I. Introduction

The literature on innovation has focused primarily on the decisions of firms to engage in research and development and specifically on the interaction between market structure and the incentives to innovate (e.g., Dasgupta and Stiglitz 1980; Lee and Wilde 1980; Reinganum 1982, 1983). However, having engaged in innovating activity, firms also have to decide when and how to deploy the innovations. The timing of adoption of innovations has been studied by several authors, considering the preemptive aspects of the adoption decision (e.g., Reinganum 1981a, 1981b; Fudenberg and Tirole 1985, 1987). How to deploy innovations to fully realize their potential rents is the focus of this paper.

The following example may illustrate the problem and the deployment options often available. Suppose that Valmet, a Finnish manufacturer of paper machines, develops a unique and highly effective pollution control technology, which substantially reduces pollution originated by paper machines. As is usually the case, this innovation may be deployed in several ways. The most obvious option faced by the firm is to keep the

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innovation to itself, that is, to use it captively, to create a competitive advantage in product markets. Valmet may incorporate the innovation in its own paper machines to strengthen its product-market position. Paper producers that want to benefit from the innovation have to buy their paper machines from Valmet. Alternatively, the firm may share the innovation with other firms. In our example, Valmet may share the new technology with other paper machine manufacturers through licensing contracts, outsourcing agreements, or other types of collaborative arrangements. Finally, the firm may capture the rent potential of the innovation through independent selling, that is, it may use the innovation to produce a complementary product or service, which is sold separately to consumers. In fact, Valmet may decide to sell the pollution control device independently to paper producers as an add-on or an upgrade.

The deployment decision has been extensively studied from a transaction cost perspective (e.g., Williamson 1975, 1985; Teece 1986, 1987; Hennart 1988, 1991; Kogut 1988; Hill 1992; Chi 1994). This approach proposes that firms should organize their boundary activities with other firms according to the criterion of minimizing production and transaction costs. Transaction costs refer to the negotiating, monitoring, and enforcement costs that have to be borne to allow an exchange between two parties. While this literature highlights the importance of transaction costs, additional insights can be gained by studying the competitive implications of the interactions among firms’ asset positions and deployment strategies, under given environmental constraints.

In this paper, we use a game-theoretic model to study how the combined impact of production cost differences and market competition affects the deployment decision of innovations. To focus on how competitive considerations influence the deployment decision, our model sets aside a number of factors considered in the transaction cost literature. For example, we assume that there is no uncertainty about the value of the innovation and that it is possible to share the innovation with competitors without diffusing the general knowledge underlying the innovation to be transferred. By focusing on the competitive implications of deployment decisions, our paper complements the existing literature that analyzes the deployment decision from a transaction cost perspective.

To study a broad range of deployment options, it is necessary to examine the case of an innovation that can not only be deployed captively but also sold independently to consumers or shared with other firms through collaborative agreements. For instance, the case of cost-reducing

1. Generally speaking, the sharing of an innovation can occur by one of three means: the transfer of the skills and organization routines that make up the innovation beyond the firm that presently employs it, the purchase of the service of the innovation from the firm that possesses it, or the acquisition of the part of the firm where the innovation resides (e.g., Chi 1994).
innovations would be too restrictive. Indeed, while such process innovations can be deployed captively or shared with other firms, such as competitors or suppliers of inputs, independent selling to consumers is not a feasible option. Cost-reducing innovations typically cannot be used to produce a complementary product or service that is sold separately to consumers. Consider, for example, a new production process that allows the firm to save on labor costs. Captive use and the engagement in collaborative agreements with other firms, for example, through licensing contracts, are the only deployment options. In contrast, innovations that enable a firm to improve the quality of an existing product or service usually allow for a broader range of deployment options. A new safety device or climate control system for automobiles, a new accessory for cameras, a new maintenance service, a better post-sale service, or a new home-delivery service constitute examples of quality-improving innovations.

