# HOW TO LICENSE INTANGIBLE PROPERTY*

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We examine the optimal licensing strategy of a research lab selling to firms who are product market competitors. We consider an independent lab as well as a research joint venture. We show that (1) demands are interdependent and hence the standard price mechanism is not the profit-maximizing licensing strategy; (2) the seller's incentives to develop the innovation may be excessive; (3) the seller's incentives to disseminate the innovation typically are too low; (4) larger ventures are less likely to develop the innovation, and more likely to restrict its dissemination in those cases where development occurs; and (5) a downstream firm that is not a member of the research venture is worse off as a result of the innovation.

## I. INTRODUCTION

The introduction of new products and lower cost means of manufacturing existing products are important elements of industry conduct and performance. Market economies largely rely on private development and dissemination of product and process innovations. In order to give private agents incentives to engage in costly research and development activities, intellectual property rights, such as patents, copyrights, and trademarks, are assigned to innovators. These property rights include the right to sell or license innovations for use by other firms. Even absent patent protection, owners of intangible assets have the right to keep their innovations or technical know-how secret, and they may demand payments from other firms in return for divulging these secrets. Rostoker's [1984] survey of 37 American firms found that 68 percent of the licensing agreements involved at least some information not subject to patent protection (i.e., know-how and trade secrets).

There are two issues that arise under a system of private development and dissemination. First, are successful innovations disseminated to the socially optimal extent? In some cases successful innovations are disseminated through R&D spillovers or imitation, where the innovator has little control over the extent of the sharing. In many other cases innovations are shared as a

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result of explicit sales such as licensing or a cooperative research agreement. The licensing and sale of intangible property to foreign firms (including subsidiaries of American firms acting as licensees) accounted for almost eight billion dollars of revenues for United States' corporations in 1984 alone.[1] Although comparable data are not available for domestic licensing by American firms, the limited evidence that we have found suggests that the dollar volume of trade is on a similar scale.[2] Caves, Crookell, and Killing [1983] found that licensees acquired intangible assets both to improve existing products and to diversify into new products.

Recently, several authors have explored the incentives to share innovations. Katz [1985] analyzes cooperative research agreements. Gallini and Winter [1985], Gallini [1984], and Katz and Shapiro [1985b] examine the incentives to license a process innovation in a duopolistic product market where the innovation is owned by one of the producers. Kamien and Tauman [1986] examine the licensing of a process innovation to an arbitrary number of firms in a linear demand, Cournot example. In general, these papers support the view that the social incentives to license exceed the private ones.

A second issue that arises under a system of private development and dissemination is whether firms have socially optimal incentives to conduct research and development activities. There is a large literature (see, for example, Dasgupta and Stiglitz [1980] and Lee and Wilde [1980]) examining private development incentives in the absence of licensing. It is important to extend these models to include the effects of licensing. In markets where licensing is feasible, the revenues from licensing may be a substantial component of the incentives to engage in research and development activities. In their survey of British licensors, Taylor and Silberston [1973, p. 163] found that firms collected license and royalty fees equal to approximately 12 percent of their overall R&D expenditures. In a duopoly context we have examined the effects of licensing on the incentives to develop a

1. *Survey of Current Business* [March 1985, p. 41]. This number understates the true value of trade in intangibles to the extent that the U.S. corporate income tax motivates companies to set artificially low transfer prices in selling to their foreign subsidiaries.

2. Wilson [1977] reports that, in 1971, domestic licensing receipts accounted for 44 percent of total licensing receipts by U.S. firms. In contrast, Japanese domestic receipts were only 23 percent of total Japanese receipts. Rostoker [1984, p. 63] found that firms in his sample tended to license twice as often to domestic firms as to foreign firms during 1975–1980.

process innovation in Katz and Shapiro [1985b], and on the timing of innovation in Katz and Shapiro [1985c].

In this paper we focus on the incentives of a research lab to develop an innovation and then to license it to firms in a downstream oligopoly. We consider both an independent lab and a research joint venture. Our model of the innovation and the form of downstream imperfect competition is very general, and goes well beyond the case of a process innovation in a homogeneous good industry. We also extend the literature by considering more sophisticated selling strategies than those allowed by earlier authors.

Given that the potential purchasers of the licenses are competitors in the downstream market, their demands for the licenses may be interdependent. Interdependencies will be present if the new technology alters the marginal costs of producing the current product, or if it permits the production of a new substitute product. In such cases, one firm's willingness to pay for a license will depend upon how many of its rivals are obtaining licenses. If the seller merely sets a (uniform) price and allows the buyers to choose quantities, then the seller does not have to consider the interdependencies explicitly; the market demand function contains all of the information that the seller needs to calculate the optimal price. We show, however, that a simple uniform price strategy is not optimal when demand interdependencies are present.

We focus on a research lab that has the following class of licensing strategies available. The licensor can announce that it will sell (no more than) some fixed number of licenses, each subject to a minimum bid. Setting the number of licenses *offered* equal to the number of downstream firms and setting a single positive minimum bid is equivalent to a pure price strategy. After describing the model in Section II, we show in Section III that the developer in general can earn higher profits by restricting the number of licenses offered for sale (even when all of the downstream firms are identical).

When analyzing licensing, it is important to distinguish two basic patterns of intangible property ownership, both of which arise in practice. The first pattern is that of a developer who has no financial interest in the downstream firms—for example, a domestic firm that licenses its technology to foreign firms in a market where it has no presence. The second pattern is that of a development lab owned by one or more of the downstream firms. A firm that licenses its technology to a foreign subsidiary (and, possibly, to other firms in the foreign market as well) is an example of this pattern of vertical relations. So, too, is the case of a research joint venture. Much of our analysis is concerned with analyzing the effects that the pattern of ownership has on the market outcome.

Having characterized the form of the optimal selling strategy for both the independent developer and the research joint venture in Section III, we examine the extent to which the seller disseminates the innovation in Section IV. We show that as the number of downstream firms that own the development lab increases, the number of firms receiving the technology decreases. We also give conditions under which a private developer will issue fewer than the socially optimal number of licenses.

