Using the Threat of Disclosure to Enforce Knowledge Sharing in Joint Ventures Which Span Multiple Innovation Markets

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Abstract

This paper shows how firms can use threats of intellectual property disclosure to enforce R&D joint venture agreements. A multi-stage game is developed in which firms contract to (a) exchange knowledge and (b) coordinate the introduction of innovations to the marketplace. The question we address is whether firms can self-enforce such joint venture agreements. We find that, under some parameter configurations, such agreements are enforceable. In particular, we show that (1) joint ventures are straightforward to enforce when knowledge is readily transferable to fringe firms; (2) maintenance of a joint venture agreement is easier when at least one of the firms is small and financially constrained, and (3) the welfare effect of such R&D joint ventures is ambiguous, depending heavily on the probability that firms will be able to innovate in the absence of knowledge exchange.

1 Introduction

In the late 1980's a small R&D firm, Advent Inc., developed a software document management system, which allowed for the transformation of engineer drawings into a computer data base. Lacking the hardware and marketing capacity to actually bring a product to market, Advent went searching for a partner. They eventually found one and entered into a joint venture with the computer company Unisys. In accordance with the joint venture agreement, Advent sent a number of technical personnel to Unisys to help develop a marketable innovation. Two years later, Unisys reneged on the agreement. The reason: Unisys had decided to develop its own integrated document management system independent of Advent. Obviously, Unisys acted opportunistically, using the knowledge Advent had transferred for its own benefit.[1] In every joint venture that involves knowledge sharing and the potential development of competing innovations the possibility for this sort of opportunistic behavior exists. The question becomes, then, with such opportunism looming, why do so many firms enter into R&D joint ventures and share knowledge in the first place?[2]

The literature, which addresses this question in the context of simple contracts, gives two answers to this question: A legal answer – the threat of suit deters opportunistic breach of contract (Posner, R. [1998] and Shavell [1980]), and a reputation answer – a firm which acts opportunistically will develop a bad reputation which will, in turn, limit its ability to enter into a joint ventures in the future (Bernstein [1992], Posner, E. [1998] and Klein and Leffler [1981]). For a number of reasons, we think these answers are insufficient to explain why firms share knowledge and coordinate R&D agendas in joint ventures. First, the possibility of judicial error is quite high when it comes to interpreting complex contracts which involve the cross-licensing of complicated intellectual property rights.[3] In the face of a lot of judicial

[1]This example is taken from the facts of *Advent Systems, Inc. v. Unisys Corp.*, 925 F.2d 670 (3rd Cir. 1991).

[2]Between 1985 and 1996 there were a total of 609 R&D joint ventures registered with the U.S. Department of Justice, Bingaman [1996]. This number reflects only those ventures registered under the National Cooperative Research and Production Act of 1993. This Act provides some extra protection against antitrust scrutiny. However, since few cases are ever filed against R&D joint ventures, this number underestimates the total number of these ventures.

[3]In fact, it would be somewhat surprising if judges could understand complicated joint venture contracts. One survey of cases has shown that many judges don't even understand

error, the legal system provides little deterrence of opportunistic behavior. (Posner, R. [1998]). In fact, the case of *Advent v. Unisys* is relatively rare. Only in a few instances have firms gone to court for breach of an R&D joint venture agreement. Second, parties to an R&D joint venture are often small firms which are likely to have a high discount rate (think of the dot-coms of the world). These kinds of firms might not care very much about the future costs of developing a bad reputation.

This paper provides a different answer to the question of contractual opportunism, an answer specific to joint venture contracts. In particular, we show that the threat of disclosure of intellectual property to other firms (via public disclosure or direct transfer) is enough to prevent firms from cheating on joint venture agreements. This mechanism works even if courts are completely incompetent and firms care little about their reputations.

In our model, we consider joint venture agreements of the following sort: Two R&D firms that are ahead of the competition in two innovation markets first agree to exchange knowledge, and then they coordinate their research agendas. That is, each firm focuses on developing one of two possible innovations.

The idea behind the disclosure mechanism is simple. A leading firm which fails to share knowledge faces a credible threat by the other leading firm to have some information disclosed to other firms. This threat is credible because it is only carried out when the firm which is victim of opportunistic behavior is unable to innovate on its own. Knowledge disclosure hurts the renegade firm by inducing entry of firms which were initially lagging in the innovation markets (firms which were on the fringe). Coordination of research agendas is sustained using a two-pronged threat. First, if a firm observes its rival deviating from the coordinated scheme, then it enters and competes in the renegade's market in the subsequent period. Second, if the firm is constrained (due, perhaps, to a limited amount of research funds) to develop only one product and it observes renegade behavior, then it discloses to firms on the fringe. Both of these threats are credible and, therefore, serve as a self-enforcing mechanism for the joint venture.

Disclosure, or making information available to fringe firms, is a key feature of our model. For example, firms could disclose explicitly by publishing information in a scientific journal, or implicitly by failing to vigorously en-

the concept of present value, Allen and Staaf [1982].

force intellectual property rights.[4] Disclosure could also take the form of direct knowledge transfer to another firm (e.g., by licensing).

Our analysis generates several useful predictions.

First, when knowledge is easy to transfer to firms on the fringe, leading firms will always be able to enforce information sharing in a joint venture. On the contrary if the transfer of knowledge is difficult, then the threat to disclose will have no bite because the firms "waiting in the wings" – ready to enter an R&D race if given some knowledge – do not pose a serious threat to the renegade firm.[5] When the threat has no bite there is little incentive to adhere to the coordinated behavior – the gains from acting opportunistically outweigh the costs imposed by the disclosure punishment. Knowledge transfer depends on (a) the ability of fringe firms to innovate after acquiring knowledge from a leading firm and on (b) the number of fringe firms. Knowledge transfer is made easier either by the presence of many fringe firms, each with a low but positive probability of being able to innovate, or by the presence of a small number of large fringe firms each with a high probability of being able to innovate.