The recent transformations at General Electric (GE) illustrate the importance of quality-improving innovations and how they may be deployed. As reported by Business Week (October 28, 1996, pp. 42–50), Jack Welch, GE’s former chairman and CEO, launched a few years ago two companywide initiatives aimed at increasing the company’s growth. The first was a drive to boost quality. The second represented a departure from captive use. Jack Welch realized that, for the company to fully appropriate the potential rents associated with its core industrial strengths in businesses as far afield as health care, aircraft engines, power generation, and utilities, GE should no longer rely on keeping these assets in-house. For example, GE Medical Systems signed exclusive multiyear service deals with big hospital chains, which involve servicing rival manufacturers’ medical equipment; and GE Aircraft Engines signed a deal with British Airways (BA), under which GE was supposed to do 85% of the engine maintenance work on BA’s entire fleet, including engines made by rivals Rolls-Royce and Pratt & Whitney. In these examples, GE decided to appropriate rents through independent selling. In other businesses, GE decided to share assets with firms that had complementary ones of its own. For instance, GE Transportation formed a joint venture with electronics specialist Harris Corp. to design and sell global-positioning systems similar to those used in air-traffic control; GE Capital decided to build a global computer outsourcing business and, in 1995, joined forces with Anderson Consulting to beat major competitors for a contract to manage LTV Corp.’s mainframe-based computer needs; and GE Power Systems agreed to manage power plants for independent power producers. To the extent that the engineering and management capabilities deployed by GE in these examples contribute to improving the quality of the underlying products or services, they constitute quality-improving innovations. According to Business Week, GE’s efforts were “closely watched . . . as
a pattern for the refashioning of an industrial company in a postindustrial economy" (ibid., pp. 43–44).

The deployment decision of quality-improving innovations is particularly interesting because, as GE’s example illustrates, the owner of such an asset often faces all the deployment alternatives identified previously. The firm may use the innovation captively, that is, it may incorporate the innovation in its own product, in an attempt to create a differentiation advantage. It may share the innovation with a competitor, for example, through a licensing contract. And it may follow an independent selling strategy, that is, it may use the innovation to produce a new component, an add-on, an upgrade, or a complementary service sold separately to consumers. Consumers may then combine this separate offering with products from competitors.

In this paper, we study the deployment of quality-improving innovations, comparing captive use, independent selling, and a particular form of sharing an innovation with competitors, licensing. In particular, we analyze how cost differences and the range of feasible licensing contracts affect the deployment decision. We identify three underlying concerns that influence the choice among the different deployment options: (1) achieving cost-efficient production, (2) ensuring coordinated pricing of the basic and enhanced products, and (3) mitigating competition within products. Furthermore, we study how the interplay of these efficiency and competitive forces favors certain deployment options relative to others.

This paper is related to the industrial organization literature on technology transfer through licensing. Several aspects of the competitive implications of deployment decisions have been identified in this literature. In general, there is an incentive to license when it results in higher industry profits, provided side payments are possible. Licensing may increase industry profits through the replacement of inefficient production techniques (e.g., McGee 1966; Salant 1984; Gallini and Winter 1985; Katz and Shapiro 1985), by increasing industry demand (e.g., Shepard 1987; Farrell and Gallini 1988), by facilitating collusion (e.g., Shapiro 1985; Lin 1996), by eliminating R&D expenditures that are wasteful from the industry’s point of view (e.g., Gallini 1984; Gallini and Winter 1985), or by deterring entry of a stronger competitor.

2. Some quality-improving innovations cannot be used to produce a complementary product or service that is sold separately to consumers. Consider, for example, a technological capability that allows the production of a new engine or a new rear suspension for cars. In these cases, independent selling is not possible. Captive use and the engagement in collaborative agreements with other firms are the only possible uses of the innovation.

3. In some cases, the quality-improving innovation may have a strong tacit dimension, and, therefore, cannot be transferred through a licensing contract to a competitor. However, in such cases, the innovating firm may produce the complementary product or service and sell it to other firms. Much of what we say about licensing in this paper also applies to situations where we have such sourcing agreements.
once the patent expires, prolonging the innovating firm's dominant position in the industry (e.g., Rockett 1990).

While this literature focuses on cost-reducing innovations or new products, comparing captive use and licensing, little attention has been paid to quality-improving innovations. Furthermore, as already mentioned, the deployment decision of these innovations is particularly interesting because, besides using them captively or sharing them with competitors, for example, through licensing agreements, firms often face the possibility to follow an independent selling strategy. Our concern in this paper is to study the deployment of quality-improving innovations, comparing these three deployment options.

We show that, as in the case of cost-reducing innovations (e.g., McGee 1966; Salant 1984; Gallini and Winter 1985; Katz and Shapiro 1985), licensing a quality-improving innovation may increase industry profits through the replacement of inefficient production techniques. If the innovating firm has a disadvantage in the production of the underlying (or basic) product, licensing leads to cost-efficient production. However, in the case of quality-improving innovations, cost efficiency may also be achieved through independent selling, because under this deployment strategy consumers may combine the innovation with the underlying (or basic) product offered by the most efficient firm. We discuss how, when both licensing and independent selling induce the replacement of inefficient production techniques, the choice of the optimal deployment strategy is influenced by two competitive forces: the need to coordinate pricing across the basic and enhanced products and the desire to limit competition within products. We identify situations where, in spite of increasing industry profits relative to captive use through the replacement of inefficient production techniques, licensing is dominated by independent selling. This makes the deployment decision of quality-improving innovations particularly complex and suggests that independent selling is, in fact, an interesting strategy.

