Intellectual Property Disclosure as 'Threat'

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Abstract

This paper models the disclosure of knowledge via licensing to outsiders or fringe firms as a threat, useful in ensuring firms keep their commitments. We show that firms holding intellectual property are better able to enforce agreements than firms that don't. In markets requiring innovation to make a product, IP disclosure presents a more powerful threat than entry by the punishing firm alone. Occasionally, a punishing firm won't be able to translate its intellectual property into a full-blown product, making it impossible for it to enter the cheating firm's market and punish. Even if it can't make a product itself, the punishing firm can always credibly threaten to license the intellectual property it has on hand to someone else. With this intellectual property as a springboard, chances are at least one fringe firm will be able to do the translation, make the product and enter the cheating firm's market. In short, the potential for licensing increases the likelihood of punishment for uncooperative behavior. 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 implications 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 innovators 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 under-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.

To see why, consider a tacit agreement between two firms to divide up markets. The standard story is that the threat of entry into the other firm's market can maintain the market division agreement (see, for example, Calem [1988] and Bulow et. al [1985]). But what if one firm has capacity to only enter one market? In that case, the capacity constrained firm lacks a credible entry threat and the market division agreement falls apart. Intellectual property as an essential input in production alters this story. Now even though the capacity constrained firm can't enter its rival's market, any knowledge the firm has can be sold to someone else. Because it is non-rival, information licensed to one firm is never depleted. In other words, unlike physical capital, intellectual property doesn't depreciate. If the first firm who buys a license fails to innovate, that same information can be licensed to a second firm. If the second firm fails to innovate, the information can be sold to a third firm. And so on. By repeated disclosures, a firm can guarantee that some firm will innovate, build a competing product, and enter the market of a counter-party that reneges on its promises. The fear of license-induced entry, then, provides an incentive for each firm to keep its word. Simply put, knowledge disclosure works as an effective hammer to punish deviations from both express and implied agreements between firms whose business model is based on intellectual property. As a result, firms holding intellectual property find enforcing agreements – whether those agreements are pro-competitive or anti-competitive– easier than firms that don't. The power of the disclosure threat depends on two factors: (1) the degree to which knowledge can be easily transferred between firms, that is, how easy it is to learn what another firm knows; and (2) the number of fringe firms willing and able to bring a product to market if given the essential intellectual property.

Better enforcement works for good and ill. On the plus side of the ledger, the threat of disclosure means that joint ventures where firms exchange knowledge can be 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 of the ledger, 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 released upon observing a deviation from a tacit agreement.

The antitrust ramifications of this latter point suggest care in the treatment of R&D joint ventures. Although the potential anti-competitive effects of such agreements are well-known, the literature has focused on ancillary clauses in the agreement itself, such as promises to share price information (Grossman and Shapiro [1986]), or promises to cross-license at supracompetitive rates (Shapiro [1985] and Katz and Shapiro [1985]). Our model shows that the mere presence of intellectual property at the core of the business can facilitate collusive behavior.

The insights offered here also provide a new rationale for the common practice of licensing technology on a non-exclusive basis to R&D joint ventures. The conventional wisdom is that firms use non-exclusive licenses because they don't want to tie up knowledge assets in the joint venture, especially if the technology might be useful for unrelated projects. Our model shows that the non-exclusive license serves another purpose: maintaining the intellectual property disclosure threat. The non-exclusive license is equivalent to loading a gun, ready to be discharged if participants in the joint venture fail to uphold their end of the bargain.

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. As an example, consider two technology firms forming a joint venture. Each firm licenses its technology to the joint venture, allowing the joint venture to use the knowledge whether protected by patent or trade secret. This knowledge can be the basis of a variety of potential products, from a new cell-phone to a higher-speed computer to a higher definition flat screen television. Market entry demands incorporating the technology into an innovative new product. Each firm might be able to innovate and produce the product without access to the other firm's technology. What access does is increase the chance of a successful innovation. The exchange of knowledge is tough to verify and, as a result, non-contractible. Under these circumstances, each firm has an incentive to withhold information from its counter-party. By withholding, a firm benefits from the other firm's knowledge, while at the same time maintaining an edge in the race to innovate.