In Section V we analyze the seller's incentives to develop the innovation given that profit-maximizing licensing will be feasible after development. We show that, because the innovator is able to play the potential licensees off against one another, all downstream firms who are not owners of the research lab (but who may purchase a license) are worse off as a result of the development. In other words, the gains to the licensor exceed the change in the profits (gross of licensing fees) of the downstream industry. The private incentives to innovate may thus be greater or less than the social incentives, depending on the relative magnitudes of the gain in consumer surplus (which the licensor ignores) and the rent transfer between the licensees and the licensor (which the licensor counts as a benefit).

While auctions with a fixed number of units, each subject to a minimum bid, are a rather broad class of licensing mechanisms, there do exist more general mechanisms. Implicitly, the analysis to this point assumes that the upstream supplier cannot extract payments from firms that do not receive licenses. In Section VI we relax this assumption and characterize a licensing strategy that yields the greatest possible profits to the innovator given the property rights of the downstream firms. This strategy entails the innovator charging an entrance fee for an auction of the form considered above, where the size of the entrance fee is contingent on the number of firms that pay it. We show that most of our earlier results continue to hold when one allows for an arbitrarily general form of licensing mechanism. There is a short conclusion summarizing our results and placing the problem within the context of the general problem of interdependent demands.

## II. The Model

### *Assumptions and the Auction Mechanism*

We consider an industry where there is an upstream monopolist selling an input that can be used by producers in a downstream industry composed of $n$ firms. For simplicity, we shall assume that the upstream firm has access to an infinite supply of the input at zero marginal cost. It is trivial to extend the analysis to the case of constant, positive marginal cost. The input can be thought of as access to some central facility, the right to use an industry standard, or a license to use an innovation. In all of these examples, the fixed costs of supplying the input must already have been expended. We shall emphasize the innovation interpretation.[3]

A key assumption underlying our analysis is that each downstream firm has use for at most one unit of the input, i.e., only one license for a given patent. Thus, we can speak of a downstream firm as either purchasing the input or not. We also assume that the downstream firms are identical.

Assumption 1. Each downstream firm has use for only one unit of the input.

Assumption 2. All $n$ downstream firms are identical.

Given symmetry, a firm choosing its bid or reservation price is concerned only with the total number of firms purchasing the input—not the competitors' identities. Moreover, the performance of the market is summarized entirely by the number of downstream firms purchasing licenses, $k$. Let $W(k)$ denote the profits of a firm that "wins" a unit of the input (i.e., adopts the innovation) in a market where a total of $k$ firms have done so. Similarly, let $L(k)$ denote the profits of a "loser" (i.e., a firm that has not adopted the innovation) in a market where $k$ other firms have obtained the input. These profit levels are gross of any fees paid to the upstream firm. We are implicitly assuming that the licensing contracts are fixed fee contracts, so that the behavior of a downstream firm, as determined by its marginal cost curve, depends only on whether it has a license. The restriction to fixed fee li-

3. With this interpretation, the marginal cost of supplying the input, i.e., a patent license, to an additional firm would comprise the contracting costs and any technology transfer costs.

censes is a natural one in cases where the licensor cannot observe the licensees' output levels. Given this informational asymmetry, licensing contracts with per-unit royalties are not enforceable.

Our assumption about payoffs is quite weak, and encompasses a wide range of downstream oligopoly behavior.

ASSUMPTION 3. (a) A downstream firm without a license is worse off when an additional competitor acquires a license, i.e., $L(k) \leqslant L(k-1)$; and (b) the profits (gross of license payments) of a downstream firm with a license are higher than those of a firm without one, i.e., $L(k) < W(k)$.

Assumptions 1, 2, and 3 will be maintained throughout the analysis.

We characterize the optimal licensing strategy among the following class of sales mechanisms. The upstream supplier of the input runs a $k$-units, sealed-bid auction with a minimum bid of $\underline{b}$, where $\underline{b} \geqslant 0$.[4] That is, the upstream firm makes available $k$ licenses subject to the buyers paying at least $\underline{b}$ for each. We assume that each firm submits a bid for a single license.[5] Faced with mechanism $(k,\underline{b})$, the downstream producers, $i = 1,2,\ldots,n$, submit bids $b_1,\ldots,b_n$. For a given set of bids, the highest bidder receives the first unit, for a fee equal to its bid, provided that its bid is greater than or equal to $\underline{b}$. Then the second highest bidder receives a unit, paying its bid if its bid exceeds or equals $\underline{b}$. This process continues until either $k$ firms have received units or there are no remaining bids meeting the minimum bid requirement. If there are ties in bidding for the last unit, they are resolved by a random choice among the tied bidders.

This class of sales mechanisms includes several familiar forms as special cases. We shall speak of these sales strategies as auc-

4. There is an extensive literature dealing with auctions in markets where there are *indirect* interdependencies induced by the inferences that buyers draw from the behavior of other bidders. With imperfect information, the willingness of one agent to pay for the innovation may depend on the observed "demands" of other agents. Our concern in this paper is with *direct* demand interdependencies, where the value of the product to a given buyer depends upon the number of others who receive it. We focus on these direct effects by assuming that all potential buyers have complete and perfect information.

5. We are restricting the selling mechanism by only allowing each firm to bid for at most one license. We have constructed examples in which "sleeping licenses" (i.e., a single downstream firm buying multiple licenses for a given innovation) can be used to raise the seller's profits. We do not consider sleeping licenses here, both because they would be a blatantly anticompetitive and because they will not arise in the more general auction mechanism that we examine in Section VI.

tions, but an equivalent interpretation is that the innovator sells licenses at a uniform price with the contractual obligation to sell no more than $k$ licenses. $\underline{b} = 0$ and $k = 1$ corresponds to a first-price, sealed-bid auction for a single license. $k = n$ and $\underline{b} > 0$ corresponds to offering licenses at a set price of $\underline{b}$. It is useful to think of the mechanism $(k,0)$ as a *quantity* sales strategy, and the mechanism $(n,\underline{b})$, as a (pure) *price* strategy.