This paper also contributes to the "resource-based" view of strategy, a prominent perspective in the strategic management field today (e.g., Rumelt 1984, 1987; Wernerfelt 1984; Barney 1986, 1991; Dierickx and Cool 1989; Peteraf 1993; Henderson and Cockburn 1994). This approach maintains that firms may be heterogeneous with respect to the bundle of resources they control. Furthermore, since some of these resources, such as a firm's reputation or other information-based resources, are imperfectly mobile (i.e., cannot be bid away from their current employer) and imperfectly imitable (i.e., other firms encounter difficulty in replicating the resource on their own), resource uniqueness may persist over time.4

4. It is noteworthy that, although only in the last 15 years the focus on the strategic role of firms' idiosyncratic resources came to the core of the strategic management field, the roots
As pointed out by Chi (1994), a firm that owns an imperfectly mobile resource, that is, a resource that cannot be bid away from its current employer, may face the opportunity to deploy it in different ways. For example, replication of the resource under the guidance of its current employer may still be possible. In other words, “firm-specific resources that are immobile across firms are not necessarily untradeable” (Chi 1994, p. 274). This means that, in addition to choosing which resources to develop and how to accumulate them, firms have to decide how to deploy their unique (or scarce) resources to fully realize their potential rents (e.g., Gabel 1984; Wernerfelt 1984). This paper addresses this issue. While the paper is framed in terms of innovations, the assets examined here may correspond to imperfectly mobile and imperfectly imitable resources. In this perspective, we propose a game-theoretic model to study rent-maximizing deployment options of quality-improving resources.

As explicitly recognized by several authors (e.g., Conner 1991; Mahoney and Pandian 1992), the resource-based view can be enriched by incorporating game-theoretic models that study the implications of the interactions among competitors’ resource positions and competitive strategies under given environmental constraints. As Conner puts it, “It is apparent that a resource-based approach views a firm’s performance as resulting from the simultaneous interaction of at least three forces: the firm’s own asset base; the asset bases of competitors; and constraints emanating from the broader industry and public policy environment. Although further development of the resource-based approach will benefit from employment of a variety of research methods, developing the theoretical implications of such complex interactions is an area in which the resource-based theory may gain from application of the new IO’s game-theoretic techniques” (1991, p. 145).

Studying alternative deployment options is meaningful only when the underlying asset is capable of generating rents. The ability of an asset to generate rents can be traced back, among other contributions, to David Ricardo’s (1965 [1817]) discussion of resource deployment and rents, to Selznick’s (1957) notion of “distinctive competencies,” to Penrose’s (1959) theory about the growth of the firm, and to Nelson and Winter’s (1982) evolutionary theory of the firm.

5. Nelson and Winter (1982, ch. 5) elaborate on the distinction between replication (i.e., the situation where a firm is trying to apply a routine it already possesses on a larger scale) and imitation (i.e., the situation where one firm is trying to copy a routine of some other firm). What distinguishes imitation from replication “is the fact that the target routine is not in any substantial sense available as a template” (p. 123). Therefore, imitation is more problematic than replication. Imitation with the active support of the firm being imitated is seen as an intermediate case between imitation and replication.

asset to generate rents may be constrained by two problems. The first problem relates to mobility and imitability of the asset, two concepts that have been extensively addressed by "resource-based" theorists (e.g., Dierickx and Cool 1989; Barney 1991; Peteraf 1993). For example, competitors are interested in some kind of asset sharing agreement only when they find it difficult to accumulate the asset internally or substitute the asset with another one.

The second problem relates to excludability, an issue that has received much less attention by resource-based theorists. This problem can perhaps best be illustrated by the following example, suggested by Meade (1952). Take the case of an apple grower and a beekeeper. The apple grower provides nectar to the beekeepers' bees. In turn, the bees provide fertilization services to the apple grower. Theoretically, one could envision an arrangement where each pays for the product (nectar) or service (fertilization) provided by the other. The reason why both are provided free of charge is "the inability of a producer of a good or service physically to exclude users, or to control the rationing of his produce among them" (Bator 1958, p. 361, footnote 8). The problem of excludability may become particularly acute in the case of sharing assets with competitors. As discussed later, the excludability problem then acquires a particular twist, not often noted in the literature, namely, the difficulty to exclude oneself from using the asset.

II. The Model

We now introduce the game-theoretic model used to study the deployment decision of quality-improving innovations.