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 through licensing. The first threat is a variant on the 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 engages in sequential licensing to fringe firms until one fringe firm can innovate. The transfer of intellectual property provides fringe firms a gateway into the renegade's market.

Our paper relates to a large literature on the strategic transfer of knowledge. Anton and Yao [1994] analyze a pro-competitive effect of information disclosure. 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 market rival. In another set of papers, Anton and Yao [2002] and [2003] provide another justification for IP disclosure: expropriable partial disclosure can be used to credibly signal the quality of an inventor's innovation. Our model focuses on disclosures by symmetric firms, rather than private disclosures by an inventor. We show that threats of knowledge disclosure can ensure compliance with both pro-competitive and anti-competitive agreements between firms. The threat of disclosure facilitates knowledge sharing by firms, a pro-competitive effect, but it also makes it easier for firms to divide-up the innovation markets, an anti-competitive effect.

Also close to the concerns here is the large literature on licensing. This literature often addresses the relationship between licensing and the speed of innovation (see, e.g., Katz and Shapiro [1988]). Other times, authors are concerned with what structures the terms of the licensing agreement. For example, Gans and Stern [2000] study bargaining over the licensing terms between an incumbent and a potential entrant with a technological innovation. They find that an incumbent might, under certain conditions, invest in R &D purely to improve their position in the licensing negotiation. d'Aspremont et al. [2000] study the sharing of interim research knowledge between two firms engaged in a patent race. There, because of the nature of information, they find that the non-informed agent is able to obtain full disclosure of the informed party's knowledge, while forfeiting none of the gains from trade to the informed seller. Bhattacharya and Guriev [2006] consider two R &D firms deciding how to sell their ideas to development firms. The potential for leakage of knowledge in the patent process pushes firms toward protecting knowledge through trade secrets. Bhattacharya et al. [1992] explore two licensing contacts that ensure efficient sharing of knowledge and efficient expenditures on R &D. Like most of this literature, we focus on a special characteristics of knowledge: the ability to license the same knowledge to multiple actors. In our model, it is this characteristic that makes it easier to sustain cooperative behavior between firms.

Finally, our paper connects with the literature on multimarket contact. Bernheim 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 via licensing to fringe firms facilitate knowledge sharing and market division.

The paper is organized as follows. Section 2 develops the model; in the first round two leading R&D firms decide whether to share knowledge, and in the second round they play an entry game in two potential markets. Section 3 studies the entry game. It shows that market coordination (each firm cornering one market) is easier to sustain if a firm can use the threat of disclosing intellectual property in the other firm's market, when it is not able to enter itself. Section 4 studies knowledge sharing agreements. It shows that when the threat of IP disclosure is available, it is also easier for firms to share knowledge prior to divvying up the markets. 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. We deliberately use the reduced form $V(m_j)$ for the stage payoffs, in order to abstract from the firms' pricing strategies, and focus instead on their information sharing, licensing and entry strategies.

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.[1] Third, each firm decides whether to license knowledge to fringe firms. 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.

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

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 license any of their knowledge to the fringe firms. Figure 1 illustrates the extensive form of the game.

We solve the game by backward induction, considering first the equilibrium in the market entry game and then equilibrium where an agreement to share know how precedes the market entry game. Our plan is to show how, at each stage, firms holding knowledge can better coordinate their activities than firms without knowledge.

2.1 Licensing and the Value of Innovations

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 can develop an innovation with probability p_l using only its own knowledge, while it is able to develop the innovation with probability p_h, with $p_h > p_l$, when it also has access to the knowledge of the other leading firm. We will say that a firm with access only to its own knowledge has a low knowledge level, while it has a high knowledge level if it has access to both technologies.

