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Licensing in the theory of innovation

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This article analyzes licensing in a noncooperative R&D game. We ask two questions: What are the incentives for licensing a production technology and what is the impact of licensing on the pattern of innovation and the consequent evolution of industry costs and market structure? The gains from trading information through licensing contracts are achieved through the replacement of inefficient production techniques (the ex post *incentive) and the elimination of inefficient research expenditures (the* ex ante *incentive). In a duopoly the availability of licensing encourages research when the firms' initial production technologies are close in costs and discourages research when initial costs are asymmetric.*

1. Introduction

■ The challenge in the economic analysis of research and development is to explain the evolution of both technology and market structure as the outcome of interaction among individual firms' research and development decisions. The theoretical literature, beginning with Schumpeter (1947) and exemplified best by Reinganum (1982; 1983), assumes generally that this interaction is noncooperative and takes the form of competition among firms for the discovery of progressively superior technologies and products. Schumpeter argued persuasively that this rivalry in the innovation process was the essential competition in capitalistic economies.

In reality, the innovation process of discovery, development, and adoption of new technology is not one of Schumpeterian competition alone. Firms not only compete in trying to discover superior products and production processes, but often through licensing contracts trade information and rights to the use of superior technologies. The innovation process involves a mix of competition in research and cooperative agreements to share the information gained from research.

The effects of the transfer of information from an inventing firm to its rivals are studied in the theoretical literature on R&D. The earlier focus of this literature is on the possibility of spillovers—that newly discovered technology is *unavoidably* shared with its rivals (Kamien and Schwartz, 1972; Dasgupta and Stiglitz, 1980). In recent articles the issue of *intentional*

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sharing in the market for technology information has received attention. In the models of this literature information is transferred through requests for financing of current research projects (Bhattacharya and Ritter, 1982), through patents (Horstmann, MacDonald, and Slivinski, 1983), or through licensing of superior products or technologies (Nordhaus, 1969; Kamien and Schwartz, 1982; Tandon, 1982; Salant, 1984; Gallini, 1984; Katz and Shapiro, 1984a, 1984b).

This article examines information sharing through the institution of licensing in the context of the theory of innovation. Its purpose is to address two interrelated questions: First, what are the incentives for licensing; i.e., the gains from trade in the market for information on production technology? Second, what is the impact of licensing on the pattern of innovation and the consequent evolution of industry costs and structure? We address these questions in a simple model of process innovation under uncertainty.

We find, in this model, that the availability of licensing neither increases nor decreases unambiguously the extent of innovation. The impact of licensing is to *encourage* research when the existing production technologies of firms in the market are close in costs and to *discourage* research in markets where firms face widely divergent production costs.

This overall impact reflects the existence of two distinct incentives for licensing. First, licensing yields rents from the replacement of relatively inefficient means of production; this incentive for licensing would exist even if all research had terminated in an industry and is therefore labelled the *ex post incentive.* The possibility of rents of this sort leads to additional research in the innovation game as each individual firm foresees these rents, in the form of royalties from licensing, as an additional benefit from achieving the lowest cost position in the market. This incentive to license is relatively strong when costs of production under existing technologies are close.

When the existing costs are far apart, however, this incentive for licensing is weak. Licensing results instead from an *ex ante* or strategic incentive: A licensing contract offered by a firm with a very efficient production technique can provide a high-cost firm with a technology at its reservation cost, the maximum production cost this high-cost firm would tolerate before undertaking research, without any research expenditure at all. At the same time, by reducing the licensee's incentive to do research, licensing in this case prevents the possible erosion of the low-cost firm's market position by its rival's discovery of a superior technology.[1] Where the *ex post* incentive reflects rents from the replacement of inefficient production, the *ex ante* incentive reflects rents from the elimination of (privately) wasteful research expenditures by high-cost firms. In short, because of the *ex post* incentive, licensing encourages research when costs are symmetric, but because of the *ex ante* incentive, licensing discourages research when cost differences are large.[2]

Our model can be interpreted as an analysis of the effect of patent protection in a market where production techniques, if not licensed, are easily kept secret (i.e., information is private). Licensing occurs in such a market only if patent protection is available to the licensor. Thus, the role of patents in our model is not the traditional role of creating monopolies by *prohibiting* the exploitation of informational spillovers. Rather, by protecting property rights, patents here *open* the market for trade in technological information.

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[1] Considerable evidence indicates that the strategic incentive is behind licensing in some markets. For example, Scherer (p. 447) indicates that competitive research was apparently discouraged by favorable licensing agreements in Xerographic copying and float glass production. Vaughan (1956, p. 147) reports that in the development of synthetic rubber in the United States, license contracts were apparently used for the purpose of discouraging research by rival firms.

[2] The *ex post* incentive to license is recognized by Nordhaus (1969), Kamien and Schwartz (1982, p. 39), Tandon (1982), Salant (1984), and Katz and Shapiro (1984a, b). Gallini (1984) points out the *ex ante* incentive and isolates this incentive by considering "drastic" inventions that yield a large cost advantage, making the innovator a monopolist. The model developed here integrates both incentives to consider the impact of licensing on research activity.

We adopt Reinganum's (1983) duopoly model as a model of innovation in the "benchmark" case of no licensing. This is outlined briefly in the following section. Licensing is introduced into the model in Section 3, and Section 4 contains the main results. The concluding section summarizes the results and discusses extensions of our analysis.

2. Innovation without licensing

■ We adopt Reinganum's (1983) model of innovation as a benchmark against which to compare the equilibrium under licensing. We outline Reinganum's model here, with slight adaptations in assumptions and interpretation to fit our needs, and refer the reader to her article for more detailed discussion. In this model two firms compete as duopolists in what we shall interpret as a two-period, discrete-time setting. In the first or *ex ante* period, the two firms make decisions on research; this research results in a pair of costs at which production takes place in the second or *ex post* period.

Firms enter the first period with knowledge of existing technologies that yield production costs $m = (m_1, m_2)$. An opportunity for research is available to each firm that costs k dollars and results in a new technology that yields a cost of production (for the second period) of c_i for firm i. We assume that each cost c_i is a random variable on $[\underline{c}, \bar{c}]$ with distribution F, and let $c \equiv (c_1, c_2)$. The two firms must decide *simultaneously* in the first period whether to undertake the research.[3] In the second period research results are realized and observed by both firms before production decisions are taken. Each firm, however, has private information on the *means* of producing at cost c_i. Of course, if the new technology results in a production cost higher than a firm's existing cost, it is discarded. The profits $\Pi_1(c)$ and $\Pi_2(c)$ earned in the second period are derived from a Cournot-Nash duopoly game.

Following Reinganum, we make the following assumptions:

Assumption 1. F is strictly increasing with density f and is independent of the current costs m_i; $m_i \in [\underline{c}, \bar{c}]$.