Given a sales mechanism $(k,\underline{b})$, we look for the Nash equilibrium in the bidding game among potential buyers. In other words, the downstream producers choose their bids taking the bids of other producers as given. Firm $i$'s maximum willingness to pay for the good, $\overline{b}_i$, is given by

$$\overline{b}_i = W(k^i) - L(k^{-i}), \tag{1}$$

where $k^i$ is the number of producers (including firm $i$) who purchase licenses if firm $i$ does, and $k^{-i}$ is the number of other producers who buy licenses if firm $i$ does not. $k^i$ and $k^{-i}$ may or may not be equal. Equation (1) demonstrates the importance of the firm's expectations about its competitors' purchase behavior; demands are interdependent.

Note that in any bidding equilibrium all downstream producers who purchase licenses pay the same price. If not, the winning firm making the highest bid could lower its offer slightly and continue to receive the innovation.

## III. THE FORM OF THE PROFIT-MAXIMIZING SALES STRATEGY

We can now characterize the selling mechanism that maximizes the upstream supplier's objective function. For each selling strategy $(k,\underline{b})$, the supplier calculates the bidding equilibrium, where the downstream firms take $(k,\underline{b})$ as given. The upstream supplier then chooses the selling strategy that induces the bidding equilibrium that yields the highest level of the seller's objective function.

The behavior of the upstream supplier (whom we shall also call the innovator) depends upon the pattern of its ownership. We consider two patterns of ownership. First, the innovator may be owned entirely by agents having no financial interest in any of the downstream firms. We shall call such a supplier an *independent researcher*. Alternatively, the innovator may be owned by one or more of the oligopolists in the industry to which the patent licenses are sold. We shall call an innovator that is jointly and equally owned by $m$ downstream firms an *m-firm research joint venture*.[6]

*An Independent Research Lab*

Our first observation is that the independent lab should use a quantity selling strategy if it is not licensing to all of the oligopolists. If $k < n$ licenses are sold using the quantity strategy $(k,0)$, each buyer knows that $k$ licenses will be sold, whether he purchases one or not. Hence, by equation (1) competition among the buyers will drive the winning bid up to $W(k) - L(k)$. If $k$ licenses are sold using the price mechanism $(n,\underline{b})$, however, each buyer knows that only $k - 1$ licenses will be sold if he declines to buy. In this case the highest price that the seller can earn is $W(k) - L(k - 1) \leqslant W(k) - L(k)$. The use of a pure price strategy is strictly *inferior* to the pure quantity strategy when the innovator sells fewer than $n$ licenses and $L(\cdot)$ is strictly decreasing. The price mechanism is not in general a profit-maximizing selling strategy when there are demand interdependencies.

In fact, a profit-maximizing seller has no need to impose a strictly positive minimum bid, unless it sells the input to all of the downstream firms. No buyer ever would pay more than $W(k) - L(k)$ to be one of $k$ licenses. A pure quantity strategy $(k,0)$ is at least as good as a combination strategy, $(k,\underline{b})$, for $\underline{b} > 0$; the strategies $(k,0)$ and $(k,\underline{b})$ are equivalent for $\underline{b} \leqslant W(k) - L(k)$. Hence, we can think of the innovator as selling licenses at $W(k) - L(k)$ each, so long as he can commit himself to selling no more than $k$ licenses.[7] The fact that the innovator can set $\underline{b} = 0$ shows also that the seller need not offer the input to more firms than will buy it in equilibrium.

The nonoptimality of a uniform price mechanism does not arise due to screening or price discrimination as in the nonuniform pricing literature. And the incomplete information issues raised in the standard auction literature are not the cause. Rather, it is the fact that a quantity restriction can be used to influence a downstream firm's expectations about the number of other firms purchasing licenses. With a quantity strategy, each bidder knows that if he fails to submit a winning bid, not only will he be left

6. In practice, the patentee could be owned jointly by independent firms and by some of the oligopolists. In this case the different types of owners of the patent may fail to agree on the optimal licensing strategy. When there is not a coincidence of interests among the owners, it is necessary to develop an explicit model of corporate governance—a task that we do not propose to undertake here.

7. If the seller cannot commit to limiting future license sales, he will always sell $n$ licenses and earn $n\{W(n) - L(n - 1)\}$.

out in the cold, but another firm will obtain the license he would have bought.

What if the upstream supplier wants to sell the input to all $n$ firms? When $n$ licenses are offered, the bids of other firms do not affect whether a given firm's bid will be successful. Hence, each firm will bid at most $\underline{b}$. A positive minimum bid is necessary for profit maximization; a minimum bid of zero will yield no revenues.

To say more about the outcome when the seller offers $n$ licenses for sale and uses a minimum bid, it is useful to introduce some further notation for the downstream profit functions. Define

$$V(k) \equiv W(k) - L(k - 1) \qquad k = 1,2, \ldots, n,$$

where $V(k)$ is the value of purchasing a license, given that $(k - 1)$ others are doing so. Whether $V(k)$ increases or decreases with $k$ reflects the nature of the downstream industry.

We begin with the case in which $V(k)$ decreases with $k$. $V(\cdot)$ decreasing reflects a situation where a given firm finds a license *less* valuable if more of its rivals purchase one. Many oligopoly models have the property that $V(\cdot)$ is decreasing. Consider, for example, a homogeneous good, linear demand, Cournot model in which the innovation reduces (constant) marginal costs.[8] In this example it is easy to check that $V(k)$ is strictly decreasing with $k$. Essentially, the value of a license to a process innovation is proportional to the licensee's output. This output, in turn, is lower if the licensee's rivals produce more output themselves, as they will if more of them own licenses.

If the upstream supplier does sell to all $n$ downstream firms, each firm knows that it cannot be replaced if it drops out of the bidding. Thus, the highest minimum bid that could possibly induce all $n$ firms to purchase licenses is $\underline{b} = W(n) - L(n - 1) = V(n)$.[9] For $V(k)$ decreasing in $k$, a sales strategy of $(n,V(n))$ will, in fact, induce all $n$ firms to purchase a license. The patentee earns $nV(n)$.

