ($\pi_l \leq V(2)$ implies $\delta_1 \geq \max\{\delta_2, \delta_3\}$). ■

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