Assumption 2. Π_i is decreasing in m_i, increasing in m_j, $j \neq i$, and $\partial^2\Pi_i/\partial m_i \partial m_j < 0$.[4]

In addition, we shall find useful the following assumption:

Assumption 3. $\partial^2\Pi_i/\partial m_i \partial m_j \leq \partial^2\Pi_i/\partial m_i^2$.

Assumptions 2 and 3 hold for simple classes of demand functions (including linear demand). Assumption 3 is not necessary for our main result.

Given the initial costs m, the two firms play a game in the first period in the strategies of researching and not researching. When the mixed strategies, identified by the probabilities of researching, are p_1 and p_2 for firms 1 and 2, the payoff to firm 1 is given by

$$V_1(m; p_1, p_2) = p_1 p_2 V_1(m; 1, 1) + (1 - p_1)p_2 V_1(m; 0, 1) + p_1(1 - p_2)V_1(m; 1, 0) + (1 - p_1)(1 - p_2)V_1(m; 0, 0), \quad (1)$$

where the payoffs to pure strategies are given by

$$V_1(m; 0, 0) = \Pi_1(m) \quad (2)$$

$$V_1(m; 1, 0) = \int_{\underline{c}}^{m_1} \Pi_1(c_1, m_2) f(c_1) dc_1 + [1 - F(m_1)]\Pi_1(m) - k \quad (3)$$

$$V_1(m; 0, 1) = \int_{\underline{c}}^{m_2} \Pi_1(m_1, c_2) f(c_2) dc_2 + [1 - F(m_2)]\Pi_1(m) \quad (4)$$

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[3] Production may also take place in the first period, but the profits from production in period 1 do not affect the research decision, and hence, are ignored in the analysis.

[4] The condition on the cross partial derivative ensures that a Nash equilibrium in pure strategies exists. The assumption implies that the gains from researching increase with rival's costs.

$$V_1(m; 1, 1) = \int_c^{m_1} \int_c^{m_2} \Pi_1(c_1, c_2) f(c_1) f(c_2) dc_2 dc_1 + [1 - F(m_1)] \int_c^{m_2} \Pi_1(m_1, c_2) f(c_2) dc_2$$

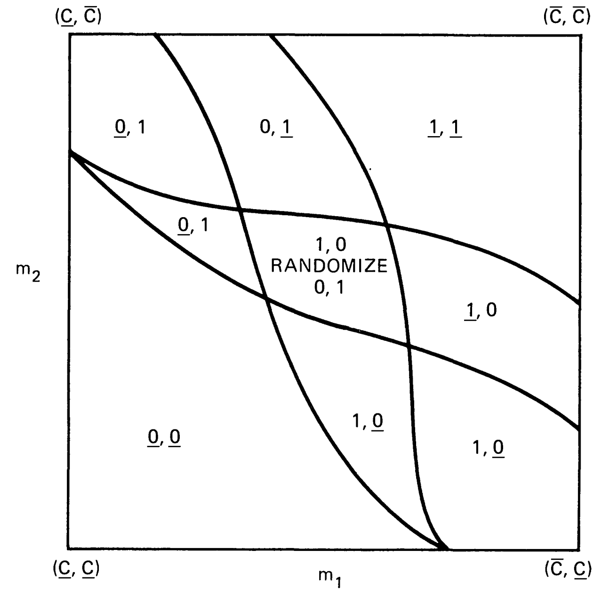
$$+ [1 - F(m_2)] \int_c^{m_1} \Pi_1(c_1, m_2) f(c_1) dc_1 + [1 - F(m_1)][1 - F(m_2)] \Pi_1(m) - k. \quad (5)$$

The primary issue that Reinganum addresses is the characterization of the Nash equilibrium in (p_1, p_2) as it depends upon initial costs, among other parameters. She shows that a pure strategy equilibrium always exists and that the configuration of Nash equilibria, for various initial costs m, is as depicted in Figure 1. In this figure $(\underline{0}, 1)$, for example, indicates an equilibrium in which $p_1 = 0$ and $p_2 = 1$ are equilibrium strategies, where player 1's strategy is dominant. In the central region of Figure 1 (0, 1) and (1, 0) are both pure strategy equilibria, and a mixed strategy equilibrium exists as well. Note that in this model the high-cost firm has the incentive to research when initial costs are very asymmetric. This suggests a "natural tendency towards more equal-sized firms rather than increasing monopolization" (Reinganum, 1983, p. 64).

The stage is now set for the introduction of the market for information on technology, or licensing contracts. Figure 1 yields a partition of existing technologies and market structures into sets in which research does and does not take place. Our main concern, the impact of licensing on the pattern of innovation, is posed in the following question: *Does licensing increase the set of costs under which some research takes place* (Figure 2a), *decrease this set* (Figure 2b), *or neither?*[5]

FIGURE 1

THE EQUILIBRIUM OF THE RESEARCH GAME WITH NO LICENSING

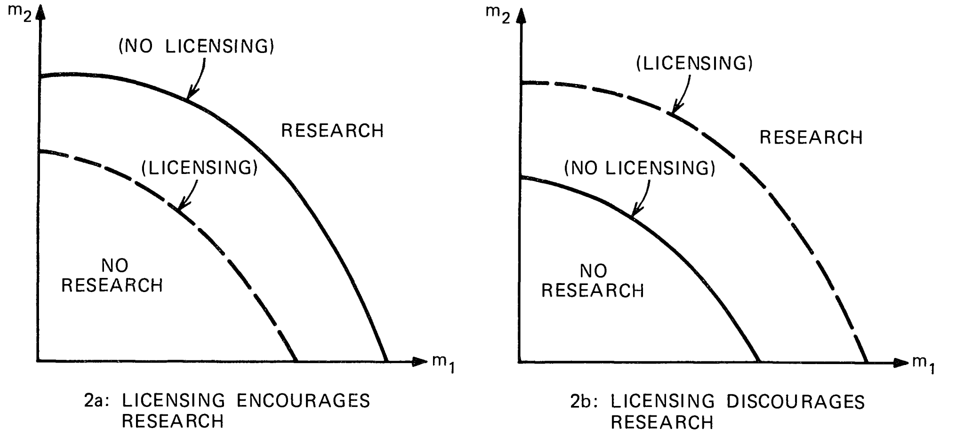


SOURCE: REINGANUM (1983, p. 61)

[5] In answering this question we provide only a partial assessment of the impact of licensing on the pattern of innovation. We focus on the partition of costs into "no-research" and "some-research" sets rather than on the complete partition of Figure 1.