Second, we find that if knowledge is easy to transfer to fringe firms, then the threat of disclosure is typically more effective at enforcing cooperation in joint ventures when at least one of the leading R&D firms is small and financially constrained. The intuition: A small firm can credibly threaten to disclose knowledge to the fringe firms upon observing non-cooperative entry behavior. A large firm, in contrast, cannot credibly make this threat. The large firm can only threaten to enter itself into the rival firm's market upon observing non-cooperative behavior. Because disclosure to the fringe firms is generally a more severe punishment than the entry of the leading firm, enforcing the joint venture is easier. This result explains some empirical findings from the biotechnology industry. One study found that of the collaborative R&D arrangements among biotech firms, 62 percent were between large established firms and small boutique firms. In contrast, only 10.5 percent of the R&D collaborations were between two large established firms, Pisano et al [1988].

Third, we look at the welfare implications of two different kinds of joint ventures among R&D firms – ventures among firms engaged in two patent

[4]Recently, a number of results from the human genome project have been "disclosed" by R&D firms to the general public, Eisenburg [2000].

[5]We define precisely "some knowledge" in Section 5 of the paper.

races, and ventures among firms racing to develop similar innovations in two different markets. A joint venture results in (1) knowledge sharing – a societal gain because it allows for the development of a wider array of innovations – and (2) coordination of market entry decisions.

In the multiple patent race case, coordination of market entry results in a single firm racing for each patent. This eliminates the duplication of research efforts (a societal gain) but delays the expected time of innovation.[6] The extent of the social cost associated with this delay depends on the amount of consumer surplus generated under the patent monopoly. With delay, consumers receive any surplus later, and hence are worse off. In short, the welfare impact of joint ventures when firms are engaged in multiple patent races is ambiguous, depending heavily on the amount of consumer surplus the patents will render.

In the case of similar innovations, coordination of market entry decisions generates a social loss because at the end of the day there is less competition in each innovation market. Whether this effect dominates the knowledge sharing effect determines the welfare impact of the joint venture. Our model provides an analytical framework that allows for the precise weighing of the two effects. In particular, we find that if the probability that a leading firm is able to innovate when it has a low knowledge level is sufficiently high, then preventing the formation of a joint venture is welfare enhancing. That is, the social cost of the coordination of entry decisions outweighs the social benefit of information sharing.[7]

Our antitrust analysis extends and formalizes many of the insights first made by Grossman and Shapiro [1986]. In their article, Grossman and Shapiro suggest that antitrust officials look at both the upstream and the downstream markets when evaluating research joint ventures. They discuss

[6] See Loury [1979], Lee and Wilde [1980] and Reinganum [1982, 1987] for models of patent races where firms engage in duplicative R&D. On R&D races see also Denicolo [2000].

[7] This result is similar in spirit to the result found in d'Aspremont and Jacquemin [1988]. They assume that R&D coorperation provides the same unit decrease in marginal cost for all firms, and then consider the impact of R&D spillover effects and cooperation. Our model, in contrast, highlights the crucial role that the probability of innovation without knowledge sharing plays when determining the welfare effects of R&D joint ventures.

Many joint venture participants, when questioned by the antitrust authorities, claim that without the joint venture a new technology would not be developed, Justice Department Letter [1999]. Our paper provides a framework for assessing the merits of these sort of claims.

informally the efficiency effects of a reduction in competition in either market. We expand on the Grossman and Shapiro theme, looking formally at the case where an R&D joint venture results in one type of inefficiency downstream (less competition in each innovation market) and one type of efficiency upstream (i.e., knowledge sharing which then increases the chance of a successful innovation). Our analysis precisely delineates when the efficiency effect will dominate the inefficiency effect, and thus the R&D joint venture should be allowed.

The paper is broken down as follows. Section 2 develops the model. Section 3 solves the entry subgame in the innovation market assuming that each firm has an unlimited R&D budget. This section shows that firms can, under certain parameter configurations, successfully enforce joint venture contracts which coordinate innovation-market entry decisions. Section 4 looks at the sharing of knowledge among joint venture participants in the absence of fringe firms. Section 5 allows for public disclosure and/or direct transfer of intellectual property. This section specifies the conditions under which the threat of disclosure serves to facilitate knowledge sharing among R&D firms. Section 6 imposes a constraint on the ability of one firm to finance the development of an innovation – finding that joint venture agreements are easier to enforce if one firm faces such a constraint. Section 7 looks at the welfare effects of these types of R&D joint ventures. Section 8 offers some concluding remarks.

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; 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 exists n fringe firms each of which, if given a sufficient amount of knowledge, may be able to enter either market A or B. The precise notion of the fringe 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 of introducing an innovation in market j as a function of the total number of innovations.[8] To simplify the exposition we will assume symmetry

[8]One can think of the model developed in this section in two different ways. First, as a model of the strategic development of new, already patented, products. Under this

of the two markets and the firms' payoff functions: $V_i^j(m_j) = V(m_j)$ for all i and all j. A nice way to think about the model is that the two leading firms are contemplating entering into a joint venture and therefore are trying to see whether cooperation within such a venture will be enforceable without resorting to the court system.

The timing of the game is as follows: First, firms decide whether or not to privately share their knowledge about technology in the two markets. Second, each firm learns whether or not it actually can, given a sufficient amount of R&D expenditures, bring a product to market, the probability of which depends on the firm's knowledge. Third, each firm decides whether to disclose any of its knowledge to fringe firms. The choice of whether to disclose depends on the make-up of the fringe and will be addressed in detail in Section 5. Fourth, firms play a market entry game. Finally, firms must pay some fixed development cost F for each innovation they have chosen to bring to market.