Knowledge disclosure and licensing play a critical role in the analysis. In each market, there exists n_j fringe firms. Without any knowledge transfer from the leading firms, none of them can innovate. Because knowledge transfer from a leading firm to a fringe firm might be imperfect, fringe firms can innovate with probability $p_f \leq p_l$ when given access to a leading firm's technology.[2]

Licensing to a fringe firm takes on the following form. The leading firm offers the information or technology. If it is able to innovate, the fringe firm pays a fee which is a fraction α of its stream of profits, $\frac{V(m)}{1-\delta}$. If the fringe firm is unable to innovate, it pays nothing. If it decides to license, the leading firm keeps offering exclusive licenses to fringe firms until at least one firm can innovate and then stops. Thus, when a single leading firm

[2] It would seem plausible to assume that if the licensing firm has access to the other leading firm's technology, then the probability p_f^h that a fringe firm innovates after licensing is higher than the probability p_f^l that it innovates after licensing from a leading firm with low knowledge. This assumption would complicate the notation without affecting any of the results, provided that the difference between p_f^l and p_f^h is not too large. To simplify the notation, we assume that $p_f^l = p_f^h = p_f$.

licenses, the probability that at least one fringe firm will be able to innovate is $\gamma_1 = 1 - (1 - p_f)^{n_j}$, which converges to one as the fringe becomes large (i.e., as $n_j \to \infty$). We can think of $\alpha = 0$ as the special case in which the leading firm freely and publicly discloses its knowledge.

When both leading firms license to the fringe, the probability that at least two fringe firms will be able to innovate (and hence both leading firms will be able to collect their profit shares) is $\gamma_2 = 1 - (1 - p_f)^{n_j} - n_j p_f (1 - p_f)^{n_j - 1}$. The probability that only one fringe firm will be able to innovate is $\gamma_1 - \gamma_2$; in such a case each leading firm is equally likely to be the one to license. Hence, the probability that each leading firm will receive its profit share from the only innovating fringe firm is $\frac{1}{2}(\gamma_1 - \gamma_2)$.

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 $V(m) > V(m+1)$. Finally, we assume that monopoly profit is higher than total duopoly profit, $V(1) > 2V(2)$. 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. Our assumptions also hold if firms compete in prices, provided products are not perfectly homogeneous.

3 Market Entry

To begin the analysis, it is useful to delineate the behavior in the market entry game subgames. Figure 2 lists the possible subgame configurations.

(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; Firm 2 can innovate in the other market
(4)	Firm 1 can innovate in one market; Firm 2 can innovate in both markets
(5)	Firm 1 can innovate in both markets; Firm 2 can innovate in one market
(6)	At least one of the two firms cannot innovate in any markets

Figure 2: Possible Subgame Configurations

Absent the threat of licensing, subgame configuration (2)-(6) 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.) 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 when the threat of IP disclosure is available; then market entry coordination is possible in subgame configurations (3)-(5).

When IP disclosure is not possible, entry 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 (or immediate entry).[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:

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

Proposition 1 *Suppose IP disclosure is not possible. 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.

[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.

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.

Now allow for knowledge disclosure and licensing. Licensing increases the number of subgames where the firms can coordinate their actions. Before getting to the proposition that shows this result, define δ_2 as

$$\delta_2 = \frac{V(2)}{\gamma_1[V(1) - V(2)]}$$

Proposition 2 *Suppose IP disclosure and licensing are possible. There exists a subgame perfect equilibrium outcome of the entry game in which each leading firm enters a different market in the following scenarios: (1) When one firm can develop an innovation in one market and the other firm can develop an innovation in both markets; (2) when each leading firm can develop an innovation in both markets; and (3) when one firm can develop an innovation in one market only and the other firm can develop an innovation only in the other market. This equilibrium exists if and only if $\delta \geq \delta_2$.*

Proof: See the Appendix

A few remarks are worth making here. First, whether this equilibrium exists depends on γ_1, the chance that licensing will result in fringe entry. As γ_1 gets smaller, the needed threshold value of δ_2 gets bigger. γ_1 depends on (1) the number of fringe firms and (2) the success of the knowledge transfer, p_f. In other words, the power of the licensing threat to enforce entry coordination turns on the ease of knowledge transfer and the depth of the fringe. Second, without disclosable intellectual property, cooperation is possible in just one of the six possible market entry subgames, and then only if the firms are sufficiently patient. In contrast, with licensing, firms can enforce cooperation in more subgames, in particular cooperation is possible where one firm can enter both markets and the other firm can enter one market only. Meanwhile, the threat of entry by a leading firm continues to ensure cooperation where both firms can enter both markets.