Consider an industry with two firms, indexed by $j = 1, 2$, which produce a homogeneous product $x_B$ (the basic or original product), at a constant marginal cost $c_j$. In addition, one firm, say, firm 2, developed a complementary product or service $y$ that, when used with product $x_B$, results in an enhanced (higher-quality) product $x_E$. Specifically, one unit of the enhanced product $x_E$ consists of one unit of the basic product $x_B$ plus one unit of the innovation $y$. Product $x_E$ is vertically differentiated: If both products are offered at the same price, consumers strictly prefer to buy product $x_E$ to product $x_B$. Without loss of generality, we may assume that the marginal cost of production of the complementary product or service, $c_y$, equals zero. The innovator, firm 2, may either be a low-cost producer ($c_2 \leq c_1$) or the high-cost producer ($c_2 > c_1$) of the basic product.

7. Following the industrial organization literature on vertical differentiation (e.g., Gabszewicz and Thisse 1979; Shaked and Sutton 1982), we say that firm A has a vertical differentiation advantage over firm B if all consumers prefer the product of firm A to the product of firm B when both products are offered at the same price.
We define \( D_B(p_B, p_E) \) as the demand for product \( x_B \), where \( p_B \) is the price of the basic product \( x_B \) and \( p_E \) is the price of the enhanced product \( x_E \). Similarly, \( D_E(p_E, p_B) \) is the demand for product \( x_E \). \( D_E(p_E, p_B) \) is strictly positive for all nonnegative prices. \( D_B(p_B, p_E) \) is strictly positive for any pair of prices \( (p_B, p_E) \) such that \( p_B < p_E \) and equal to zero for any pair of prices such that \( p_B \geq p_E \) (due to vertical differentiation). \( D_B \) and \( D_E \) are differentiable in both arguments for any pair of prices \( (p_B, p_E) \) such that \( p_B < p_E \). Furthermore, for any pair of prices such that \( p_B < p_E \), \( D_{ii} = \frac{\partial D_i}{\partial p_i} < 0 \), \( D_{ik} = \frac{\partial D_i}{\partial p_k} > 0 \) and \( |D_{ii}| > |D_{ik}| \).

We study the choice between captive use, independent selling, and licensing. Several licensing contracts are considered. In general, a licensing agreement may stipulate a fixed-fee \( F \) and a royalty \( r \) per unit of \( x_E \) produced by the licensee. However, a royalty may not always be feasible. For example, it may be difficult for the licensor to monitor the licensee’s output, which is necessary to enforce a contract specifying a royalty. Therefore, we devote a part of this paper to situations where the licensor is restricted to fixed-fee licensing contracts.

A license may be exclusive or nonexclusive. The excludability problem mentioned previously lies at the heart of this distinction. In an exclusive license, the right to use the innovation is granted to the licensee to the exclusion of all the other firms, including the licensor. It is important to note that explicit contractual language does not necessarily guarantee that the license is effectively exclusive. A common problem is that the licensor may be able to invent around the licensed technology. After all, it is the licensor who came up with the technology and who wrote the patent. Hence, it is the licensor who is in the best position to invent around it. If explicit contractual language is not able to prevent the licensor to do so, then, effectively, the license is nonexclusive.

We consider both the case where exclusive licensing is possible (i.e., the contract is “watertight”) and the case where it is not possible.

We consider a two-stage game. In stage 1, the deployment stage, firm 2 decides how to deploy the quality-improving innovation. First, the firm may follow a captive-use strategy, selling the enhanced product \( x_E \), consisting of one unit of the basic product \( x_B \) and one unit of the innovation \( y \). Second, firm 2 may choose a licensing strategy. Under the assumption that the innovating firm has all the bargaining power, firm 2 proposes a contract that allows it to capture all the gains from licensing, subject to the constraint that firm 1 is willing to accept the contract. This assumption affects only the distribution of profits between the two firms (which is not our concern in this paper) and not the optimality of licensing relative to the other deployment decisions. The results are unaffected by changing the distribution of bargaining power, provided that the licensor earns a nonzero share of the gains from licensing. Since side payments are possible (through the fixed fee), licensing is
beneficial whenever it leads to higher joint profits. Finally, firm 2 may follow an independent selling strategy, selling the complementary product or service separately to consumers, who can then combine it with the basic product offered by both firms. In stage 2, the pricing stage, firms set prices simultaneously, after having observed the deployment decision.

When the innovating firm has a cost advantage in the production of the basic product \( c_2 < c_1 \) or if the two firms are equally cost efficient \( c_2 = c_1 \), captive use is clearly the optimal deployment decision. In this case, the innovating firm has no incentive to engage in licensing or independent selling. This is so for two reasons. First, licensing or independent selling does not lower production costs and, therefore, does not create any efficiency gains. Second, by using the quality-improving innovation noncaptively, the innovating firm loses its monopoly in the enhanced product (or in one of its components, the basic product to be consumed with the complementary product or service), thereby inducing rent dissipation due to increased competition.