2.1 The Market Entry Subgame

In our setup, if each firm is able to introduce an innovation in both markets, then the firms benefit from coordinating and each entering one market. Suppose that firms decide simultaneously and once and for all whether or not to enter an innovation market. Then each firm would always enter any market where it can introduce an innovation. The two firms would be subject to a coordination failure. In order to allow for coordinated entry decisions by the two firms, we introduce some element of repeated interaction in the entry subgame. Rather than modeling this subgame as a full-fledged repeated game, we allow each firm to make a temporary decision, observe the temporary decision made by the other firm with some positive probability, and then revise its decision. This structure will allow firms to coordinate their entry decisions provided that the probability of observing the opponents decision is sufficiently high. This approach has the additional advantage of highlighting the importance of observing the opponents actions in enforcing R&D joint

scenario, $V_i^j(m_j)$ is the oligopoly rent earned by firm i in market j when there are m_j firms in the market. Alternatively, we can think of the model as firms engaging in two R&D patent races at the same time. In this case $V_i^j(m_j)$ is firm i's expected value from participating in race j with m_j participants. Because most R&D expenditures happen after patents have been issued (see Kitch [1977]) the first interpretation is probably the most interesting.

venture contracts.

To be precise, the entry subgame is modeled as follows. First, each firm makes a simultaneous decision about whether to bring to market each of the innovations it can develop. Then, with positive probability q the game enters a revision stage, and with probability $1-q$ the game ends. In a revision stage, each firm gets to observe the choice of the rival firm and revise its original decision. If at least one firm revises its decision, then the game goes to another revision stage with probability q. If in a revision stage each firm decides not to revise its decision, then the market entry game ends.

2.2 Development Probability and the Value of Innovations

In each innovation market j, we assume that the fringe firms have no prior knowledge, while the two leading firms' knowledge level can take on two values, low or high. Without any knowledge transfer from the leading firms, the fringe firms cannot innovate in any of the two markets. Let k_j^i be the knowledge level of leading firm i in market j, $k_j^i \in \{l, h\}$ with $0 < l < h$ and $k^i = (k_A^i, k_B^i)$ be the knowledge level of firm i in the two markets. Whether a leading firm is in a position to develop a marketable innovation in market j depends on k_j^i. Naturally, firms with more knowledge have a greater probability of being able to innovate. To capture this idea in the simplest possible way, denote as $p_j^i(k_j^i)$ the probability that firm i can develop innovation j, and let the probability $p_j^i(k_j^i)$ have the following properties:

$$p_j^i(k_j^i) = \begin{cases} p & \text{if} \quad k_j^i = l \\ 1 & \text{if} \quad k_j^i = h \end{cases}$$

A leading firm with a low amount of knowledge can develop an innovation with probability p. A leading firm with a high knowledge level, on the other hand, is able to develop the innovation for sure.

A firm that is able to develop innovation j and decides to do so will obtain the innovation at cost F. In order to capture the idea that the innovations in each market are substitutes we assume that the total payoff to the firms if there are m firms in the innovation market is greater than the total payoff if there are $m+1$ firms: $m\,[V(m) - F] > (m+1)\,[V(m+1) - F]$ for all integers m. Note that if $V(m+1) > F$, then this implies $V(m) > V(m+1)$. We will assume that there exists $m^E \geq 2$ such that $V(m^E) > F > V(m^E + 1)$; m^E

is the maximum number of firms that could profitably enter the market. To make our analysis more concrete we offer the following two examples.

2.2.1 Multiple Patent Races

Let each innovation market represent a different patent race (a la Lee and Wilde [1980]). The fixed cost of entering each of the races is F. At time zero each firm decides how much to invest in research intensity, x_j^i, in each race that it has entered. Discovery occurs according to a Poisson process. The probability that a firm is successful by time t is $\Pr\{\tau(x_j^i) \leq t\} = 1 - \exp\{-h(x_j^i)t\}$; where $h(\cdot)$ is the concave hazard function. Each firm's payoff in each race it enters is thus:

$$V_j^i(x_j^i) = \int_0^\infty \left[Vh(x_j^i) - x_j^i\right] e^{-\left(\sum_{\ell=1}^m h(x_j^\ell)+r\right)t} dt - F = \frac{Vh(x_j^i) - x_j^i}{r + \sum_{\ell=1}^m h(x_j^\ell)} - F$$

where r is the discount rate, V is the total value of the patent, and the sum is taken over the m firms in the patent race. Under a stability assumption that requires that the reaction curves are not too steep (see Lee and Wilde (1980)), as the number of firms in the race increases the equilibrium research intensity, x_j^i, increases, and the expected payoff of each firm, V_j^i, decreases. The intuition: a firm in this winner-take-all market does not take into account the negative effect of its investment on the expected innovation date of its rivals.[9] Thus, under a mild assumption we can easily derive the reduced form properties of $V(\cdot)$ postulated in the previous section ($m\,[V(m) - F] > (m+1)\,[V(m+1) - F]$) from an underlying multiple patent race game.

2.2.2 A Development Game

Consider firms introducing identical innovations into two different markets. If we model the market as a symmetric Cournot oligopoly, then our reduced form assumptions on V hold. For example, with a linear demand and a 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.

[9] It is important to note that the duplication of effort in the patent race increases the expected time of innovation. Formally, $1/\sum_{\ell=1}^m h(x_j^\ell)$ decreases as the number of firms increases.

3 Enforcing Market-Entry Agreements with Two Firms

In this section, we assume that there are no fringe firms that can enter any market. This will be the case if neither of the two leading firms shares knowledge with the fringe firms. At one extreme is the case in which knowledge is difficult to transfer between the leading firms and the fringe, so that no fringe firms could enter either innovation market A or B.[10]

There are five possible types of market entry subgames between the two leading firms. In the first type, one firm is able to develop an innovation in one or both markets, while the other firm cannot develop any innovations. In the second type of subgame, one firm can develop innovations in both markets, while the other firm can develop an innovation in only one market. In the third type of subgame, one firm can develop the innovation only in market A, while the other firm can develop the innovation only in market B. In the fourth type of subgame, both firms can develop the innovation in the same market j. Clearly, all these subgames have unique subgame perfect equilibria in which each firm enters a market 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.)