We turn next to the case in which $V(k)$ is increasing with $k$. This relationship is likely to hold, for example, if the innovation establishes a new industry standard or if the input is access to

8. Kamien and Tauman [1986] have studied the use of price strategies in this case.

9. Throughout the analysis we assume that whenever the buyers are indifferent between two equilibria, the seller's preferred equilibrium obtains. Clearly, the seller could lower the minimum bid by some $\varepsilon > 0$ so that buyers will strictly prefer to buy. We ignore the trivial "open set problem" that this would lead to.

some central facility. In such cases, the payoff to obtaining a license (or access to the facility) is greater when more rivals do so, a type of agglomeration effect. This effect is seen most clearly in the "pure networks" case where the input is a new industry standard and $W(k+1) > W(k)$.[10] Then $V(k+1) - V(k) = \{W(k+1) - W(k)\} + \{L(k-1) - L(k)\}$, which is positive by Assumption 3a.

If $V(\cdot)$ is increasing, a type of "instability" arises when the seller sets $(n,\underline{b})$. Each firm $i$ finds it more important to submit a successful bid if more of its rivals do so. This "instability" implies that there can be no equilibrium with $0 < k < n$ licenses sold, given the mechanism $(n,\underline{b})$. If such an equilibrium did exist, a firm with a license would want to reduce its bid unless $W(k) - L(k-1) \geq \underline{b}$, i.e., $V(k) \geq \underline{b}$. But a firm without a license would prefer to have one (at the offered price $\underline{b}$) unless $W(k+1) - L(k) \leq \underline{b}$, i.e., $V(k+1) \leq \underline{b}$. These conditions together give $V(k+1) \leq \underline{b} \leq V(k)$, which contradicts the fact that $V(\cdot)$ is increasing.

When $V(\cdot)$ is increasing and the seller uses mechanism $(n,\underline{b})$, there may exist multiple bidding equilibria with $k = 0$ and $k = n$. A necessary and sufficient condition for an equilibrium at $k = n$ is $V(n) \geq \underline{b}$, while $V(0) \leq \underline{b}$ gives rise to an equilibrium at $k = 0$. When there are two bidding equilibria given $(n,\underline{b})$, all of the downstream firms strictly prefer the equilibrium with $k = 0$ (resp. $k = n$) if $\underline{b}$ is greater (resp. less) than $W(n) - L(0)$.

There are two approaches to take regarding these multiple equilibria. Our approach is to assume that the buyers choose the equilibrium at $k = n$ when multiple equilibria exist. We make this assumption to capture the fact that the seller could induce this outcome as the unique bidding equilibrium by using a slightly more general selling mechanism than the one described above. In particular, if the seller could offer $n - 1$ licenses at minimum bid 0, but the $n$th license at minimum bid $V(n)$, he could break the equilibrium in which no licenses are sold. In this way, the innovator could earn $nV(n)$, just as in the $V(\cdot)$ decreasing case. A second approach, on which we shall only remark, is to assume instead that discriminatory minimum bids are not feasible and that the buyers converge on their Pareto-preferred equilibrium when two equilibria exist. These latter assumptions limit

10. Katz and Shapiro [1985a] and Farrell and Saloner [1985] provide explicit analyses of such network effects.

the seller to $\underline{b} \leqslant W(n) - L(0)$; the innovator selling $n$ licenses can then earn only $n\{W(n) - L(0)\}$ when $V(\cdot)$ is increasing.

Taking the first approach, we have

PROPOSITION 1. The independent research lab's optimal selling strategy has one of two forms: (a) $(k,0)$, where $k < n$ and the winning bid is $W(k) - L(k)$; or (b) $(n,\underline{b})$, where the winning bid is $\underline{b} = W(n) - L(n - 1)$.

There is an important case in which we can easily determine the optimal selling strategy of the independent researcher. When $V(\cdot)$ is increasing, $k\{W(k) - L(k)\}$ is likely to increase with $k$.[11] Proposition 1 then implies that the independent researcher's optimal selling strategy is to sell licenses to either $n - 1$ or $n$ downstream firms. Selling to all $n$ is optimal if and only if $n\{W(n) - L(n - 1)\}$ exceeds $(n - 1)\{W(n - 1) - L(n - 1)\}$. This inequality is equivalent to $nW(n) > (n - 1)W(n - 1) + L(n - 1)$. In choosing between $n - 1$ and $n$ licensees, the innovator sells to the number that induces the higher level of downstream industry (gross) profits.

For the purposes of comparing the independent researcher to a research joint venture, one piece of additional notation is useful. Let $R^o(k)$ denote the maximal profits (= licensing revenues) that the innovator can earn when it sells $k$ licenses; $R^o(k) = k\{W(k) - L(k)\}$ for $k < n$, and $R^o(n) = nV(n)$. An independent research lab, whose behavior has just been characterized, chooses $k$ to maximize $R^o(k)$.

## *A Research Joint Venture Owned by Downstream Oligopolists*

Now, suppose that the innovation is owned by $m$ of the downstream oligopolists, whom we shall call *insiders*. The objective of each owner is to choose a licensing strategy that maximizes the sum of that owner's share of the profits earned by the joint venture

11. A sufficient condition for $k\{W(k) - L(k)\}$ to increase with $k$ is that $W(k) - L(k)$ does so. If $L(k)$ *or* $W(k)$ is concave *or* linear in $k$, then $V(\cdot)$ increasing implies that $W(k) - L(k)$ also increases. To see this, let $\Delta W(k) \equiv W(k) - W(k - 1)$, and $\Delta L(k) \equiv L(k) - L(k - 1)$. So $V(k)$ increasing is equivalent to $\Delta W(k + 1) > \Delta L(k)$. If L is concave or linear $\Delta L(k) \geqslant \Delta L(k + 1)$, so $\Delta W(k + 1) > \Delta L(k + 1)$, i.e., $W(k) - L(k)$ increases with $k$. If $W$ is concave or linear, then $\Delta W(k) \geqslant \Delta W(k + 1)$ so $\Delta W(k) > \Delta L(k)$, again showing that $W(k) - L(k)$ increases with $k$. Moreover, observe that $W(k) - L(k)$ increasing in $k$ is much stronger than $k\{W(k) - L(k)\}$ doing so. We expect that in markets with "bandwagon" or "network" effects, $k\{W(k) - L(k)\}$ will increase with $k$. For example, if $W(k)$ increases with $k$ due to network effects, then so does $W(k) - L(k)$.

and the resulting profits that the owner earns in the downstream market, minus any licensing fees paid to the venture by the owner's downstream firm.