When the innovating firm has a cost disadvantage in the production of the basic product \( c_2 > c_1 \), production efficiency favors either licensing or independent selling over captive use. However, in this case, to track the implications of market interaction and competition, we have to characterize the subgame perfect equilibria of the game. This is done in section III.

III. Deployment Decision

To characterize the optimal deployment decisions when the innovating firm has a cost disadvantage in the production of the basic product \( c_2 > c_1 \), we first compare captive use and independent selling.

A. Captive Use vs. Independent Selling

Assume first that firm 2 uses the quality-improving innovation captively selling the enhanced product \( x_E \) in the product market. In this case, firm 1 offers \( x_{B1} \), charging a price \( p_{B1} \), and firm 2 offers \( x_{B2} \), charging a price \( p_{B2} \), and \( x_{E2} \), charging a price \( p_{E2} \).
The Nash equilibrium of the resulting pricing game can be characterized as follows. Due to competition between the two firms in $x_B$, in equilibrium firm 1 (the low-cost firm) sells $x_{B1}$ charging a price $p_{B1}^{cu} \leq c_2$, while firm 2 does not sell $x_{B2}$ and sells $x_{E2}$ charging a price $p_{E2}^{cu}$ (the superscript $cu$ indicates equilibrium under captive use).\(^1\) The equilibrium profits of firms 1 and 2 are given, respectively, by

\[
\begin{align*}
\Pi_1^{cu} &= D_B(p_{B1}^{cu}, p_{E2}^{cu}) \cdot (p_{B1}^{cu} - c_1) \\
\Pi_2^{cu} &= D_E(p_{E2}^{cu}, p_{B1}^{cu}) \cdot (p_{E2}^{cu} - c_2).
\end{align*}
\]

Suppose now that firm 2 sells the enhancement independently as a complementary product or service to consumers, who can then combine it with the basic product $x_B$ offered by both firms. In this case, firm 1 offers $x_{B1}$ charging a price $p_{B1}$, and firm 2 offers $x_{B2}$ charging a price $p_{B2}$ as well as $y$ charging a price $p_y$.

The Nash equilibrium of the resulting pricing game can be characterized as follows. Since firm 1 faces competition of firm 2 in $x_B$, in equilibrium firm 1 charges a price $p_{B1}^{is} \leq c_2$, supplying the whole market for $x_B$, and firm 2 sells $y$, charging a price $p_{E2}^{is} > 0$ (the superscript indicates equilibrium under independent selling).\(^2\) The equilibrium profits of firms 1 and 2 are given, respectively, by

\[
\begin{align*}
\Pi_1^{is} &= [D_B(p_{B1}^{is}, p_{B1}^{is} + p_y^{is}) + D_E(p_{B1}^{is} + p_y^{is}, p_{B2}^{is})] \cdot (p_{B1}^{is} - c_1) \\
\Pi_2^{is} &= D_E(p_{B1}^{is} + p_y^{is}, p_{B1}^{is}) \cdot p_y^{is}.
\end{align*}
\]

To compare firm 2’s profits under captive use and independent selling assume, for a moment, that the price of the basic product is the same under these two deployment alternatives ($p_{B1}^{cu} = p_{B1}^{is}$). In this case, firm 2’s profits under independent selling are always greater than or equal to its profits under captive use ($\Pi_2^{is} \geq \Pi_2^{cu}$). The intuition is as follows. Independent selling leads to low-cost production, because in equilibrium the basic product is produced only by the most efficient firm. Since the price charged by firm 1 for the basic product is smaller than or equal to firm 2’s cost of production of that product ($p_{B1}^{is} \leq c_2$), the innovating

11. To ensure the existence of such an equilibrium, we assume that, for $p_{B1} \in [c_1, c_2]$ and $p_{E2} > c_1$, the profit function of firm 1 is concave in $p_{B1}$ and the profit function of firm 2 is concave in $p_{E2}$.

12. For any $p_y > 0$, $p_{E2}(\equiv p_y + p_y) > p_{B2}$, and, consequently, we may restrict our attention to situations where $D_B$ and $D_E$ have the desired properties mentioned previously. To ensure the existence of an equilibrium of this pricing game, we assume that, for $p_{B1} \in [c_1, c_2]$ and $p_y > 0$, the profit function of firm 1 is concave in $p_{B1}$ and the profit function of firm 2 is concave in $p_y$. 
The Strategic Deployment of Quality-Improving Innovations

A firm may be able to capture part of the efficiency gain. This firm may benefit from the fact that, under independent selling, consumers of the enhanced product buy the basic product at a price that is lower than its own cost to produce this product. We may define \( e = c_2 - p_{B1}^S \) as a measure of the part of the efficiency gain captured by firm 2. This is the cost reduction effect of selling the complementary product or service separately to consumers instead of using it captively.