The fifth subgame, when both firms are able to develop innovations in both markets, is the most interesting. In this case there are two different types of subgame perfect equilibria. In the first type of equilibrium, both firms enter both markets. In the second type of equilibrium, firms are able to coordinate: One firm enters market A and the other enters market B. This second type of equilibrium, however, only exists if the probability q that a firm can observe entry by the other firm is sufficiently high. This result is formalized in the following proposition:

Proposition 1 *When each leading firm can develop an innovation in both markets, the entry game has two types of subgame perfect equilibrium outcomes. In the first equilibrium outcome, both firms enter both markets. This type of equilibrium always exists. In the second equilibrium outcome, each*

[10] An example of this type of R&D market is the gene therapy market. The number of firms which could produce drugs useful for gene therapy, even if given the necessary intellectual property at a low-cost, is quite small. See Ciba-Geigy Limited, 62 FR 409 [1997], outlining a proposed consent order in the case of a merger between two companies engaged in gene therapy R&D.

leading firm enters a different market. This type of equilibrium exists only if $q \geq q^*$ *where* $q^* = [V(2) - F] / [V(1) - V(2)]$.

Proof. Consider the first type of equilibrium. The strategy of each firm is to enter both markets in the first stage, and not to revise its decision if the entry choice of the other firm becomes known. 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. In the first stage, firm 1 only enters race A. If the entry choice of firm 2 becomes known, then firm 1 does not revise her decision if firm 2 only entered market B, while it revises and enters both markets otherwise. Firm 2 follows a similar strategy. Equilibrium payoffs are $V(1) - F$ 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 payoff equal to $(1-q)(V(1) + V(2) - 2F) + q(2V(2) - 2F)$. This deviation is not profitable if $q \geq q^*$, where

$$q^* = \frac{V(2) - F}{V(1) - V(2)}.$$

Note that $q^* < 1$, since $V(1) - F > 2[V(2) - F]$.

It remains to be shown that there cannot be any other type of equilibrium. This follows from the fact that 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. ■

Note that if entry decisions by firms are completely unobservable, then there does not exist any equilibrium of the market entry subgame where firms can successfully enforce a contract which coordinates their innovation market entry decisions. This makes intuitive sense. If a firm cannot observe that its rival has deviated from the coordinated behavior, then it does not know when to "punish" by entering both markets. Nevertheless, this result is limited to the case of complete unobservability. In other cases, where the probability of observing entry is sufficiently high, enforcement of such an agreement is possible. Note, however, that with imperfect observability firms sometimes fail to punish when a rival deviates and enters both innovation markets. This makes deviating more attractive, which in turn makes it harder to sustain this sort of joint venture agreement.

4 Information Sharing without Knowledge Disclosure

We want to study whether it is possible for the two leading firms to form a joint venture in order to share knowledge. As we have argued before, such contractual arrangements are difficult to enforce through the court system or reputation mechanisms. In this section we focus on the possibility of self-enforcement when there are no fringe firms that could innovate after knowledge transfer from a leading firm.

At the beginning of the game, each leading firm i only has low knowledge in both markets, $k_j^i = l$ for all i and all j. For simplicity, we assume that by sharing its knowledge a firm enables the other firm to have high knowledge in both markets.[11] In the first stage, of the game firms simultaneously decide whether or not to share their knowledge. Presumably they have made a joint venture agreement and now must make sure that they benefit from it. Then, nature determines whether firms are able to develop the innovations according to the probability function $p_j^i(k_j^i)$. We will look for the subgame perfect equilibria of the game.

Proposition 2 *When there are no fringe firms, there is no subgame perfect equilibrium of the game in which firms share knowledge if* $p < p^* = [V(1) - F] / 2 [V(1) - V(2)]$*, or if* $q < q^*$*. If, on the other hand,* $p \geq p^*$ *and* $q \geq q^*$*, then there is an equilibrium in which firms share knowledge and in the entry game each firm enters a different market.*

Proof. If $q < q^*$, then 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 $q \geq q^*$, information sharing can be part of an equilibrium if and only if it induces coordination in the entry game. Suppose each firm follows the strategy of sharing knowledge and then entering one of the two markets if the rival also shared knowledge (assume firm 1 enters market A and firm 2 enters market B). However, 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

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

thus it gives us the best option to sustain knowledge sharing in equilibrium. The equilibrium payoff of this strategy for each firm is $V(1) - F$. The most profitable deviation is to fail to share knowledge; this yields the payoff

$$U^D = (1-p)^2 [2V(1) - 2F] + 2p(1-p) [V(1) + V(2) - 2F] + p^2 [2V(2) - 2F] .$$

It is easy to check that $U^D \leq V(1) - F$ if and only if $p \geq p^*$, where

$$p^* = \frac{V(1) - F}{2[V(1) - V(2)]}.$$

This concludes the proof. ■

To sustain this equilibrium each firm credibly threatens to enter each market where it can develop an innovation if the rival firm fails to share knowledge.

When $p < p^*$ or $q < q^*$ 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 innovation markets. Nevertheless, this sort of cooperation is unobtainable in equilibrium; each firm has an incentive to take the knowledge shared by its rival and then fail to return the favor. This incentive to renege makes enforcing a contract with knowledge sharing impossible.

5 Information Sharing with Knowledge Disclosure

In this section we show that knowledge disclosure to fringe firms provides a credible threat, allowing for the enforcement of knowledge sharing agreements.