We assume that the venture can use any mechanism of the form $(k,\underline{b})$, like the independent researcher, but that the venture can elect to give its own members special treatment (e.g., free licenses) if it so desires. We assume that all $m$ firms own the venture equally, and restrict our attention to outcomes where the insiders have equal payoffs (although they need not all receive licenses).

With this convention, the members of the venture all share the same objective function, the sum of the members' ultimate payoffs, and thus will be unanimous regarding the pattern of licensing. If the venture issues $k$ licenses, $\bar{k}$ of which go to insiders, and if the venture receives revenues of $R$ from *outsiders* from the sale of the licenses, then the sum of the insiders' payoffs is $\bar{k}W(k) + (m - \bar{k})L(k) + R$.

Clearly, for any given $k$ and $\bar{k}$, the joint venture will seek to maximize $R$. If $k < n$ units are sold in total, we know that the venture can get a maximum of $W(k) - L(k)$ for each license sold to an outsider. Hence, $R = (k - \bar{k})\{W(k) - L(k)\}$, and the insiders' aggregate profits, given $k$ and $\bar{k}$, are $k\{W(k) - L(k)\} + mL(k)$. This expression is independent of the value of $\bar{k}$. The reason is that an insider gains $W(k) - L(k)$ if it is given a license instead of some other firm. But if the other firm were an outsider, the joint venture would lose revenues of $W(k) - L(k)$. When the number of licenses is fixed at $k$, $W(k) - L(k)$ is the venture's opportunity cost of giving the license to an insider rather than selling it to an outsider. Thus, it is optimal for the insiders to sell licenses to themselves at this price.[12] Selling the licenses in this fashion ensures that the payoff to an insider is independent of whether it receives a license or not.

12. Some readers might find it odd that the venture need not make the innovation available to all of its members. If the optimal number of licenses for the $m$-firm venture to issue equals or exceeds $m$, then we can assume without loss of generality that all the venturers are given licenses (for free, say). It could be optimal, however, to exclude some members from using the innovation, and *will* be if $m$ exceeds the optimal number of licenses. If, for example, the innovation is drastic (so that a single licensee would enjoy a monopoly unconstrained by the firms without the licenses), then it will be optimal to license to only one firm, even if $m > 1$. In Section IV we discuss the behavior of the venture if it is constrained to give licenses to all of its members.

Recall that an independent researcher who sells $k < n$ licenses receives revenues of $R^o(k) \equiv k\{W(k) - L(k)\}$. The venturers' aggregate payoffs when selling $k < n$ licenses optimally can be written as $R^m(k) = k\{W(k) - L(k)\} + mL(k)$, or

$$(2) \qquad R^m(k) = R^o(k) + mL(k) \qquad k = 1, \ldots, n - 1.$$

Clearly, this formula applies for $m = 0$ as well as $m = 1, \ldots, n$.

We must also examine what would happen if the joint venture were to sell the input to all $n$ firms. In this case, all of the owners receive the input, and their aggregate downstream profits are $mW(n)$. Given an equal-sharing rule for the profits of the upstream supplier, the innovation can be given free of charge to all of the insiders, and the owners all will want to pursue the revenue-maximizing strategy in selling to the other $n - m$ firms.

A zero-minimum-bid auction would yield no revenues when $n - m$ units are offered to the outsiders. By setting the optimal bid, the innovator can earn $W(n) - L(n - 1)$ from each buyer. We have established

PROPOSITION 2. The $m$-firm joint venture's optimal selling strategy has one of two forms: (a) $(k,0)$, where $k < n$ and the winning bid is $W(k) - L(k)$; or $(n,\underline{b})$, where the winning bid is $\underline{b} = W(n) - L(n - 1)$.[13]

## IV. THE NUMBER OF LICENSES ISSUED

### *Research Joint Ventures and Patent Licensing*

We turn now to the question of how many licenses the innovator will sell, and how this number varies with the pattern of ownership of the patent. Let $k^m$ denote the number of licenses issued by the $m$-firm venture ($m = 0$ is the independent researcher). By definition, $k^m$ maximizes $R^m(k)$. Consider the $m$-

13. When $V(\cdot)$ is increasing, discriminatory minimum bids are not feasible, and buyers can coordinate on their preferred equilibrium, $\underline{b} = W(n) - L(m)$ is the largest minimum bid that prevents the $n - m$ outsiders from flocking to the equilibrium in which no outsiders purchase licenses. Because the $m$ owners can credibly "threaten" to license to themselves, $\underline{b}$ is an increasing function of $m$. The outsiders compare the situation in which just the $m$ owners receive licenses with the bidding equilibrium in which all $n$ firms buy licenses. Therefore, larger ventures can extract more from outsiders.

firm venture's incentive to sell $k$ rather than $k - 1$ licenses. For $k < n$, the change in the venturers' profits is

$$\Delta R^m(k) \equiv R^m(k) - R^m(k-1)$$
$$= \{R^o(k) - R^o(k-1)\}$$
$$+ m\{L(k) - L(k-1)\}.$$

Comparing venture sizes, we have $\Delta R^m(k) - \Delta R^{m-1}(k) = \{L(k) - L(k-1)\} \leq 0$. The larger venture has *less* incentive to sell the $k$th license for $k < n$.

Of course, the $m$-firm venture may sell $n$ licenses. The calculations above do not apply to the sale of the $n$th license. We must compare $\Delta R^m(n)$ and $\Delta R^{m-1}(n)$. $R^m(n) = R^o(n) + mL(n-1)$, and by equation (2), $\Delta R^m(n) = \Delta R^o(n)$. Hence, $\Delta R^m(n)$ is independent of $m$, and we have proved

PROPOSITION 3. An $(m - 1)$-firm venture issues at least as many licenses as does an $m$-firm venture.[14]

Note that $k^n$ maximizes industry profits; the industrywide venture will sell licenses so as to maximize $R^n(k) = kW(k) + (n-k)L(k)$. Hence, Proposition 3 implies that any venture other than the industrywide one may license to more firms than would maximize industry profits, but never to fewer.