FIGURE 2

TWO EXAMPLES OF THE POSSIBLE IMPACT OF LICENSING ON RESEARCH



3. Innovation with licensing

■ **Incorporating licensing in the innovation game.** In the model outlined above, innovation decisions and consequent changes in industry costs are the outcome of an entirely non-cooperative game. In this section, by introducing licensing, we open the market for information on existing technologies or those discovered as a result of research. We analyze the impact of this market on the pattern of innovation—specifically, on the partition of industry costs into research and no-research sets. Patent protection is a necessary and sufficient condition for licensing in the simplest version of this model: Without such protection of property rights, a licensee could terminate a licensing contract and continue to use the knowledge acquired through the contract.[6]

□ **Permissible license contracts.** We first describe the nature of the license contracts that are permissible in our model. A license agreement in our model stipulates in general that the high-cost firm may use a low-cost technology for production in the second period, at a payment of a specified royalty (per unit output) to the low-cost firm. Such an agreement can be struck before research decisions are made or after the realization of research results; licensing agreements, therefore, take one of two specific forms in our model:

Ex ante licensing. An agreement struck in the *ex ante* period providing for the use in *ex post* production of the more efficient *current* technology, of cost min (m_1, m_2). The contract specifies a per unit royalty, to be paid by the licensee (high m_i firm) to the licensor (low m_i firm).

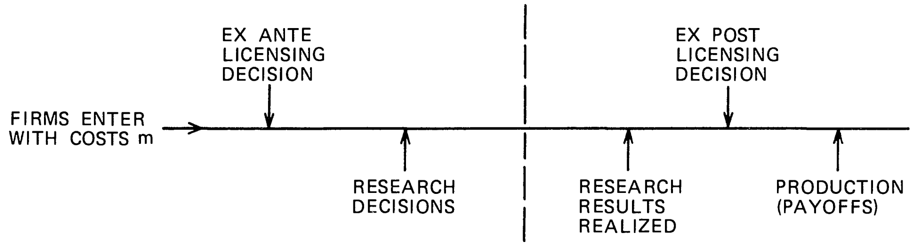
Ex post licensing. An agreement struck in the *ex post* period for the use in production of the most efficient technology discovered to date, of cost min (c_1, c_2). This contract also specifies a per unit royalty, to be paid by the licensee (high c_i firm) to the licensor (low c_i firm).

The timing of decisions in the model with licensing is summarized in Figure 3.

[6] The model in this section can therefore be interpreted as analyzing the impact of patent protection. That is, the model in Section 2 describes a research environment where information on technologies can be kept secret and there is no patent protection; the model in this section introduces patent protection. This interpretation is important for the second of our two questions (what is the impact of licensing?) because for the answer to have any potential empirical content, the world of no licensing must be a logical possibility.

FIGURE 3

TIMING OF LICENSING, RESEARCH AND PRODUCTION DECISIONS



An *ex ante* license contract effectively provides the high-cost firm with an *option* to use the licensor's existing technology in the future production at the specified royalty, if a better technology is not discovered. Actual license contracts combine elements of both *ex ante* licensing (licensing existing technology for future production) and *ex post* licensing (licensing for current production). As it turns out, the incentives for the use of each type of licensing differ sharply; it is therefore useful to analyze them as distinct contracts.

Licensing contracts in reality are not always so simple as those considered here. For example, some contracts specify that the licensee have exclusive rights to a particular market, often a geographical area distinct from the area served by the licensor. Second, the payment schemes are not always simple per unit royalties: About 10% of observed contracts specify lump-sum payments, and roughly 40% include two-part tariffs or more complicated royalty schemes. About half of all licensing contracts, however, do specify linear royalties (Calvert, 1964; Taylor and Silberston, 1973).

Given the frequent use of linear royalties, we consider the simple contracts to be a reasonable approximation to many observed contracts. More importantly, the complications of exclusivity and two-part payment schemes are either infeasible or unprofitable in this model when the model is imbedded in a realistic institutional setting. If exclusive licenses and lump-sum payments were allowed, the low-cost firm could use the licensing contract to sell monopoly rights to its rival for a lump-sum fee. We assume that this arrangement, which would be a trivial solution in *any* duopoly model, is legally prohibited.[7] Similarly, we can rule out negative lump-sum licensee fees: Payments from the licensor to the high-cost licensee in our model would be established (in the *ex ante* period) only to induce the licensee to terminate research. We assume that the payment would be interpreted by the courts as a bribe to do just that and would be disallowed. This leaves as institutionally feasible any payment scheme with a nonnegative fixed component. But any payment scheme with a positive fixed fee is always dominated by a per unit royalty in this model; in any Cournot duopoly with constant returns to scale the royalty is not only a mechanism for collecting rents, but also an instrument to increase the price towards the monopoly level.[8]

□ **Extending the innovation game.** In our extension of the game to incorporate licensing, we must specify two elements: the impact of licensing on the payoffs to the firms in the final production stage of the game and the precise game tree with licensing. To consider the first of these, suppose that the two firms enter production with costs (c_1, c_2), say

[7] In the 1970s, the U.S. Department of Justice identified a set of licensing practices that it thought should be illegal. One such practice was for "a patentee to agree with his licensee that he will not, without the licensee's consent, grant further licenses to any other person." Although these "guidelines" have come under considerable attack by lawyers and economists in recent years, the practice of exclusive licensing that is followed by a formerly active producer's leaving the market would presumably be regarded with suspicion.

[8] See Katz and Shapiro (1984a) for a formal proof. Note that an *arbitrary* nonlinear royalty is equivalent to a two-part payment scheme, which has been eliminated as a possibility.

$c_1 \leq c_2$, and with a license contract at royalty R. In this case the firms make production decisions on the basis of costs c_1 and $c_1 + R$. The payoffs to the two firms in the production period are $\Pi_1(c_1, c_1 + R) + RQ_2(c_1, c_1 + R)$ and $\Pi_2(c_1, c_1 + R)$, where $Q_2(c)$ is the equilibrium output of firm 2 and Π_1 and Π_2 are as defined in Section 2.

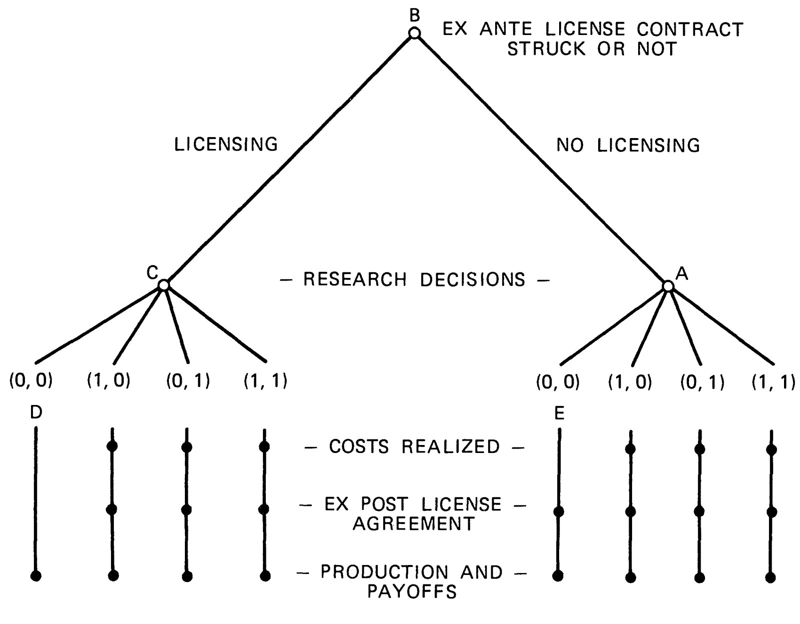
Regarding the specification of the game, we retain for simplicity the noncooperative game framework in modelling the licensing agreement in either period: The low-cost firm offers a royalty rate for a licensing contract to the high-cost firm, which the latter then accepts or rejects. This assumption allows the licensor to set the maximum royalty acceptable to his rival.[9]