Each of the n fringe firms initially has zero knowledge about both technologies, and thus cannot develop either innovation. If, however, knowledge is readily transferable to the fringe firms, then this inability can be overcome; if some knowledge is disclosed about technology A, B, or both, a fringe firm may be able to develop either innovation and thus may decide to enter into either innovation market. Intuitively, disclosure allows other R&D firms to "get up to speed." This, in turn, facilitates entry into the various innovation markets. Formally, we treat fringe firms similarly to firms 1 and 2; that is, their ability to develop an innovation depends on their knowledge level. If a fringe firm acquires a low knowledge level in a market, then it is able to innovate with probability p_F; if it acquires a high knowledge level, then it can innovate for sure. We treat fringe firms as being symmetric for simplicity, but we allow for the probability that a fringe firm with low knowledge is able to innovate, p_F, to be different from p, the probability that a leading firm with low knowledge can innovate. Two cases can be distinguished. In the first $p > p_F$ and a fringe firm with low knowledge is still at a disadvantage (i.e., less likely to be able to innovate) relative to a leading firm. In the second case $p_F > p$, the fringe firms are more likely than the leading firms to be able to innovate with a low level of knowledge. This latter case seems relevant when the leading firms in a particular innovation market are two small firms which have some proprietary knowledge or original idea, and the fringe firms are large established firms with a greater ability to develop an original idea and bring it to market.

We allow for knowledge disclosure to take place after the leading firms have learned whether they are able to innovate and before the entry game. We assume that if some knowledge is transferred, then all firms in the fringe acquire it. This is an assumption that allows us to sidestep issues of bargaining over licensing agreements between a leading firm and the fringe firms.[12] Since a leading firm will only consider disclosing knowledge if it is unable to innovate, this assumption can be justified in at least two different ways. First, the leading firm may have no bargaining power, and so it may be unable to extract any rent from the fringe firms. The best a leading firm can do in this case is simply to disclose the information to all the fringe firms. For example, if there are a large number of fringe firms, each one with a small chance of being able to innovate, none of them may be willing to pay for the licensing of the intellectual property. Second, if there is a small set of fringe firms, each of which can innovate with high probability after acquiring knowledge (p_F is close to one), then auctioning the knowledge off is the best option for a leading firm that is unable to innovate on its own. This case is formally equivalent to the case in which there is only one fringe firm, except that the leading firm will be able to extract compensation from the fringe firm winning the auction. This compensation is just a transfer between the

[12] 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], d'Aspremont et al [2000].

two firms and taking it into account would not affect any of the results in the paper.

After acquiring knowledge, and then discovering whether or not it can develop an innovation, a fringe firm participates in the entry game with the two leading firms. Suppose for example that firm 1 (or 2) reveals a low knowledge level l in race A. Then each fringe firm will be able to develop innovation A (and only innovation A) with probability p_F. Let n be the number of fringe firms. Then, the probability that exactly ℓ fringe firms will be able to innovate is

$$g(\ell, n, p_F) = \begin{cases} \binom{n}{\ell} p_F^{\ell} (1 - p_F)^{n-\ell} & \text{if} \quad 0 \leq \ell \leq n \\ 0 & \text{if} \quad \ell > n \end{cases} .$$

The probability $G(m, n, p_F)$ that at most m fringe firms are able to develop an innovation in market j, given that a low knowledge level has been disclosed in race j is

$$G(m, n, p_F) = \sum_{\ell=0}^{m} \binom{n}{\ell} p_F^{\ell} (1 - p_F)^{n-\ell} .$$

Recall that m^E is the largest integer such $V(m^E) - F > 0$; that is, m^E is the maximum number of firms that could profitably enter an innovation market. If m^E fringe firms enter market j then it is not profitable for firm 1 or 2 to also enter. Note that for any fixed m and p_F, $G(m, n, p_F) \to 0$ as $n \to \infty$, and for any given m and n, $G(m, n, p_F) \to 0$ as $p_F \to 1$. This implies that if the number of fringe firms is large, or if the probability that a fringe firm with low knowledge is able to innovate is close to one, then the probability that the profit in race A dissipates after disclosure is also large. As we will see, when disclosure is possible, an increase in n or in p_F makes knowledge sharing more likely. In the extreme cases of a very large number of fringe firms n or of a probability p_F of being able to innovate close to one, there will always be an equilibrium that involves knowledge sharing.

Suppose that firm i is the only leading firm that is able to innovate in a market. Suppose also that the other leading firm has disclosed knowledge to the fringe firms and that all the fringe firms that are able to innovate, up to m^E, enter the market. Then firm i's expected profit from this market is

$$\pi = \sum_{\ell=0}^{\min\left\{m^E-1, n\right\}} g(\ell; n) \left[V(\ell + 1) - F\right] . \tag{1}$$

The following threshold value of p will come up in the next proposition

$$p^{**} = \max\left\{\frac{2\pi - [V(1) - F]}{2\pi - 2[V(2) - F]}, 0\right\}. \quad (2)$$

Proposition 3 *If $p \geq p^{**}$ and $q \geq q^*$, then there is a subgame perfect equilibrium in which the leading firms share knowledge and each enters a different market in the entry game. In this equilibrium, knowledge is not transferred to the fringe firms. If $[V(2) - F] \geq \pi$, then there is a subgame perfect equilibrium in which the leading firms share knowledge and each enters both markets in the entry game. Again, in this equilibrium, knowledge is not transferred to the competitive fringe. If $p < p^{**}$ and $[V(2) - F] < \pi$ there is no subgame perfect equilibrium of the game in which firms share knowledge.*

Proof. First, we claim that if $p \geq p^{**}$ and $q \geq q^*$ then 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. 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 or license its knowledge in that market.
- When information was shared in the first stage and no knowledge was disclosed to fringe firms, then firm 1 enters only market A. If the entry choice of firm 2 becomes known, then firm 1 does not revise its decision if firm 2 only entered market B, while it revises and enters both markets otherwise.
- If one of the two firms did not share information in the first stage and/or knowledge was disclosed to fringe firms in a market, then firm 1 will enter any market where it can develop an innovation and only $m^E - 1$ other firms are able to innovate. If the entry choice of firm 2 becomes known, then firm 1 does not revise its decision.
- Choices at other, off-the-equilibrium-path decision nodes are not important and are omitted.

- Let m_j^D be the number of fringe firms that are able to develop innovation j. The number of fringe firms that enter innovation market j, $j = A, B$, is $n_j^E = \min(m_j^D, m^E)$, where m^E is the largest integer such $V(m) - F_j > 0$.