A common worry about research joint ventures is that they may be used to restrict the intensity of industry R&D activities (see Grossman and Shapiro [1984] or Katz [1985]). In the present model there is another possible restriction; a joint venture may license its invention to fewer firms than would an independent research lab, and this output restriction is greater, the larger is the venture. This restriction of licenses by larger ventures can be explicitly calculated in the case of a process innovation and a downstream Cournot oligopoly. In this example, for the appropriate choice of the demand and cost parameters, $k^m$ declines strictly with $m$, as shown in Figure I.

A natural objection to our argument that larger ventures sell fewer licenses is that, in practice, joint ventures may make their results freely available to their members. Under this view that

14. When $V(\cdot)$ is increasing, discriminatory minimum bids are not possible, and buyers can coordinate on their preferred equilibrium, we can no longer be sure that a smaller venture issues as many licenses as does a larger venture if the larger venture issues $n$ licenses. The larger venture has a greater incentive to sell the $n$th license.

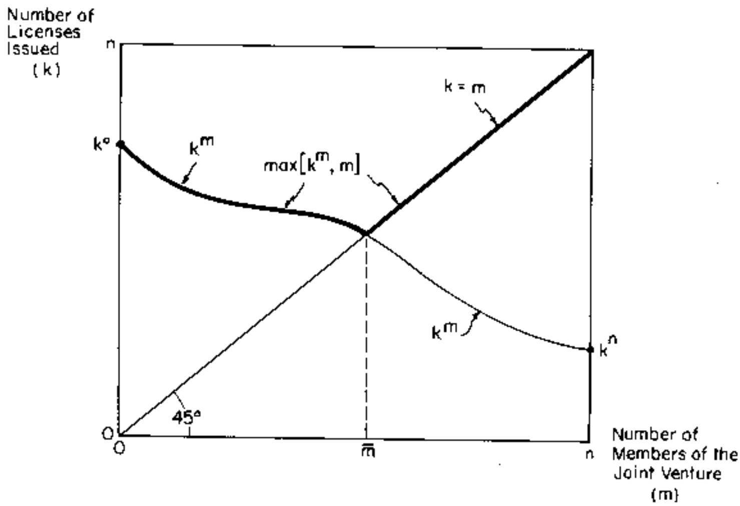


FIGURE I
Patent Ownership and Dissemination

the $m$-firm venture faces a constraint that it issue at least $m$ licenses, we find that the number of licenses issued is largest for the very small and the very large ventures; the $m$-firm venture licenses to max $(k^m, m)$ firms. In Figure I the intermediate venture size $\overline{m}$ leads to the least dissemination of the innovation.

*The Case of Process Innovations*

We can say much more about the number of licenses issued in the case where the licensed property is a process innovation and the oligopolists produce a homogeneous good. In this setting, it is socially optimal for licenses to be issued to all $n$ firms if (1) the equilibrium price for the oligopolists' product is a non-increasing function of the number of licenses issued (i.e., equilibrium prices fall as costs fall); and (2) either (a) each firm produces with decreasing returns to scale; or (b) all firms remain active in all cases and produce with nondecreasing marginal costs.[15]

Clearly, when it is socially optimal to set $k = n$, private own-

15. Part (1) ensures that the oligopolistic output restriction is not exacerbated by licensing, and part (2) ensures that there are no adverse effects on production efficiency due to licensing. Katz and Shapiro [1985b] show that it may not be socially optimal for one duopolist to license to another when condition (2) is not satisfied. This result holds even when one is considering fixed fee licenses and ignoring the effects of such (mandatory) licenses on development incentives.

ership of the patent cannot lead to excessive licensing. The upstream firm may, however, sell to strictly fewer than the welfare-maximizing number of downstream firms. This restriction of licenses will occur if the innovation creates a $k$-firm *natural oligopoly* for some $k < n$ (i.e., if the innovation is so valuable that the $n - k$ firms without licenses would be unable to remain active in the market even if the $k$ firms with licenses were to act as if the downstream industry were a $k$-firm oligopoly). Much of the literature on patenting has concentrated on the case where a downstream natural monopoly would be created by giving the innovation to only one firm. Here, we consider an arbitrary number of oligopolists. Let $\hat{k}$ denote the minimum value of $k$ such that if $\hat{k}$ downstream firms receive licenses, they are natural oligopolists.

A reasonable property to impose on the downstream equilibrium is that if $\hat{k}$ has this property, then so does any larger $k$. Absent sunk costs of production, $L(k) = 0$ for all $k \geqslant \hat{k}$; the losers drop out. For homogeneous goods industries, it is also reasonable to assume that for all $k \geqslant \hat{k}$, industry profits $kW(k)$ are a decreasing function of $k$. In this case, if $k$ licenses are sold, where $\hat{k} < k < n$, then $R^m(k) = R^o(k) + mL(k) = R^o(k) = kW(k)$, since $L(k) = 0$. For $k = n$, $\underline{b} = V(n) = W(n)$, and upstream revenues equal $nW(n)$. But $\hat{k}W(\hat{k}) > kW(k)$ for $k > \hat{k}$. Thus, we have

PROPOSITION 4. If the patent is important enough to create a $\hat{k}$ firm natural oligopoly, the the innovator will sell no more than $\hat{k}$ licenses.

The restriction of licenses is most striking in the case of drastic innovations, i.e, for $\hat{k} = 1$, which is the familiar result that the innovator will create a downstream monopoly if it is possible to do so. If $\hat{k} = 1$, the innovator will act to maximize the gross profits of the downstream industry. We have seen, however, that the upstream supplier does not always do so. Since $k^m > k^n$ is possible, the $m$-firm venture may issue more licenses than would maximize downstream (gross) profits.

The restriction of licenses that we have identified here is not the usual monopolistic output restriction. Given identical downstream buyers, the upstream monopolist would sell the input to all of the downstream firms if their demands were not interdependent. Rather, the restriction arises because $k$ affects the value of a license to a downstream producer. The upstream monopolist reduces the number of licenses in order to raise the value of a license to a downstream firm.