A summary of the structure of the innovation game with licensing is given in Figure 4. We invoke the usual concept of perfect Nash equilibrium. Under this equilibrium concept the decision by the low-cost firm to offer a license contract specifying some royalty is based upon the expected payoffs to various alternatives under the assumption that both players follow rational (subgame perfect equilibrium) strategies at the subsequent decision points. In particular, the licensor *recognizes the effect that a license contract will have on the licensee's incentive to research.* The same foresight is invoked in modelling the research decisions.

□ **Necessary and sufficient conditions for no research in equilibrium.** Now that the strategy space of the research game has been extended to include licensing, we are ready to determine the conditions under which no research takes place when licensing is possible. We must determine when branches D or E of Figure 4 are followed in equilibrium; no research may be an equilibrium if an acceptable *ex ante* license contract is offered (branch D) or if no *ex ante* contract is offered, but further research is not profitable (branch E). If, however, E is the equilibrium of the game and an *ex post* contract is written with royalty R, then it is easily shown that in this case neither player has the incentive *not* to establish in the first period the eventual license contract at R. Hence, without loss of generality branch E can

FIGURE 4

SUMMARY OF INNOVATION GAME WITH LICENSING



[9] An alternative would be to assume the Nash bargaining solution is applied in which the agreement maximizes the product of the rents.

be ignored as an outcome of the game. Our search for the initial costs under which no research takes place in this game is a search for when branch D of Figure 4 is an equilibrium of the game.

It is evident from Figure 4 that two conditions must be met for branch D to be an equilibrium, i.e., for a licensing contract with royalty R to be acceptable to both firms at the current cost pair m and for (0, 0) to be an equilibrium of the subgame at node C. First, each firm's profits under the contract must exceed that firm's derived profits from continuing research alone. Second, the contract must yield profits to each firm that are at least as large as the payoff to that firm from the equilibrium of the subgame at node A, since each firm has the option of effecting this equilibrium. (We refer to the subgame equilibrium at node A as the *alternative equilibrium.*) In other words, for (0, 0) to be the equilibrium of the game the following conditions must be met:

Condition 1. D must be the equilibrium of the subgame beginning at C.

Condition 2. D must be the equilibrium of the subgame beginning at B of Figure 4, under the assumption that D will be the outcome at C.

We analyze these two conditions below by solving the equilibrium of the game recursively, working backwards to node B, where an *ex ante* license decision is taken. We start by determining the equilibrium of the subgame beginning at node A. At this node a research game is played and is followed by an *ex post* license decision. Analysis of this subgame provides, as a by-product, results on the impact of *ex post* licensing on research decisions. Then we analyze the equilibrium for the subgame at C. Analysis of the subgame at C enables us to specify Condition 1 for no research in the licensing game. After determining the equilibrium for these research subgames, we then move to the *ex ante* license decision at node B. Analysis of the license decisions below provides an expression for Condition 2 for a no-research equilibrium under licensing.

Given these two conditions, we then examine, in Section 4, the impact of licensing on research activity, production costs, and prices.

□ **The equilibrium of the subgame at node A: the *ex post* license contract after the research subgame at node A.** After the realization of the outcomes from the research decisions at A, an *ex post* licensing contract is struck. The following lemma implies that the *ex post* contract will be struck at a royalty equal to the full difference in costs. (Proofs appear in the Appendix.)

Lemma. In a Cournot duopoly with constant costs (c_1, c_2), with licensing of the low-cost technology, and with no further research opportunities, the licensor's optimal royalty is equal to $|c_2 - c_1|$.

The intuition behind the lemma is clear. Any reduction in the royalty below the maximum rate must reduce the market price (further below the monopoly level) and hence reduce total profits. Since the licensee's profits increase with the fall in royalty, the licensor's profits must decrease.

□ **Equilibrium in research decisions at node A.** Given initial costs m, research strategies at node A are $p_i \in [0, 1]$. Having established that an *ex post* contract is always struck at the full cost difference, we can now determine the payoffs to research at A by specifying the expected profits to the firms upon the realization of research results. Let $Q_i(c_1, c_2)$ be the Cournot-Nash equilibrium output for firm i in a static duopoly production game with costs (c_1, c_2). We extend the profit function definitions of Section 2 to include royalty payments where the per unit royalty is $|c_2 - c_1|$ for the low-cost firm. The profits under licensing are given by

$$\Pi_1^L(c_1, c_2) \equiv \begin{cases} \Pi_1(c_1, c_2) + (c_2 - c_1)Q_2(c_1, c_2) & \text{if} \quad c_1 < c_2 \\ \Pi_1(c_1, c_2) & \text{if} \quad c_1 \geq c_2, \end{cases}$$

with Π_2^L defined analogously. Note that $\Pi_i^L(c_1, c_1 + R)$ is the payoff earned by i when firm 1 licenses to firm 2 at a royalty R not exceeding $c_2 - c_1$. The payoffs, V_i^L, of the research game at node A are given by equations (1)–(5) with Π_i replaced by Π_i^L everywhere. For reference, label these equations, which we do not repeat here, (1a)–(5a). Firms now recognize in their research decisions that payoffs from research include royalties from the future licensing agreement.

Recall that Assumption 2 ensured the existence of a pure strategy equilibrium for the no-licensing game. When *ex post* licensing becomes available as in the alternative equilibrium, the assumption $\partial^2\Pi_i/\partial m_1\partial m_2 < 0$ does not extend to Π_i^L for typical demand curves. As a consequence, one cannot conclude that an alternative equilibrium exists in pure strategies. From Nash (1951) and the finiteness of the research decision (research or not), we know that at least one mixed-strategy equilibrium exists. Assume, for the sake of simplicity only, that the alternative equilibrium is unique in mixed strategies and denote it by (p_1^A, p_2^A). The equilibrium payoffs to the two firms in the subgame starting at A are then given by $V_1^L(m; p_1^A, p_2^A)$ and $V_2^L(m; p_1^A, p_2^A)$.

At this point, we digress slightly from the path towards a characterization of the overall impact of licensing to analyze the effect of *ex post* licensing alone on research incentives.