We now prove that the specified strategies constitute an equilibrium. 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 payoff equal to $V(1) - F$. If firm 1 does not share information, then its expected payoff is

$$U^D = 2p^2 [V(2) - F] + 2p(1-p) \{V(2) - F + \pi\} + 2(1-p)^2 \pi$$

where π is given by equation (1). It is easy to check that $V(1) - F \geq U^D$ if and only if $p \geq p^{**}$.

We now show that if $[V(2) - F] \geq \pi$ then 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, firm 1 does not disclose knowledge in any market in which it is able to innovate and it discloses in all markets in which it cannot innovate (note that for this latter case to happen firm 2 must not have shared knowledge).
- In the entry game firm 1 enters all markets where it can innovate.
- Choices at other, off-the-equilibrium-path decision nodes are not important and are omitted.
- The number of fringe firms that enter innovation market j, $j = A, B$, is $n_j^E = \min(m_j^D, m^E)$,

To see that the specified strategies constitute an equilibrium, first note that they constitute an equilibrium in each entry subgame. 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. Firm 1's equilibrium payoff is $2[V(2)-F]$. If firm 1 does not share information, then its expected payoff is

$$U^D = 2p^2[V(2)-F] + 2p(1-p)\{V(2)-F+\pi\} + 2(1-p)^2\pi$$

where π is given by equation (1). One can check that $2[V(2)-F] \geq U^D$ if and only if $V(2)-F \geq \pi$.

Finally, if $p < p^{**}$ and $[V(2)-F] < \pi$, then the threat of disclosing to the fringe firms is not sufficient to deter a leading firm from not sharing knowledge with the other leading firm. ■

In one interesting equilibrium, the leading firms both share knowledge and coordinate their entry decisions. To sustain this equilibrium, each leading firm credibly threatens to disclose information to the fringe in any market where it cannot develop an innovation, and to enter all markets where it can develop an innovation if the rival firm fails to share knowledge. This equilibrium only exists if the probability of observing the entry decision of the opponent is sufficiently high, $q \geq q^*$ and if the probability of being able to innovate with a low knowledge level is higher than a threshold value p^{**}. It is important to note that if there are no fringe firms, $n = 0$, then $\pi = V(1) - F$, $p^{**} = p^*$ and this equilibrium reduces to the equilibrium described in Proposition 2. In this case, it is only the threat of entering in all markets that may sustain knowledge sharing. The threshold value p^{**} decreases in the number of fringe firms n and the probability that a fringe firm is able to innovate p_F. In the extreme case of $n = \infty$ or $p_F = 1$, we have $\pi = 0$ and $p^{**} = 0$.

In another interesting equilibrium the leading firms share knowledge, but they enter both innovation markets – i.e., they cannot sustain coordinated entry as part of the joint venture agreement. This equilibrium is enforced by the threat to disclose information to the fringe. For this equilibrium to exist, a leading firm's expected profit in a market in which the other firm has disclosed information to the fringe firms must be sufficiently low, $\pi \leq V(2) - F$. Note that if there are no fringe firms, $n = 0$, then $\pi = V(1) - F$, and this equilibrium does not exist. The value of π decreases in the number of fringe firms n and the probability that a fringe firm is able to innovate p_F. Thus, in both equilibria where knowledge sharing agreements are enforceable the disclosure threat works better if the firms "waiting in the wings" – ready to enter either innovation market if given the right amount of knowledge – are either more numerous (in which case public disclosure facilitates entry) or better able to develop an innovation with a low knowledge level (in which case licensing facilitates entry). Obviously, whether or not these conditions actually hold varies from market to market – depending heavily on the kind of innovation.

6 Information Sharing between Small Leading Firms

In this section we study the case in which at least one of the leading firms is small. Two features of the model may need to be changed to cover this case. First, a small leading firm may be constrained, perhaps due to a binding R&D budget constraint, to enter only one innovation market. Second, there may be a few large fringe firms - waiting in the wings - that would be tougher competitors in the innovation markets than the leading firm itself, if knowledge was transferred to them. To deal with these issues, we will modify the model by allowing a firm to disclose knowledge to the fringe firms not only after it becomes known whether the firm can develop an innovation, but also in the market-entry subgame. In other words, we allow a firm two opportunities for disclose. Once disclosure has taken place, the leading firms can revise their entry decisions after observing which of the fringe firms is able to innovate. We will show that in this case the enforcement of coordinated entry in the innovation markets is still possible; in fact it is generally easier, because it can be supported by the threat of disclosure to the fringe firms, as opposed to the threat of entry by the leading firm.

We begin by assuming that a leading firm has limited R&D financing; that is, it only has the funds to develop one innovation. Note first that if both firms have a limited R&D budget, entry coordination and knowledge sharing are trivially sustained because these constraints are binding. That is, neither firm can deviate and enter both innovation markets. Now consider the case in which only one firm has limited R&D funds. We will see that the threat to disclose to the fringe can support coordination of innovation market entry decisions.[13]

[13] Note that in the case of no financing constraint which we have analyzed in the previous

Proposition 4 *Suppose both leading firms can develop the innovations, but one firm has limited R&D funds. If* $q \geq q^{**} = [V(2) - F] / [V(1) - F - \pi]$, *then in the innovation entry subgame there exists an equilibrium where the leading firms coordinate research agendas; that is, each firm only enters one market. If* $q < q^{**}$ *then there is no equilibrium in which the firms coordinate research agendas.*

Proof. Without loss of generality, suppose firm 1 is the firm with limited R&D funds. Strategies which support this equilibrium are as follows: Firm 1 enters market A only and does not disclose knowledge to the fringe. If the entry choice of firm 2 is observed, and firm 2 has entered market A, then firm 1 discloses knowledge in market B to the fringe firms. If firm 1 observes that firm 2 did not enter market A, then firm 1 does not revise its strategy. Firm 2's strategy is to enter market B only. Up to m^E fringe firms enter, if they are able to innovate in a market.