4 Knowledge Sharing and Market Entry

As in the previous section, we first look at the possible equilibria where firms cannot license to the fringe and then compare those equilibria to the equilibria where the leading firms can license. Without sharing of knowledge, each leading firm i can only innovate with probability p_l in each market. By sharing its knowledge a firm raises the other leading firm's probability of innovating to p_h in both markets. 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. 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 3 *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 $p_l \geq p_l^*$.[4] The restrictions on p_l makes it sufficiently likely the firms will end up in a market entry subgame where both firms can enter both markets. Only in this subgame can entry coordination occur and, accordingly, only then can firms use threats to deviate from the coordinated scheme to punish a failure to 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

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

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.

By way of contrast, consider the case in which IP disclosure is possible. As shown in the previous section, licensing gives an additional punishing tool against renegate firms, enlarging the number of subgames where cooperation can occur in the entry game. As a result, the licensing threat makes it easier to sustain knowledge sharing in a joint venture of the two leading firms. Now if a leading firm fails to share knowledge, the rival firm can credibly threaten to license to a fringe firm in all markets in which it cannot enter. This enhances the probability a firm will experience punishment in the entry game after reneging on the knowledge-sharing agreement (punishment can be meted out in four subgames, rather than one subgame).

Proposition 4 *Suppose IP disclosure and licensing are possible. There is a value $p_l^{**} < p_h$ such that, if $p_l \geq p_l^{**}$ and $\delta \geq \delta_2$ then there exists an equilibrium where firms share knowledge and coordinate market entry (each leading firm entering a different market) in the following scenarios: (1) When one firm can develop an innovation in one market and the other firm can develop an innovation in both markets; (2) when each leading firm can develop an innovation in both markets; and (3) when one firm can develop an innovation in one market only and the other firm can develop an innovation only in the other market.*

Proof. See the Appendix

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 enforcement concerns are potentially overstated. The threat of intellectual property disclosure to fringe firms 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 disclosable intellectual property.

Finally, 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. From a static viewpoint, knowledge sharing is always socially beneficial, because it increases the chance of innovation in both markets. On the other hand, while we did not model it in this paper, the dynamic effect of knowledge sharing is ambiguous, because the prospect of future knowledge sharing may reduce a firm's incentive to invest in knowledge acquisition (i.e., R&D).

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). More interestingly, the prospect of future market coordination ought to strengthen the firms' incentives to invest in R&D, and thus raise welfare by increasing the innovation rate. It is also important to note that allowing market coordination makes it easier for firms to share knowledge, and this has a positive effect on welfare.

6 Concluding Remarks

The model developed in this paper demonstrates how firms can use the threat of licensing to fringe firms as a mechanism to enforce agreements to exchange knowledge and coordinate entry decisions. For some parameter configurations, the threat of knowledge 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 fringe firms. (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.[5] 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

Consider each scenario in turn. In scenario (1), one firm can enter one market and the other firm can enter both markets. Without loss of generality, consider the case where firm 1 can enter market A only and firm 2 can enter both markets. The following strategy supports the equilibrium where firm 1 enters market A only and firm 2 enters market B only. For firm 1, do not license to the fringe unless firm 2 enters market A in the previous period. For firm 2, remain in market B only unless firm 1 licenses and induces fringe entry into market B in the previous period. Each firm's discounted payoff from this strategy is $V(1)/(1-\delta)$. Firm 1's best deviation is to license in market B immediately. This deviation results in a payoff of $V(1) + \alpha\frac{\gamma_1 V(2)}{1-\delta} + \frac{\delta V(2)}{1-\delta}$.