□ **The impact of *ex post* licensing.** To analyze the effect of *ex post* licensing on the partition of Figure 1, we need only consider the alternative equilibrium of the research subgame beginning at node A. We show that *ex post* licensing encourages R&D activity by comparing the sets of costs where $(p_1, p_2) = (0, 0)$ is an equilibrium in the no-licensing game with the corresponding sets of costs for the alternative equilibrium. Denote these sets by S_{00} and S_{00}^A, respectively.

Proposition 1. Under Assumptions 1, 2, and 3, S_{00}^A is a proper subset of S_{00}. The sets intersect each axis at the same cost.

The following intuition might seem adequate to prove this proposition. Since *ex post* licensing adds royalties to the final payoffs, the prospect of *ex post* licensing can only increase the incentive for *both* firms to do research; the rewards to successful innovation are increased, and the payoff to not researching (and to a poor draw from researching) are unchanged. This argument is not quite correct, however. Royalty revenues will eventually decrease with a decrease in the licensor's cost of production, so that the *gain* to researching may be lower under licensing for the more efficient firm.[10]

Fortunately, to prove Proposition 1 it is enough that the increased incentive to do research holds for the high-cost firm. We use the following logic in the proof. First, we show that without licensing the high-cost firm has the greater incentive to research, as indicated in Figure 1. This implies that the set of costs where the high-cost firm prefers not researching, given that its rival has terminated research, equals S_{00} (without licensing). Next, we show that the high-cost firm's no-research set shrinks with licensing because of the prospect of future royalties. Since the high-cost firm's no-research set under licensing contains S_{00}^A, we can conclude that $S_{00}^A \subseteq S_{00}$. Strict containment then follows from considering the incentive to research when costs are equal and showing that this incentive is strictly greater under *ex post* licensing.

□ **The equilibrium of the subgame at node *C*.** We next determine the equilibrium of the research subgame at node C. As in the subgame at A, the research game is played in strategies

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[10] This point can be illustrated with the following example. Consider the case in which firm 1 currently has a moderate cost advantage. Under licensing, the firm's current profits are higher. Suppose that this firm were to research so successfully that it achieved a monopoly position. Firm 1's profits upon this realization would be the same with or without licensing. Hence, in this example, the *realized* gain to research falls when licensing is made possible, and one cannot exclude in general the possibility that the *expected* gain to researching falls with licensing.

$\{0, 1\}$, and *ex post* licensing is a possibility after research results are realized. In this case, however, an *ex ante* license contract has been struck at a royalty rate $R \leq |m_2 - m_1|$.

For expositional ease, assume that $m_2 > m_1$. The payoffs to both firms in the subgame at C are identical to the payoffs achieved if the firms entered the subgame at A with costs $(m_1, m_1 + R)$. Whatever the final cost pairs realized after the research decisions, the royalty set in the subsequent *ex post* licensing agreement will be the royalty that would have been set had firm 2 entered the game with costs $m_1 + R$ and no licensing option. In effect, firm 2 is guaranteed a cost no greater than $m_1 + R$. The payoffs to the research decisions at node C are therefore $V_1^L(m_1, m_1 + R; p_1, p_2)$ and $V_2^L(m_1, m_1 + R; p_1, p_2)$, where $V_i^L(m; p)$ is defined above as the equilibrium payoffs in equations (1a)–(5a).

We can now determine Condition 1 for branch D of Figure 4 to be an equilibrium of the licensing game, given an *ex ante* contract with $R \leq |m_2 - m_1|$ (when $m_1 \leq m_2$):

$$V_1^L(m_1, m_1 + R; 1, 0) \leq V_1^L(m_1, m_1 + R; 0, 0) = \Pi_1^L(m_1, m_1 + R)$$

$$V_2^L(m_1, m_1 + R; 0, 1) \leq V_2^L(m_1, m_1 + R; 0, 0) = \Pi_2^L(m_1, m_1 + R). \tag{6}$$

□ **The equilibrium branch at node *B*: the *ex ante* licensing decision.** We have established Condition 1 for no research to be an equilibrium. Condition 2, that there exists a royalty R such that each firm prefers the *ex ante* licensing contract (*assuming* no subsequent research) to the alternative equilibrium, is straightforward. With (p_1^A, p_2^A) denoting the alternative equilibrium, the second condition for D to be an equilibrium of the game in Figure 4 (for $m_1 \leq m_2$) is that an $R \leq m_2 - m_1$ exists which satisfies:

$$V_1^L(m; p_1^A, p_2^A) \leq \Pi_1^L(m_1, m_1 + R)$$

$$V_2^L(m; p_1^A, p_2^A) \leq \Pi_2^L(m_1, m_1 + R). \tag{7}$$

If such a royalty exists, then an *ex ante* contract is made. Furthermore, branch D is an equilibrium for the subgame beginning at B, conditional on the royalty's satisfying the inequalities in (6).[11]

In sum, a necessary and sufficient set of conditions for no research to take place at initial cost pair m is that (6) and (7) (or the symmetric conditions for licensing by firm 2) be satisfied for some $R \leq |m_2 - m_1|$.[12]

We are now ready to analyze the net impact of both *ex ante* and *ex post* licensing on the partition of initial costs into research/no research sets.

4. The impact of licensing

■ **The net impact of *ex post* and *ex ante* licensing on research.** Given the two conditions (6) and (7) for no research to be the equilibrium when licensing becomes available, we can now ask what effect the introduction of the possibility of licensing current and future technologies has on the set of initial costs under which no research takes place. The impact of licensing on the partition in Figure 1 is shown to be neither an increase nor a decrease in the no-research set. This ambiguity arises because of two offsetting incentives that are associated with the *ex post* and *ex ante* licensing arrangements. We describe this result in the following proposition.

Define S_{00}^L as the set of costs m for which (0, 0) is an equilibrium of the research subgame under licensing.

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[11] In this section, we have not excluded the possibility that licensing will be chosen to effect a mixed strategy equilibrium other than (0, 0), e.g., to reduce the probability with which the licensee undertakes research.

[12] Note that the royalty will generally be less than the full cost difference in the case of *ex ante* licensing. Conventional wisdom has been that the profit-maximizing license fee will always equal the full cost difference.