Now, let us drop the assumption that \( p_{B1}^C = p_{B1}^S \). Indeed, the deployment decision affects industry structure and, therefore, it may influence the equilibrium price \( p_{B1} \). From the first-order conditions, it is easy to verify that \( p_{B1}^C \) may be greater than, equal to, or smaller than \( p_{B1}^S \). Therefore, by leading to a different equilibrium price \( p_{B1} \), independent selling may have a second effect on firm 2’s profit. This competition effect may either reinforce the efficiency effect or have the opposite impact. However, even if the competition effect has the opposite impact, it is always (weakly) dominated by the efficiency effect. This is so because \( p_{B1}^C - p_{B1}^S \leq e \). As a consequence, firm 2’s equilibrium profits are greater or equal under independent selling than under captive use.\(^13\)

B. Independent Selling vs. Licensing

Since captive use is dominated by independent selling, optimal deployment is either independent selling or licensing. To compare these two deployment options, we need to look only at joint profits, the “total size of the pie.” The reason is that, under licensing, profits can be redistributed at will through the fixed licensing fee. Indeed, this fixed fee is a side payment that transfers profits between the two companies without affecting joint profits. This implies that both firms can be made better off under licensing if and only if joint profits are greater under this deployment option than under independent selling.

Exclusive Licensing. Whenever possible, exclusive licensing is preferred over nonexclusive licensing. The major drawback of nonexclusive licensing is increased product market competition and, consequently, lower joint profits. Furthermore, if the contract is “watertight”, that is, exclusivity is effectively guaranteed by explicit contractual language, the optimal licensing contract sets no royalty \( r = 0 \). This ensures that the licensee (firm 1) makes its decisions according to its true marginal cost, thus maximizing joint profits.

The Nash equilibrium of the ensuing pricing game can be characterized as follows. Firm 1 supplies both \( x_B \) and \( x_E \), charging a price

\(^{13}\) A formal proof of this result is given in Appendix A. From Appendix A, it can be seen that the profits of firm 2 are strictly greater under independent selling than under captive use unless (1) \( p_{B1}^C = p_{B1}^S = c_2 \) or (2) \( p_{B1}^C < p_{B1}^S = c_2 \) and \( |D_{B2}| = |D_{B2}| \). In these two cases, \( \Pi_2^C = \Pi_2^S \). For ease of exposition, we focus on the general case, where firm 2’s profits are strictly greater under independent selling than under captive use.
\[ p_{B1} \leq c_2 \text{ (because the two firms compete in } x_B) \]. Firm 1 chooses the prices \( p_{B1}^{el} \) and \( p_{E1}^{el} \) that maximize

\[
\Pi_{1+2} = D_E(p_{E1}, p_{B1}) \cdot (p_{E1} - c_1) \\
+ D_B(p_{B1}, p_{E1}) \cdot (p_{B1} - c_1)
\]

so that

\[ p_{B1} \leq c_2, \tag{4} \]

where \( \Pi_{1+2} \) denotes the joint profits of the two firms and the superscript \( el \) indicates equilibrium under exclusive licensing.\(^{14}\)

Both independent selling and exclusive licensing lead to cost-efficient production. However, exclusive licensing has an advantage over independent selling: It leads to coordinated pricing of the basic and the enhanced products. Under independent selling, firm 1 sells \( x_B \), while firm 2 sells \( y \). The problem with this arrangement is that firm 1’s pricing decision does not take into account the impact of the price of \( x_B \) on sales of \( y \). Similarly, firm 2’s pricing decision for the complementary product or service does not internalize the impact of the price of \( y \) on sales of \( x_B \). The result is suboptimal pricing. In contrast, exclusive licensing involves coordinated pricing of the different products and services, as they are sold by the same firm.\(^{15}\) Therefore, when exclusive licensing is possible, it is the optimal deployment decision for a high-cost firm.\(^{16}\)

**Nonexclusive Licensing.** Consider now the situation where exclusive licensing is not possible. Assume also, for the moment, that firms are restricted to fixed-fee licensing contracts.

The Nash equilibrium of the nonexclusive licensing pricing game can be characterized as follows. Due to price competition between the two firms in \( x_B \) and \( x_E \), firm 1 supplies both products, charging prices \( p_{B1} \leq c_2 \) and \( p_{E1} \leq c_2 \) (the superscript \( 1 \) indicates equilibrium under nonexclusive licensing).