[5] 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.

This deviation is unprofitable if $\delta \geq \frac{\alpha\gamma_1 V(2)}{V(1)-V(2)}$, which holds whenever $\delta \geq \delta_2$. Firm 2's best deviation is to enter firm 1's market immediately, provoking licensing by firm 1 in the following period. This deviation results in a payoff of $V(1) + V(2) + \frac{\delta(1+\gamma_1)V(2)}{1-\delta} + \frac{\delta(1-\gamma_1)V(1)}{1-\delta}$. This deviation is unprofitable if $\delta \geq \delta_2$.

In scenario (2), both firms can enter both markets. By the same argument as in proposition 1, trigger strategies support the equilibrium where each firm enters a different market. The punishment upon observing a deviation is the leading firm's entry into the other market. This is clearly a better punishment strategy than licensing because the punishing firm need not split the proceeds with the fringe firm. Since $\delta_2 > \delta_1$, a value $\delta \geq \delta_2$ ensures this equilibrium exists.

In scenario (3), each firm can enter a different market. The following strategy ensures that neither firm licenses to the fringe: Do not license unless the rival firm has licensed in the previous period. Each firm's discounted payoff from this strategy is $V(1)/(1-\delta)$. The best deviation for both firms is to immediately license, resulting in a payoff of $V(1)+\alpha\frac{\gamma_1 V(2)}{1-\delta}+\frac{\delta\gamma_1 V(2)}{1-\delta}+\frac{\delta(1-\gamma_1)V(1)}{1-\delta}$. This deviation is unprofitable if $\delta \geq \frac{\alpha V(2)}{V(1)-V(2)}$, which holds whenever $\delta \geq \delta_2$. ■

Proof of Proposition 3

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 it is 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 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

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

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

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

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

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

This concludes the proof. ■

Proof of Proposition 4

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

In the first stage of the game: share knowledge with firm 2. In the entry game:

- If firm 1 cannot innovate in either market: license in both markets.
- If firm 2, the other leading firm, cannot innovate in either market: enter any market in which can innovate, license in any market in which cannot innovate.
- If firm 1 can innovate in only one market and firm 2 can innovate in the other market: do not license if firm 2 shared in the first stage and has not entered firm 1's market; otherwise license.
- If firm 1 can innovate in both markets and firm 2 can innovate in at least one market, say market B: enter market A only, unless firm 2 licenses in that market, enters that market itself, or fails to share knowledge; otherwise enter both markets.

- If firm 1 can innovate in one market and firm 2 can innovate in that same one market only: enter that market and license to the fringe in the other market.

From Proposition 2, we know that if $\delta \geq \delta_2^s$, then firms are able to coordinate market entry after having shared knowledge. It only remains to show that sharing knowledge is an equilibrium in the first stage of the game.

Suppose firm 2 follows the equilibrium strategy. If firm 1 also follow the equilibrium strategy and shares knowledge, its payoff is

$$U^E = p_h^2 U^E(2) + 2p_h(1-p_h)U^E(1) + (1-p_h)^2 U^E(0)$$

where $U^E(i)$ is firm 1's payoff when firm 2 is able to innovate in i markets. It is:

$$(1-\delta)U^E(2) = \left\{p_h^2 V(1) + 2p_h(1-p_h)V(1) + (1-p_h)^2 2\alpha\gamma_1 V(2)\right\}$$

$$(1-\delta)U^E(1) = \left\{ \begin{array}{l} p_h^2 V(1) \\ +p_h(1-p_h)V(1) + p_h(1-p_h)\left[V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha(\gamma_1-\gamma_2)V(1)\right] \\ +(1-p_h)^2\left[\alpha\gamma_1 V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha(\gamma_1-\gamma_2)V(1)\right] \end{array} \right\}$$

$$(1-\delta)U^E(0) = \left\{ \begin{array}{l} p_h^2 2\left[\gamma_1 V(2) + (1-\gamma_1)V(1)\right] \\ +2p_h(1-p_h)\left[\gamma_1 V(2) + (1-\gamma_1)V(1) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha(\gamma_1-\gamma_2)V(1)\right] \\ +(1-p_h)^2 2\left[\alpha\gamma_2 V(2) + \frac{1}{2}\alpha(\gamma_1-\gamma_2)V(1)\right] \end{array} \right\}$$