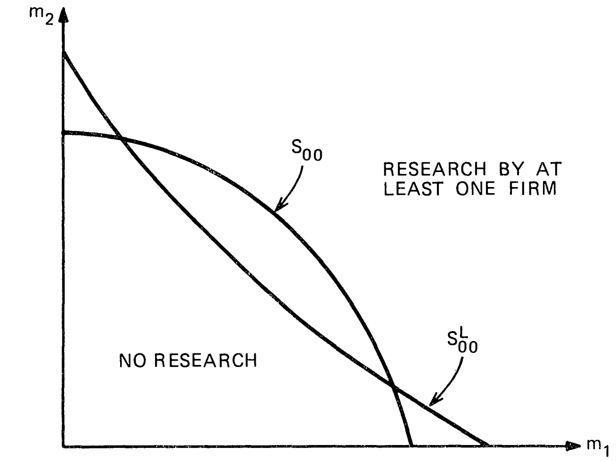
Proposition 2. Under Assumptions 1 and 2, there exists $\epsilon > 0$ such that
(a) $m \in S_{00}^L$ and $|m_2 - m_1|$ sufficiently small $\Rightarrow m \in$ interior S_{00}.
(b) $m \in S_{00}$ and m_1 or m_2 sufficiently small $\Rightarrow m \in$ interior S_{00}^L.

A typical set of partitions illustrating the proposition is given in Figure 5. The proposition states that S_{00}^L is larger than S_{00} near the axes where cost differences are large, but is smaller than S_{00} when costs are more symmetric. Thus, the overall impact of licensing is to encourage further research when costs (and hence market shares) are relatively symmetric but to eliminate research when costs are asymmetric. This impact of licensing on research and on industry costs reflects a balance of the incentives for *ex ante* and *ex post* licensing. After the results of research are known, licensing by the lowest-cost firm is clearly profitable, since it results in a savings of production costs, which can be shared by the firms (or, as in our model, captured entirely by the licensor). This incentive for licensing leads to further research when research would stop without licensing and when variation in costs is small, because a firm considering research foresees these additional profits from further research. When cost differences are large, however, the high-cost firm, which is the one engaging in research, faces relatively little chance of collecting royalties, and is therefore not greatly encouraged by the possibility of *ex post* licensing.[13]

Just as *ex post* licensing can be profitable in eliminating production cost inefficiencies, *ex ante* licensing can eliminate expenditures on research that are, from the perspective of the firms' collective interest, inefficient. *Ex ante* licensing discourages research when existing costs are most asymmetric. When one firm has very low costs and the other is undertaking expensive research to reach a more competitive cost position, it pays them to agree on a licensing contract whereby the second firm is provided with a more favorable cost position than its current one. The research expenses of the second firm are avoided entirely. From the perspective of the low-cost firm, it pays to offer a licensing contract to discourage research by competitors and thus to eliminate the chance that the competing firm will discover a very competitive or even superior technology.[14] The net effect of the *ex ante* and *ex post*

FIGURE 5

THE IMPACT OF LICENSING ON THE RESEARCH/NO RESEARCH PARTITION



[13] Another incentive for licensing arises if the assumption of constant returns to scale is relaxed. If there are eventually diminishing returns to scale, production beyond a certain output will be at a lower average cost if undertaken by a second firm. We are grateful to a referee for this point.

[14] This result is consistent with results in Gallini (1984). In her model as well an *ex ante* licensing contract is always struck when the returns from research are asymmetric for the low- and high-cost firms. It might also be

incentives for licensing is to encourage further research when variation in industry costs is low and to discourage it when costs are asymmetric.

Note that although the low-cost firm offers the maximum acceptable royalty to its rival, they share the gains from the replacement of inefficient technology. This accords well with evidence on licensing contracts.[15]

□ **The impact of licensing on the equilibrium costs and price.** We have examined the impact of licensing on the set of costs at which innovation will terminate, but we have left open the issue of its effect on the set of costs at which production will take place. This issue involves a comparison of (c_1, c_2) without licensing to $(c_1, c_1 + R)$ with licensing (for $c_1 \leq c_2$). A closely related question, also remaining, is the effect of licensing on the equilibrium market price. If one could show that the price falls when licensing is introduced, then the conclusion that licensing improves welfare (in the Pareto sense) could be reached, since consumers would benefit and firms cannot be made worse off with the option to enter license agreements.

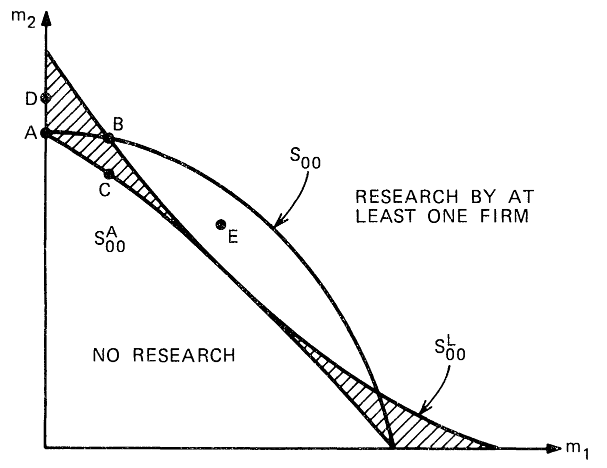
To address these issues it is useful to consider Figure 6, which depicts the sets S_{00}^A, S_{00}^L, and S_{00}—the no-research sets in the alternative equilibrium (at A), the licensing game, and the no-licensing game. Note that S_{00}^A can be characterized alternatively as the set of initial costs at which an *ex ante* agreement is struck at a full royalty, $|m_2 - m_1|$; at any m in this set the licensor need not offer a lower royalty to dissuade research, since no research will take place at the full royalty.

In $S_{00}^L \setminus S_{00}^A$ (the shaded region of Figure 6), an *ex ante* agreement is struck, but at a royalty less than $|m_2 - m_1|$. The final cost pair $(m_1, m_1 + R)$ at which production occurs must be in the set S_{00}^A to ensure no research. This illustrates a third characterization of S_{00}^A: as the set of all possible final production cost pairs under licensing.

The effect of licensing on the final cost pair in the shaded region of Figure 6 is ambiguous because it is dependent on the initial cost pair. One can easily find initial cost pairs where

FIGURE 6

THE IMPACT OF LICENSING ON PRODUCTION COSTS AND PRICE



possible for the firms to engage in a cross licensing scheme. Under this scheme, the firms could charge each other a per unit royalty, ostensibly for the use of each other's technology. This per unit royalty, could be set in such a way that at both firm 1 and firm 2's effective production costs, $m + R$, the monopoly price could be achieved. Both firms could be made better off under such a scheme. But courts are often suspicious of cross licensing arrangements that involve the entire industry, especially when research has been suppressed.

[15] Caves, Crookell, and Killing (1983) indicate that contracts between a licensor and potential licensee over the shares of expected rents, leave one-third to one-half of the rents for the licensor.

the effect is positive and others where the effect is negative. We illustrate this with two examples: points *B* and *D* in Figure 6. Consider first point *B* (or any cost pair in $S^L_{00} \cap S_{00} \setminus S^A_{00}$). At *B* research would stop in both the licensing game and in the absence of licensing. Without licensing, however, the final cost pair would be at *B*, whereas with licensing an *ex ante* contract would be negotiated at a cost pair no higher than *C*. Hence, for initial costs *B*, licensing reduces the actual production cost pair and the equilibrium price. In contrast, if the initial cost pair is *D*, licensing will increase the *expected* final cost pair; at *D* research continues in the no-licensing case, whereas in the licensing game research terminates and an *ex ante* contract is struck at point *A*. Finally, for points in $S_{00} \setminus S^L_{00}$, such as point *E* in the figure, research takes place only under licensing. Hence, expected production costs will fall as a result of licensing in that the final cost pair may be to the lower left of *E*. As with costs, the effect of licensing on the price is ambiguous.