## V. The Incentives to Innovate

Suppose that the research entity considers a research program to develop an innovation, where the objective of the joint venture is to maximize the aggregate upstream and downstream profits of its owners, as before, less any development costs. If the innovation is developed, the researcher's objective function is maximized by authorizing $k^m$ firms to utilize the input. Given that $k^m$ firms will receive the innovation if it is developed, we can ask whether it is in the social interest to develop the innovation and how the private and social incentives diverge. The social development incentives are the sum of the change in gross downstream profits and the change in consumer surplus. The private incentives depend only on the increased profits earned by the venturers.

In a typical oligopoly, the adoption of a process innovation that reduces marginal costs will lower prices in the downstream market and thus raise consumer surplus. In contrast to consumers, any downstream producer who is not an owner of the upstream innovator cannot be better off, and may be strictly worse off, as a result of the innovation. A non-owner is strictly worse off whenever $L(\cdot)$ is strictly decreasing in $k$. To see this, suppose first that $k^m < n$. In equilibrium, an outsider is indifferent between buying the innovation and not. The net profits of any such firm are $L(k^m) < L(0)$. If, on the other hand, $k^m = n$, then $\underline{b} = W(n) - L(n - 1)$ and an outsider earns net profits of $L(n - 1) < L(0)$. In either case, the upstream supplier is able to play the buyers off against one another due to the demand interdependencies. Some of the buyers' initial property rights, $L(0)$, are appropriated by the innovator. Implicitly, each outsider is threatened (credibly) with a lower payoff of $L(k^m)$ or $L(n - 1)$.

Outsiders are made worse off on account of the innovation, but consumers are (typically) made better off. The developer ignores both of these effects in making its decision. Depending upon which of these effects is larger, the seller's development incentives can be too low or too high. For example, if prices fall due to the innovation, an industrywide research joint venture has development incentives that are too low socially. The reason is that this $n$-firm joint venture will act to maximize industry profit and ignore consumer surplus. When $m < n$, however, the adverse profit effects on outsiders may dominate. Summarizing this discussion, we have

PROPOSITION 5. The upstream supplier's incentives to develop the innovation may be less than or greater than the social incentives for *private* development (i.e., the social incentives given that $k^m$ firms will receive the innovation).

The next result demonstrates that the private incentives to develop the innovation vary with the number of insiders.

PROPOSITION 6. An upstream supplier owned by $m$ of the downstream firms has greater incentives to develop the innovation than does an upstream supplier owned by $m + 1$ of the downstream producers.

*Proof of Proposition 6.* The incentives of a research joint venture owned by $m$ insiders are given by $R^m(k^m) - R^m(0) = R^m(k^m) - mL(0)$. Suppose that $k^{m+1} < n$. A research joint venture with $m + 1$ members has incentives

$$R^{m+1}(k^{m+1}) - R^{m+1}(0) = k^{m+1}\{W(k^{m+1}) - L(k^{m+1})\} + (m + 1)\{L(k^{m+1}) - L(0)\}. \tag{3}$$

By the optimality of $k^m$,

$$\begin{aligned} R^m(k^m) - R^m(0) &\geq R^m(k^{m+1}) - R^m(0) \\ &= k^{m+1}\{W(k^{m+1}) - L(k^{m+1})\} \\ &\quad + m\{L(k^{m+1}) - L(0)\}. \end{aligned} \tag{4}$$

Since $m < m + 1$ and $L(k^{m+1}) \leq L(0)$, the right-hand side of equation (4) is at least as great as the right-hand side of equation (3).

$R^m(n) = nW(n) - \{n - m\}L(n - 1)$, and equations (3) and (4) remain valid for $k^{m+1} = n$ if we simply replace $L(k^{m+1})$ by $L(n - 1)$.

Q.E.D.

The intuition is that the developer can milk downstream firms who are not members of the venture for more than the innovation is "worth," i.e., more than $W(k^m) - L(0)$. The more such nonmember firms there are, the greater are the development incentives. Since Proposition 6 applies for $m = 0$, we see that an independent researcher will have greater incentives to develop the innovation than will any joint venture.

## VI. Entry Fees

The class of sales mechanisms that we have considered above clearly is not the most general possible one. In this section we generalize the class of mechanisms by allowing the innovator to charge an entry fee $E$, which must be paid to participate in an auction of the form that we have been considering. As usual, we have to treat separately the case where the supplier licenses to all $n$ downstream firms. For this mechanism the two cases are divided by whether $k^n$ is equal to or less than $n$.

First, suppose that $k^n < n$, and consider the bidding equilibrium when the supplier operates the following selling scheme. The seller announces an entrance fee of $E = L(k^n) - L(n-1)$ to participate in a $(k^n,0)$ auction. The developer announces that if fewer than $n$ firms participate in the auction (i.e., if any downstream firm fails to pay the entrance fee), then the developer will give each firm that did pay the entrance fee a license to the innovation for free and a rebate of $E$. As in the earlier mechanism, members of the research joint venture pay the same fees as other firms and then split the developer's profits equally among themselves.

We look for a two-stage perfect Nash equilibrium among the downstream firms. In the second (final) stage if fewer than $n$ firms have paid the entry fee in the first stage, then the innovator carries out the announced rebates, and the eligible downstream firms accept them. If all $n$ downstream firms have paid the fee, then they play a $(k^n,0)$ bidding game in the second stage. Our earlier characterization of the Nash equilibrium for this stage remains valid. In the first stage each firm decides whether to participate in the auction (i.e., pay the entry fee) given the participation decisions of the other firms, and knowing that the Nash equilibrium outcome will obtain in the second stage.

Clearly, there is no equilibrium in which two or more firms refuse to participate in the auction. Suppose that $n - 1$ firms pay $E$. Then the remaining firm's payoff will be $L(n-1)$ if it does not pay the fee, and $L(k^n) - E = L(n-1)$ if it does pay the fee. Thus, in equilibrium all $n$ firms pay the fee, and $k^n$ of them receive the innovation.

Now, suppose that $k^n = n$. In this case the developer can set an entrance fee arbitrarily close to $E = W(n) - L(n - 1)$ for participation in an auction of the form $(n,0)$. Again, the seller announces that it will give the innovation away and rebate $E$ to any firm that does not pay the fee if not all $n$ firms do so. As before, there is no equilibrium in which fewer than $n - 1$ firms pay the entry fee. Trivial calculations show that there is an equilibrium in which all $n$ firms pay $E$, submit bids of 0 in the auction, and receive the innovation.