If firm 2 follows the equilibrium strategy, firm 1's payoff from withholding knowledge is

$$U^D = p_l^2 U^D(2) + 2p_l(1-p_l)U^D(1) + (1-p_l)^2 U^D(0)$$

where, as before, $U^D(i)$ is firm 1's payoff when firm 2 is able to innovate in i markets. It is:

$$(1-\delta)U^D(2) = \left\{p_h^2 2V(2) + 2p_h(1-p_h)[V(2) + \alpha\gamma_1 V(2)] + (1-p_h)^2 2\alpha\gamma_1 V(2)\right\}$$

$$(1-\delta)U^D(1) = \left\{ \begin{array}{l} p_h^2\left[V(2) + \gamma_1 V(2) + [1-\gamma_1]V(1)\right] \\ +p_h(1-p_h)\left[V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha(\gamma_1-\gamma_2)V(1)\gamma_1 V(2)\right] \\ +p_h(1-p_h)\left[(1-\gamma_1)V(1) + \alpha\gamma_1 V(2)\right] \\ +[(1-p_h)^2\left[\alpha\gamma_1 V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha(\gamma_1-\gamma_2)V(1)\right] \end{array} \right\}$$

$$(1-\delta)U^D(0) = \left\{ \begin{array}{l} p_h^2 2\left[\gamma_1 V(2) + (1-\gamma_1)V(1)\right] \\ +2p_h(1-p_h)\left[\gamma_1 V(2) + (1-\gamma_1)V(1) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha(\gamma_1-\gamma_2)V(1)\right] \\ +(1-p_h)^2 2\left[\alpha\gamma_2 V(2) + \frac{1}{2}\alpha(\gamma_1-\gamma_2)V(1)\right] \end{array} \right\}$$

Note that $U^D(1) > U^D(2)$, since

$$\begin{aligned}
0 &< \left\{ \begin{array}{l} p_h^2 \left[V(2) + \gamma_1 V(2) + [1-\gamma_1] V(1)\right] \\ +p_h(1-p_h) \left[V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right) V(1)\right] \\ +p_h(1-p_h) \left[\gamma_1 V(2) + (1-\gamma_1) V(1) + \alpha\gamma_1 V(2)\right] \\ +[(1-p_h)^2 \left[\alpha\gamma_1 V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right) V(1)\right] \end{array} \right\} \\
&\quad - \left\{p_h^2 2V(2) + 2p_h(1-p_h)[V(2) + \alpha\gamma_1 V(2)] + (1-p_h)^2 2\alpha\gamma_1 V(2)\right\} \\
&= \left\{ \begin{array}{l} p_h^2 \left(1-\gamma_1\right)\left(V(1) - V(2)\right) \\ +p_h(1-p_h) \left[-V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right) V(1)\right] \\ +p_h(1-p_h) \left[\gamma_1 V(2) + (1-\gamma_1) V(1) - \alpha\gamma_1 V(2)\right] \\ +[(1-p_h)^2 \left[-\alpha\gamma_1 V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right) V(1)\right] \end{array} \right\} \\
&= \left\{ \begin{array}{l} p_h^2 \left(1-\gamma_1\right)\left(V(1) - V(2)\right) \\ +p_h(1-p_h) \left[\left(1-\gamma_1\right)\left(V(1) - V(2)\right) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right)\left(V(1) - 2V(2)\right)\right] \\ +[(1-p_h)^2 \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right)\left(V(1) - 2V(2)\right) \end{array} \right\}
\end{aligned}$$