In sum, for asymmetric initial costs, the final costs and price under licensing exceed the expected values in the absence of licensing; in a market with small variation in production costs, the expected final costs and price will fall with licensing.[16] Licensing increases the difference in expected final production costs when initial costs are asymmetric, suggesting a dampening effect of licensing on the "natural tendency towards equal-sized firms" that Reinganum attributes to purely noncooperative R&D activity.

5. Conclusion

■ This article has explored both the effects of trade in the market for information on technology and the gains from such trade. In addition to showing why licensing to rival producers can be profitable, the model yields propositions that are, in principle, empirically testable. Licensing tends to stimulate innovation when the industry variation in costs is low, and leads to less innovation and possibly higher market prices when costs are asymmetric. Equivalently, licensing reduces innovation in a concentrated industry and increases innovation in an unconcentrated industry. Licensing contracts may stipulate royalty rates less than the cost advantage of the licensor. These effects result from the balance of the two distinct incentives for licensing we discussed.

In our model firms always license, whether *ex ante* or *ex post*. Empirical evidence suggests, however, that firms are often reluctant to license their technologies since they may be giving their rivals the knowledge necessary to develop a similar or even better technology (Scherer, 1980, pp. 450–456). This disincentive to license can be captured by relaxing the assumption of stationarity in our model and allowing the distribution of research results to depend on the firm's current technological knowledge. In this extended model the disincentive for licensing may more than offset the two positive incentives and yield an explanation of why licensing is not always observed.[17]

In industries where information on technology is private, the impact of licensing analyzed here is a prediction about the impact of patent protection. The role of patents in this model is to allow the flow of information by protecting property rights under licensing. This contrasts with the traditional view that patents invariably create monopolies by prohibiting the exploitation of information flow.[18]

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[16] Note, however, that if initial costs are extremely asymmetric, then the low-cost firm may let its rival take a research draw. In this case, licensing has no effect on the research decision, the expected final production costs, or the expected price.

[17] Simulations of an infinite time model for both stationary and nonstationary distributions are available from the authors upon request.

[18] An effect that emerges in this formulation of patents, which has been ignored in earlier models of optimal patent policy, is that reducing patent life will discourage some firms from licensing at all since, as a consequence, they may choose not to acquire a patent when information is private. Hence, a reduction in patent protection can lead to *more* concentration in the eventual (postpatent period) market structure.

Appendix

■ The proofs of the Lemma and Propositions 1 and 2 follow.

Proof of Lemma. Denote by $P(c_1, c_2)$ the equilibrium price in a Cournot-Nash game with constant costs (c_1, c_2). Consider a pair of Cournot duopolists with unit costs c_1 and $c_2 > c_1$, who have established a license arrangement whereby firm 2 uses the low-cost technology at a royalty of R per unit. The equilibrium quantities, price, and firm 2's profit are identical to the equilibrium values in a Cournot duopoly with costs $(c_1, c_1 + R)$ and no licensing.

For $R \leq c_2 - c_1$, the profits obtained in the licensing equilibrium can be expressed as

$$\Pi_1 = (P - c_1)Q_1 + RQ_2; \qquad \Pi_2 = [P - (c_1 + R)]Q_2, \tag{A1}$$

whence

$$\Pi \equiv \Pi_1 + \Pi_2 = (P - c_1)Q, \quad \text{where} \quad Q \equiv Q_1 + Q_2. \tag{A2}$$

From (A2) Π_1 can be expressed as

$$\Pi_1 = (P - c_1)Q - \Pi_2(c_1, c_1 + R), \tag{A3}$$

whence

$$\frac{d\Pi_1}{dR} = \frac{d[(P - c_1)Q]}{dP} \cdot \frac{\partial P}{\partial R} - \frac{\partial \Pi_2}{\partial R}, \tag{A4}$$

where the partial derivatives are calculated from $P(c_1, c_1 + R)$ and $\Pi_2(c_1, c_1 + R)$. Now, $d[(P - c_1)Q]/dP \geq 0$ since P is not greater than the monopoly price under costs c_1. Since $\partial P/\partial R > 0$ and, by Assumption 2, $\partial \Pi_2/\partial R < 0$, (A4) implies that $d\Pi_1/dR \geq 0$. Therefore, the optimal royalty is at least $c_2 - c_1$. But, since it cannot be greater, the optimal royalty equals $c_2 - c_1$. *Q.E.D.*

Proof of Proposition 1. Define the "termination sets" T_1 and T_1^A as follows:

$$T_1 \equiv \{m | V_1(m; 0, 0) \geq V_1(m; 1, 0)\}$$

and

$$T_1^A \equiv \{m | V_1^L(m; 0, 0) > V_1^L(m; 1, 0)\},$$

and similarly for firm 2. These are called "termination sets" because for m in such a set, the firm's best response to "no research" is "no research." Then

$$S_{00} = T_1 \cap T_2 \tag{A5}$$

$$S_{00}^A = T_1^A \cap T_2^A. \tag{A6}$$

Define $M_1 \equiv \{m | m_1 \geq m_2\}$ and $M_2 \equiv \mathbb{R}^2 \setminus M_1$. Define also

$$n_1(m) \equiv V_1(m; 1, 0) - V_1(m; 0, 0) = \int_{\underline{c}_1}^{m_1} [\Pi(c_1, m_2) - \Pi_1(m_1, m_2)] dF(c_1) - k$$

and $n_1^L(m)$ analogously. The border of T_1 is defined by $n_1(m) = 0$ and has slope

$$\left.\frac{dm_1}{dm_2}\right|_{n_1(m)=0} = -\frac{\partial n_1/\partial m_2}{\partial n_1/\partial m_1}. \tag{A7}$$

Assumption 3 implies that the slope in (A7) is less than -1. This and the symmetry of T_1 and T_2 about the line $m_1 = m_2$ imply immediately that:

$$T_1 \cap M_1 \subset T_2 \cap M_1; \qquad T_2 \cap M_2 \subset T_1 \cap M_2. \tag{A8}$$