Firm 1 chooses the prices \( p_{B1}^1 \) and \( p_{E1}^1 \) that maximize

\[
\Pi_{1+2} = D_E(p_{E1}, p_{B1}) \cdot (p_{E1} - c_1) \\
+ D_B(p_{B1}, p_{E1}) \cdot (p_{B1} - c_1)
\]

so that

\[ p_{B1} \leq c_2 \text{ and } p_{E1} \leq c_2. \tag{5} \]

\(^{14}\) \( \Pi_{1+2} \) is assumed to be concave in both arguments with a maximum at \( (p_{B1}^{el}, p_{E1}^{el}) \).

\(^{15}\) From inspection of the first-order conditions, it can easily be verified that, in fact, independent selling leads to suboptimal pricing. As a result, \( \Pi_{1+2}^1 > \Pi_{1+2}^e \).

\(^{16}\) Exclusive licensing has two advantages over captive use: increased cost-efficiency and coordinated pricing of the basic and enhanced products. Exclusive licensing increases efficiency, because the enhanced product is produced at a lower cost by firm 1 than by firm 2. Exclusive licensing involves coordinated pricing, because firm 1 supplies both the basic product and the enhanced product.
Like independent selling, nonexclusive licensing allows for low-cost production. However, nonexclusive licensing has both an advantage and a disadvantage relative to independent selling: while nonexclusive licensing involves coordinated pricing of the basic and enhanced products, it also introduces competition in the enhanced product. As we will see later, if the rent dissipation due to increased competition in the enhanced product is significant, joint profits are greater under independent selling than under nonexclusive licensing.

To compare the equilibrium joint profits under independent selling \( (\Pi^{is}_{1+2}) \) and nonexclusive licensing \( (\Pi^{is}_{1+1}) \), it is convenient to fix \( c_1 \) and compare \( \Pi^{is}_{1+2} \) and \( \Pi^{is}_{1+1} \) for different values of \( c_2 \). Therefore, we define \( \Pi^{is}_{1+2} (c_2) \) and \( \Pi^{is}_{1+1} (c_2) \) for any given value of \( c_1 \). Let us first characterize two extreme cases.

If \( c_2 \) is arbitrarily close to \( c_1 \), joint profits are greater under independent selling than under nonexclusive licensing, and, consequently, independent selling is the optimal deployment option. Under nonexclusive licensing, the two firms compete in both products, and consequently, joint profits are close to zero. Under independent selling, the two firms compete in the basic product, but firm 2 has a monopoly in \( y \), making a positive profit. As a result, joint profits are greater than zero.

If \( c_2 \geq p^{*}_{E1} \), joint profits are greater under nonexclusive licensing than under independent selling and, consequently, nonexclusive licensing is the optimal deployment option. If \( c_2 \geq p^{*}_{E1} \), firm 2 has no incentive to use the quality-improving innovation after licensing it nonexclusively to firm 1. The licensee may charge a price \( p^{*}_{E1} \) without inducing the licensor to compete in \( x_E \). Therefore, the license is de facto exclusive. Equilibrium prices and joint profits are the same as under exclusive licensing.

What happens for intermediate values of \( c_2 \), that is, if \( c_2 \) is significantly greater than \( c_1 \) but smaller than \( p^{*}_{E1} \)? Our assumptions about continuity of \( DB \) and \( DE \) and concavity of the profit functions ensure that both \( \Pi^{is}_{1+2} (c_2) \) and \( \Pi^{is}_{1+1} (c_2) \) are continuous in \( c_2 \) and that \( \Pi^{is}_{1+2} (c_2) \) is concave. We also know that \( \Pi^{is}_{1+2} (c_2) \) is increasing for \( c_2 \in [c_1, p^{*}_{E1}] \) and constant for \( c_2 > p^{*}_{E1} \) and that \( \Pi^{is}_{1+2} (c_2) \) is constant for \( c_2 > p^{*}_{E1} \), where \( p^{*}_{E1} \) is the equilibrium price firm 1 would charge under independent selling if it did not have to face the competition of firm 2 in \( x_B \). The fact that \( \Pi^{is}_{1+2} (c_2) > \Pi^{is}_{1+2} (c_2) \) for \( c_2 \) arbitrarily close to \( c_1 \) and \( \Pi^{is}_{1+2} (c_2) < \Pi^{is}_{1+2} (c_2) \) for \( c_2 \geq p^{*}_{E1} \), together with the fact that both \( \Pi^{is}_{1+2} (c_2) \) and \( \Pi^{is}_{1+2} (c_2) \) are continuous, imply that there is a value of \( c_2 \), \( c^*_2 \), where the two functions intersect. A typical representation of \( \Pi^{is}_{1+2} (c_2) \) and \( \Pi^{is}_{1+2} (c_2) \) is given in figure 1. In figure 1, we identify two regions: one where independent selling is the optimal deployment option \( (c_1 < c_2 < c^*_2) \) and one where nonexclusive licensing is the optimal deployment option \( (c_2 > c^*_2) \).
The intuition is as follows. If firm 2’s cost disadvantage relative to firm 1 is small (i.e., for values of $c_2$ sufficiently close to $c_1$), rent dissipation due to increased competition in the enhanced product under nonexclusive licensing is greater than losses due to lack of coordinated pricing under independent selling. Therefore, joint profits are greater under independent selling than under licensing, and, therefore, independent selling is the optimal deployment decision. As $c_2$ increases relative to $c_1$, rent dissipation due to competition in the enhanced product under nonexclusive licensing decreases. If firm 2’s cost disadvantage is big, rent dissipation due to competition in the enhanced product under nonexclusive licensing is smaller than losses due to lack of coordinated pricing under independent selling. If this is the case, joint profits are greater under nonexclusive licensing than under independent selling, and, therefore, nonexclusive licensing is the optimal deployment decision.17