To see that these strategies constitute an equilibrium, note first that firm 1, because of the limited R&D funds, cannot deviate and enter both markets. Firm 2's equilibrium payoff is $V(1) - F$. Firm 2's best possible deviation is to enter both markets unless (i) its entry in market A is observed by firm 1, and (ii) as a result of firm 2's decision to disclose at least m^E fringe firms are able to innovate. The payoff from this deviation is

$$U^D = (1 - q)(V(1) + V(2) - 2F) + q(V(2) - F + \pi).$$

Thus, deviating is not profitable if $q \geq q^{**}$. Under this condition the threat to disclose by the firm with limited resources is credible and entry coordination occurs in equilibrium. Note, that $q^{**} < 1$ for a sufficiently large n or for a p_F sufficiently close to 1. ■

With limited financing, disclosure serves an additional function, allowing small, financially constrained R&D firms to enforce joint venture contracts with large unconstrained R&D firms. The contracts are enforced by the threat of the leading firm with limited R&D funds to disclose to the fringe firms if the rival firm deviates and enters both innovations markets. It is simple to show that Proposition 3 extends to the case of a financially constrained

section, a firm that is able to innovate would never want to disclose to the fringe firms at the market-entry stage. When a firm is able to innovate, disclosure is dominated by entry in a market.

firm, with q^* replaced by q^{**}. Thus, there is an equilibrium with information sharing and coordination of research agendas, provided that $q \geq q^{**}$ and $p \geq p^{**}$. Note that $q^{**} < q^*$ if and only if the following inequality holds

$$\pi < V(2) - F. \tag{3}$$

This inequality is certainly satisfied if there are a large number of firms (n is large) and knowledge transfer takes the forms of public disclosure. In that case $\pi \to 0$ as $n \to \infty$, and thus $q^{**} < q^*$; it is easier – a lower probability of observability is needed – to enforce joint venture contracts between a small R&D firm and a large R&D firm than between two large R&D firms. The rationale is: A large R&D firm cannot credibly threaten to disclose to the fringe firms upon observing non-cooperative entry behavior. The most severe threat that the large firm can credibly make is to enter itself in the rival's market. Because a small firm can punish "more" than a large firm, the small firm needs to be able to observe deviations less frequently.

On the contrary, inequality (3) does not hold if knowledge is auctioned off and, as a result, licensed to a single firm. In that case $\pi = p_F[V(2) - F]$. However, it is realistic to assume that in this case the fringe firm winning the auction would be a large firm - a tougher competitor in the innovation market than the small leading firm. This leads us to the second modification of the model. We now assume that fringe firms are large, and that if a fringe firm enters a market it becomes a tough competitor for a leading firm that has also entered. Formally, this can be captured by assuming that the leading firm only obtains a payoff $\lambda V(2) - F$ from an innovation market when it competes with a fringe firm, where $\lambda < 1$. If we maintain the assumption that one of the leading firms is financially constrained, then Proposition 4 holds with q^{**} replaced by q^{***} (the proof is identical)

$$q^{***} = \frac{V(2) - F}{V(1) - p_F \lambda V(2) - (1 - p_F)F}.$$

Note that $q^{***} < q^*$ provided that

$$\lambda < \frac{V(2) - (1 - p_F)F}{p_F V(2)},$$

which holds for p_F sufficiently close to 1. Thus, for p_F close to 1, the threat to license to a competitively tough, large, fringe firm is more severe than the entry threat of a small leading firm. When the leading firm is financially constrained, this threat to license is credible and it makes coordinated entry easier to enforce. Note that this threat may also be credible when the two leading firms are small, but not financially constrained. The reason why the threat may be credible is that the leading firm may be able to extract more surplus from the fringe firm through a licensing fee than what it would obtain by entering directly.

7 Welfare Implications

In this section, we study the welfare implications of the equilibria in which firms share knowledge. First, note that knowledge sharing is always beneficial to consumers, because it increases the probability that the firms are able to innovate (our simplifying assumption is that the leading firms are always able to innovate if they share knowledge). This implies that the highest total welfare is obtained either in the equilibrium in which the leading firms share knowledge but do not coordinate their entry decision (which only exists if $V(2) - F \geq \pi$), or in the equilibrium in which the leading firms share knowledge and coordinate to each enter a different market (which only exists if $p \geq p^{**}$ and $q \geq q^{*}$, or $q \geq q^{**}$ if a firm is financially constrained). We will assume that the conditions under which these equilibria exist are satisfied. While it is clear that the antitrust authority should always encourage knowledge sharing, it is an open question whether it should prevent coordination in the entry decision. A related question is the following. Suppose that coordinated entry reduces welfare, but that the antitrust authority can only prevent it by not allowing the leading firms to form a joint venture and thus also not letting them share knowledge. Should the antitrust authority prevent the firms to form a joint venture in such a case? In the remaining portion of this section we will provide answers to these questions using the specification of the model provided by the two examples in Section 2.

Let $W(1)$ be total welfare if only one firm enters each market and $W(2)$ be total welfare if 2 firms enter in each market. The antitrust authority should prevent coordination of the entry decision if $W(2) > W(1)$. Suppose now that the only option to prevent entry coordination is to stop formation of a joint venture, thus also preventing information sharing. In this case, a leading firm is able to innovate in a market only with probability p; thus, total expected welfare if formation of a joint venture is prevented is

$$W^N = p^4 W(2) + 2p^3(1-p)\left[W(2) + W(1)\right] +$$

$$\begin{aligned} & p^2(1-p)^2\left[4W(1)+W(2)\right]+2p(1-p)^3W(1) \\ = \;& p^2W(2)+2p(1-p)W(1) \end{aligned}$$

On the other hand, total expected welfare under a joint venture and entry coordination is $W(1)$. Thus, the antitrust authority should prevent a joint venture to form if $W^N > W(1)$ or

$$\left[W(2)-2W(1)\right]p^2+2W(1)p-W(1)>0,$$

which reduces to the condition

$$p > p^{***} = \frac{W(1)-\sqrt{W(1)\left[W(2)-W(1)\right]}}{2W(1)-W(2)}. \tag{4}$$

This condition is quite intuitive, if the probability that a leading firm is able to innovate when it has a low knowledge level is sufficiently high, then preventing the formation of a joint venture is welfare enhancing. In such a case the social cost of collusion of entry decisions is not worth the social benefit of information sharing.