From (A5) and (A8) and the fact that $M_1 \cup M_2 = \mathbb{R}^2$,

$$S_{00} = \{T_1 \cap M_1\} \cup \{T_2 \cap M_2\}. \tag{A9}$$

Equation (A9) means that the boundary of S_{00} is determined by the high-cost firm. From (A6) and $M_1 \cup M_2 = \mathbb{R}^2$, $S_{00}^A = (T_1^A \cap T_2^A \cap M_1) \cup (T_1^A \cap T_2^A \cap M_2)$, whence

$$S_{00}^A \subseteq (T_1^A \cap M_1) \cup (T_2^A \cap M_2). \tag{A10}$$

From (A9) and (A10), to show that $S_{00}^A \subseteq S_{00}$, it suffices to demonstrate that

$$T_1^A \cap M_1 \subseteq T_1 \cap M_1 \quad \text{and} \quad T_2^A \cap M_2 \subseteq T_2 \cap M_2. \tag{A11}$$

To prove the first set inequality of (A11), let $m \in T_1^A \cap M_1$, i.e., $m \in T_1^A$ with $m_1 \geq m_2$. At m

$$0 \geq V_1^L(m; 1, 0) - V_1^L(m; 0, 0) = \int_{\underline{c}_1}^{m_1} [\Pi_1^L(c_1, m_2) - \Pi_1^L(m_1, m_2)] f(c_1) dc_1 - k. \tag{A12}$$

Since $\Pi_1^L(s_1, s_2) > \Pi_1(s_1, s_2)$ for $s_1 < s_2$ and $\Pi_1^L(s_1, s_2) = \Pi_1(s_1, s_2)$ for $s_1 \geq s_2$, the right-hand side of (A12) is no less than

$$\int_{\underline{c}_1}^{m_1} [\Pi_1(c_1, m_2) - \Pi_1(m_1, m_2)]f(c_1)dc_1 - k = V_1(m; 1, 0) - V_1(m; 0, 0), \tag{A13}$$

Therefore, the right-hand side of (A13) is nonpositive, which implies $m \in T_1 \cap M_1$. The second set inequality of (A11) is analogous. This proves that $S_{00}^A \subseteq S_{00}$. To prove that S_{00}^A is a *strict* subset of S_{00}, show that $V_1^L(m; 1, 0) - V_1^L(m; 0, 0)$ is positive at $\tilde{m} \in T_1$ defined by $\tilde{m}_1 = \tilde{m}_2$, $n_1(\tilde{m}) = 0$, using a comparison analogous to that of (A12) and (A13). This shows that $\tilde{m} \notin T_1^A$.

To prove that the boundaries of the sets S_{00} and S_{00}^A intersect the $m_2 = \underline{c}$ axis at the same point, note that since this axis is contained in T_2^L and T_2, it follows from (A5) and (A6) that the intersection points are determined by the respective conditions

$$V_1(m_1, \underline{c}; 1, 0) - V_1(m_1, \underline{c}; 0, 0) = 0 \tag{A14}$$

$$V_1^L(m_1, \underline{c}; 1, 0) - V_1^L(m_1, \underline{c}; 0, 0) = 0. \tag{A15}$$

From the definitions of V_1 and V_1^L and $\Pi_1^L(m_1, \underline{c}) = \Pi_1(m_1, \underline{c})$, (A14) and (A15) are equivalent. The intersections of S_{00} and S_{00}^L with the $m_1 = \underline{c}$ axis are identical by the analogous argument. *Q.E.D.*

Proof of Proposition 2. The intersection of ∂S_{00}^L with the 45° line coincides with the intersection of ∂S_{00}^A with the 45° line (since the possibility of *ex ante* licensing is irrelevant when $m_1 = m_2$). Part (a) of this proposition therefore follows from the argument proving strict containment in Proposition 1, together with continuity of the borders of the sets.

To prove (b) let $(\underline{c}, \bar{m}_2)$ be the intersection of ∂S_{00} with the $m_1 = \underline{c}$ axis. Clearly,

$$\bar{m}_2 = \max \{m_2 | (\underline{c}, m_2) \in T_2\}.$$

That is, $(\underline{c}, \bar{m}_2)$ is the intersection of the axis with ∂T_2. By straightforward continuity arguments, to prove (b) it suffices to show that there is a $\delta > 0$ such that $(\underline{c}, \bar{m}_2 + \delta) \in S_{00}^L$.

At $(\underline{c}, \bar{m}_2 + \delta)$ consider the licensing contract with royalty $= \bar{m}_2 - \underline{c}$. We shall show that this royalty satisfies (6) and (7) for δ sufficiently small. For firm 1 (6) is satisfied trivially. For firm 2 $(\forall m_2)\Pi_2^L(\underline{c}, m_2) = \Pi_2(\underline{c}, m_2)$. This implies

$$(\forall m_2) n_2^L(\underline{c}, m_2) = n_2(\underline{c}, m_2). \tag{A16}$$

Since $n_2(\underline{c}, \bar{m}_2) = 0$, (A16) implies that $n_2^L(\underline{c}, \bar{m}_2) = 0$. In other words, at a royalty of $\bar{m}_2 - \bar{c}$, (6) is satisfied with equality for firm 2.

To prove that (7) is satisfied at $(\underline{c}, \bar{m}_2 + \delta)$ by a royalty of $\bar{m}_2 - \underline{c}$, note first that the alternative equilibrium at $(\underline{c}, \bar{m}_2 + \delta)$ is (0, 1). Firm 1's optimum is (trivially) no research and $n_2^L(\underline{c}, \bar{m}_2 + \delta) = n_2(\underline{c}, \bar{m}_2 + \delta) > 0$ by (A16) and the definition of $\bar{m}_2$, so that firm 2's equilibrium strategy is to do research. Thus, (7) reduces to $V_i^L(\underline{c}, \bar{m}_2 + \delta; 0, 1) \leq \Pi_i^L(\underline{c}, \bar{m}_2)$, for both i, or:

$$V_1^L(\underline{c}, \bar{m}_2 + \delta; 0, 1) \leq \Pi_1(\underline{c}, \bar{m}_2) + \bar{m}_2 Q_2(\underline{c}, \bar{m}_2) \tag{A17}$$

and

$$V_2^L(\underline{c}, \bar{m}_2 + \delta; 0, 1) \leq \Pi_2(\underline{c}, \bar{m}_2). \tag{A18}$$

As $\delta \rightarrow 0$, the left-hand side of (A17) $\rightarrow V_1^L(\underline{c}, \bar{m}_2; 0, 1)$, which is strictly less than $V_1^L(\underline{c}, \bar{m}_2; 0, 0) =$ the right-hand side of (A17). Therefore (A17) holds for δ sufficiently small.

By the definition of $\bar{m}_2$, $\Pi_2(\underline{c}, \bar{m}_2) \equiv V_2(\underline{c}, \bar{m}_2; 0, 0) = V_2(\underline{c}, \bar{m}_2; 0, 1) = V_2^L(\underline{c}, \bar{m}_2; 0, 1)$, where the last equality follows from the argument leading to (A16). Since $V_2^L(\underline{c}, c_2; 0, 1)$ is strictly decreasing in c_2, this proves (A18), and hence part (b) of the proposition. *Q.E.D.*

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