In either case, the $(k,\underline{b})$ auction coupled with an entrance fee yields the developer profits of $k^nW(k^n) + \{n - k^n\}L(k^n) - \{n - m\}L(n - 1)$. Under this scheme the downstream industry's profits (gross of the payments to the developer) are as large as is possible ($k = k^n$). The net profits of each outsider, $L(n - 1)$, are as low as possible; under any selling scheme, a downstream firm can guarantee itself a payoff of at least $L(n - 1)$ by refusing to participate. Therefore, the profits of the owners of the developer are as large as is possible given the individual rationality constraints.

The following properties of the outcome follow immediately. Under the selling mechanism described above, (a) for any number of downstream owners, the innovator will license to $k^n$ firms; (b) development incentives fall as the number of downstream firms in the venture rises; (c) the profits of any downstream firm that is not an owner of the developer fall from $L(0)$ to $L(n - 1)$ as a result of the innovation; and (thus) (d) the development incentives are greater than or equal to the change in downstream industry profits, with strict equality if and only if $\{n - m\}\{L(0) - L(n - 1)\} = 0$.

Results (b), (c), and (d) are analogous to our earlier results for a no-entry-fee $(k,\underline{b})$ auction. Result (a) is, of course, different. Under the simple auction scheme, the number of licenses could vary with the number of downstream firms participating in the research joint venture. An immediate consequence of (a) is that, if consumer surplus is a nondecreasing function of the number of licenses, then the developer using this selling mechanism issues no more than the socially optimal number of licenses.

In concluding the analysis of the general mechanism, note that when $k^n < n$, some of the firms pay the entrance fee, yet do not receive licenses. In effect, these firms pay the fee in order to induce the innovator to license to only $k^n$ of their rivals rather than to $n - 1$ as the innovator threatens to do. These firms are paying solely to exclude their rivals from licenses. This is one reason why we feel that such a mechanism is likely to be looked upon askance by antitrust authorities. In fact, our analysis suggests that antitrust authorities should be concerned since, by Proposition 3 and the above discussion, allowing the use of entrance fees often will reduce the extent to which the innovation is disseminated (i.e., $k^n < k^m$ for $m < n$).

There are two other reasons why the general mechanism may not be effective. First, there is a serious question of whether the innovator can credibly commit himself to the general mechanism. If fewer than $n$ firms *do* participate, the innovator will earn no revenues under the announced scheme. Second, the seller's profits drop to zero if even two of the buyers can cooperate in making their participation decisions.

## VII. Conclusion

We have analyzed the profit-maximizing strategy for a monopolistic innovator selling licenses to a group of firms who are competitors in a downstream market. In characterizing the strategy, we found that, given the induced interdependence of demands for the licenses, a pure price strategy is not in general optimal. Placing a quantity restriction typically will raise profits. Moreover, except when licensing to all $n$ downstream firms, there is no need to set a price (minimum bid) at all. In cases where the innovation is a valuable input in several industries or for separated geographic areas, the innovator should run one such auction for each market.

Our analysis sheds light on the behavior of research joint ventures. In comparison with an independent lab, a research joint venture may restrict both the development of an innovation and its dissemination. Moreover, as the number of downstream firms participating in the joint venture increases, these restrictions become more severe. Of course, the development incentives of the private lab may be excessive, since the lab can extract license payments that exceed the change in industry profits.

At this point one may wonder whether firms, in fact, use the strategies that we have proposed. In his survey of licensing practices, Rostoker [1984] found that most of the firms who responded did solely use fixed fees (as we have assumed) for at least some of their licenses. Taylor and Silberston [1973, p. 120] found that lump-sum contracts are most likely to be used when there are substantial fixed costs associated with the licensing process (such as training the licensee) or when running royalties are likely to be unenforceable. They also noted that some firms use payment schemes in which the licensor receives equity in the licensee. In effect, such payments are fixed fees.

Rostoker, and Taylor and Silberston found that the majority of licensing agreements contain royalty provisions, either alone or in conjunction with fixed fee payments. There are three reasons for the use of royalty payments in addition to fixed fees. First, royalty contracts constitute a form of risk sharing. The royalty payments vary with the licensee's revenues, and thus the value of the payment is contingent on the licensee's success in its use of the innovation. Moreover, royalties are a partial solution to the problem of asymmetric information. At the time the contract is signed, it may be common knowledge that the licensor has better information about the value of the innovation than does the licensee. Under a royalty scheme, the licensee knows that his payments will be small if the innovation is of limited usefulness.[16] These two motivations for royalties do not arise in a model such as ours where there is no uncertainty or asymmetric information about the value of the innovation. Lastly, royalties may be used to facilitate collusion by raising downstream firms' effective marginal costs, and inducing the firms to restrict their output levels.[17] We have abstracted from this effect in order to focus on the implications of demand interdependencies.

An important extension of our model would be to allow the licensor to include a royalty rate as part of the license that it is auctioning. In this case as well, it is clear that auctioning such licenses is superior to selling them through a pure price strategy. Caves et al. [1983], found that often exclusive licenses are granted. The type of auction that we have analyzed almost surely is used in these markets, whether or not royalties are levied. All that the inventor need do is make clear to each potential licensee that an alternative licensee will be found if the first one fails to accept the licensing contract.

A second, and related, extension of our work is to allow buyers to have demands for multiple units of the good. We have limited attention to the sale of an intermediate good that enters into the

16. Equity payments also entail risk sharing and offer a partial solution to the problem of asymmetric information.

17. See Katz and Shapiro [1985b] or Shapiro [1985] for further discussion of this point.

buyers' profit functions purely as a fixed factor—the marginal product of a second license for any buyer is zero. This restriction limits the applicability of our analysis to markets in which buyers have zero-one demands, such as the transfer of information (i.e., the licensing of innovations) or access to a central facility. For many intermediate goods, buyers will demand multiple units. Even in this more general setting, however, the buyers' demands will be interdependent and the seller will find it optimal to use a sophisticated auction mechanism.

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