7.1 Multiple Patent Races

Suppose that after forming a joint venture the leading firms share knowledge and each compete in only one of the two races. In patent races consumer surplus has a temporal dimension. When there is competition, consumers benefit because each of the innovations reaches the market sooner (see footnote 9). But there is a downside to competition, duplicative research efforts (see Loury [1979], Lee and Wilde [1980], and Reinganum [1987]). As a result, the net effect of a joint venture and research coordination on total welfare is unclear. Given a common discount rate of r, and monopoly profit V in each innovation market, total expected producer surplus when the two firms race in both markets is

$$PS(2) = 4\int_0^\infty \left[Vh(x^*)-x^*\right]e^{-(2h(x^*)+r)t}\,dt-4F$$

where x^* is the symmetric equilibrium investment level by each firm in each race. Let S be consumer surplus at each point in time after an innovation has been introduced in a market (under a patent monopoly). Thus, total expected consumer surplus when the two firms race in both markets is

$$CS(2) = 2 \int_0^\infty 2h(x^*)s\, e^{-(2h(x^*)+r)t}\, dt$$

and total welfare with two firms racing in both markets is

$$W(2) = 4 \int_0^\infty \left[(V+S)\, h(x^*) - x^*\right]\, e^{-(2h(x^*)+r)t}\, dt - 4F.$$

Total expected producer surplus when the two firms coordinate and each races alone in an innovation market is

$$PS(1) = 2 \int_0^\infty \left[V h(x^C) - x^C\right]\, e^{-(h(x^C)+r)t}\, dt - 2F.$$

where x^C is the equilibrium investment level by each firm when it is the only competitor in a race to innovate (recall that $x^C < x^*$). When the two firms coordinate, total expected consumer surplus is

$$CS(1) = 2 \int_0^\infty Sh(x^C)\, e^{-(h(x^C)+r)t}\, dt$$

and total welfare is

$$W(1) = 2 \int_0^\infty \left[(V+S)\, h(x^C) - x^C\right]\, e^{-(h(x^C)+r)t}\, dt - 2F$$

Total welfare increases with a patent race joint venture if $W(1) > W(2)$. This may or may not be the case. Typically $PS(1) > PS(2)$ (society gains when firms coordinate in a multiple patent race game because coordination eliminates the duplication of research efforts). Nevertheless the joint venture reduces consumer surplus ($CS(2) > CS(1)$) because it delays the introduction of both innovations. The welfare impact of such ventures depends on which effect dominates.

7.2 A Development Game

In this example, the leading firms introduce identical innovations in each market. Let $p(Q)$ be the inverse market demand and $c(Q)$ be the non-decreasing marginal cost (the same for both firms); total welfare under information sharing and entry coordination (i.e., a monopoly in each market) is

$$W(1) = 2\int_0^{Q_M} [p(Q) - c(Q)]\, dQ - 2F$$

where Q_M is the monopolist's output.

Total welfare when each of the leading firms enter both innovation markets (i.e., firms fail to enforce the joint venture) is

$$W(2) = 2\int_0^{2Q_D} p(Q)dQ - 4\int_0^{Q_D} c(Q)dQ - 4F$$

where Q_D is the output produced in one market by one firm. Since $2Q_D > Q_M$ and $c'(Q) \geq 0$, it is clear that $W(2) > W(1)$.

If, for example, we have linear demand ($p = A - bQ$), a constant marginal cost of production c in both markets, and $F = 0$, then $W(2) = 4\,(A-c)^2/9b$ and $W(1) = (A-c)^2/4b$. Total welfare is less when the firms contract to enter only one development market each. This is due to the deadweight loss associated with the monopoly in each market. Thus the antitrust authority would like to discourage the leading firms from coordinating (i.e., colluding) at the entry decision stage. Furthermore, using equation (4) we see that

$$p^{***} = \frac{9 - \sqrt{63}}{2}$$

When $p > p^{***}$ the antitrust authority should stop the leading firms from forming a joint venture, even at the cost of preventing knowledge sharing and running the risk that some innovations are not introduced.

8 Concluding Remarks

The model developed in this paper shows how firms might enforce joint venture contracts which involve the sharing of knowledge and the coordination of entry decisions in innovation markets. The simple threat of disclosure is enough to deter the opportunistic breach of an R&D joint venture contract.

Some insights gained from the model are: (1) Enforcing contracts which dictate market entry decisions is less likely to occur if entry into the various R&D markets is difficult to observe (for example, if entry into an R&D market does not require a significant capital or labor expenditures). (2) If the R&D firms are small and financially constrained and cannot enter many markets at the same time, then enforcing joint venture contracts that coordinate entry in the markets is easier because the threat of disclosure typically has more bite. (3) If the technology is difficult to transfer (i.e., p_F is low and there are only a few R&D fringe firms), then firms will have difficulty enforcing joint venture contracts which specify knowledge sharing. (4) If the competitive fringe is composed of many firms each one of which has a small probability of being able to innovate, then the disclosure punishment will take the form of public disclosure to all fringe firms. Alternatively, if the competitive fringe is composed of a small number of firms each of which can innovate with a high probability (p_F is high), then the disclosure punishment will take the form of licensing to a single firm. In both cases enforcing knowledge sharing is possible. (5) If the 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. Only if the leading firms have a low probability of being able to innovate without sharing knowledge should the antitrust authority allow a joint venture.

In this paper, we have focused on substitute innovations. The story is different when innovations are complementary, so that the payoff to a leading firm that innovates in a market is higher if the other firm also innovates: $V(1) < V(2)$. In this case, 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.

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