Furthermore, $U^D(0) > U^D(1)$, since

$$\begin{aligned}
0 &< \left\{ \begin{array}{l} p_h^2 2\left[\gamma_1 V(2) + (1-\gamma_1) V(1)\right] \\ +2p_h(1-p_h) \left[\gamma_1 V(2) + (1-\gamma_1) V(1) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right) V(1)\right] \\ +(1-p_h)^2 2\left[\alpha\gamma_2 V(2) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right) V(1)\right] \end{array} \right\} \\
&\quad - \left\{ \begin{array}{l} p_h^2 \left[V(2) + \gamma_1 V(2) + [1-\gamma_1] V(1)\right] \\ +p_h(1-p_h) \left[V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right) V(1)\right] \\ +p_h(1-p_h) \left[\gamma_1 V(2) + (1-\gamma_1) V(1) + \alpha\gamma_1 V(2)\right] \\ +[(1-p_h)^2 \left[\alpha\gamma_1 V(2) + \alpha\gamma_2 V(2) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right) V(1)\right] \end{array} \right\} \\
&= \left\{ \begin{array}{l} p_h^2(1-\gamma_1)\left[V(1) - V(2)\right] \\ +p_h(1-p_h) \left[\left(1-\gamma_1\right)\left(V(1) - V(2)\right) + \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right)\left(V(1) - 2V(2)\right)\right] \\ +(1-p_h)^2 \frac{1}{2}\alpha\left(\gamma_1 - \gamma_2\right)\left(V(1) - 2V(2)\right) \end{array} \right\}
\end{aligned}$$

Define $\Phi(p_l) = U^E - U^D$ and note that Φ is increasing in p_l

$$\begin{aligned}
\frac{d\Phi}{dp_l} &= -2p_l U^D(2) - (2-4p_l) U^D(1) + 2(1-p_l) U^D(0) \\
&= 2p_l \left[U^D(1) - U^D(2)\right] + 2(1-p_l)\left[U^D(0) - U^D(1)\right] \\
&> 0
\end{aligned}$$

Moreover, when $p_l = p_h$ it is $\Phi(p_h) > 0$. To see this, note that

$$\Phi(p_h) = p_h^2 \left[U^E(2) - U^D(2)\right] + 2p_h(1-p_h) \left[U^E(1) - U^D(1)\right] + (1-p_h)^2 \left[U^E(0) - U^D(0)\right]$$

hence $(1-\delta)\Phi(p_h)$ is equal to

$$\begin{aligned}
& p_h^2 \left\{p_h^2 \left[V(1) - 2V(2)\right] + 2p_h(1-p_h)\left[V(1) - (1+\alpha\gamma_1) V(2)\right]\right\} \\
& +2p_h(1-p_h)\left\{p_h^2 \left[\gamma_1 V(1) - (1+\gamma_1) V(2)\right] + p_h(1-p_h)\left[\gamma_1 \left(V(1) - V(2)\right) - \alpha\gamma_1 V(2)\right]\right\} \\
= \; & p_h^4 \left[V(1) - 2V(2)\right] + 2p_h^3(1-p_h)\left[V(1) - (1+\alpha\gamma_1) V(2)\right] \\
& +2p_h^3(1-p_h)\left[\gamma_1 V(1) - (1+\gamma_1) V(2)\right] + 2p_h^2(1-p_h)^2\left[\gamma_1 \left(V(1) - V(2)\right) - \alpha\gamma_1 V(2)\right] \\
= \; & p_h^4 \left[V(1) - 2V(2)\right] + 2p_h^3(1-p_h)\left[(1+\gamma_1)\left(V(1) - 2V(2)\right) + \gamma_1 (1-\alpha) V(2)\right] \\
& +2p_h^2(1-p_h)^2\gamma_1 \left[V(1) - (1+\alpha) V(2)\right] \\
> \; & 0
\end{aligned}$$

It follows that there exists $p_l^{**} < p_h$ such that, for all $p_l \geq p_l^{**}$ it is $\Phi \geq 0$ and hence sharing knowledge is an equilibrium strategy. ■

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