We now consider the case where the licensing contract may include a royalty. In general, this case involves a trade-off. First, a royalty reduces the licensor’s incentives to use the quality-improving innovation after licensing occurs and thereby mitigates competition in the enhanced product. This is because using the innovation cannibalizes the licensor’s royalty revenues. Without a royalty, the licensor has the incentive to compete in the enhanced product whenever $p_{E1} > c_2$. With a royalty $r$, the licensor may no longer have this incentive when $p_{E1} > c_2$ but $p_{E1} \leq c_2 + r$.

17. Note that in addition to increased cost efficiency and coordinated pricing of $x_B$ and $x_E$, nonexclusive licensing has a third effect relative to captive use: It introduces competition in $x_E$. Under nonexclusive licensing, two firms can produce the enhanced product, the licensor and the licensee. Therefore, the licensee is constrained in the price it charges for the enhanced product by the licensor.
More specifically, assume that firm 1 sets the pair of prices \((p_{B1}, p_{E1})\), where \(p_{E1} \leq c_2 + r\). By not producing the enhanced product, firm 2 gets, through royalty payments, an amount, \(RP\), given by

\[
RP = r \cdot D_E(p_{E1}, p_{B1}).
\]  

By producing the enhanced product, charging a price \(p_{E2} < p_{E1}\), firm 2 makes a profit \(\Pi^E_2\), equal to \(\Pi^E_2 = (p_{E2} - c_2) \cdot D_E(p_{E2}, p_{B1})\), where \(D_E(p_{E2}, p_{B1}) > D_E(p_{E1}, p_{B1})\) but \(p_{E2} - c_2 < r\). Firm 2 has no incentive to compete in the enhanced product if \(RP \geq \Pi^E_2\), for any \(p_{E2} < p_{E1}\).

Second, a royalty introduces a distortion in the pricing behavior of the licensee. It changes the marginal cost of the enhanced product on which firm 1 bases its decisions from \(c_1\) to \(c'_1 = c_1 + r\).

Thus, whether the licensing contract should include a royalty or not is unclear, as it depends on the interplay of these two effects. However, there is a special case where the optimal licensing contract definitely includes a royalty, because it allows firms to replicate the exclusive licensing outcome. Indeed, under certain circumstances, a royalty \(r^* = p_{E1}^d - c_2\) eliminates firm 2’s incentives to compete in the enhanced product for \(p_{B1} = p_{B1}^d\) and \(p_{E1} = p_{E1}^d\), without introducing any distortion in the pricing decisions of firm 1.

Consider a royalty \(r^* = p_{E1}^d - c_2\). If, for \(p_{B1} = p_{B1}^d\) and \(p_{E1} = p_{E1}^d\), \(RP \geq \Pi^E_2\), for any \(p_{E2} < p_{E1}\), firm 1 may charge the exclusive licensing equilibrium prices without facing competition from firm 2 in the enhanced product. A royalty \(r^*\) also changes the marginal cost \(c_1\) to \(c'_1 = c_1 + r^*\). This implies that, without competition from firm 2 in \(X_E\), firm 1 would charge a price \(p_{E1} > p_{E1}^d\). However, firm 1 cannot set a price \(p_{E1} > p_{E1}^d\) without inducing firm 2 to compete in the enhanced product, setting a price \(p_{E2} < p_{E1}\). Therefore, the best firm 1 can do is to set the pair of prices \((p_{E1}^d, p_{E1}^d)\). As a result, the royalty solves the problem of increased competition in \(X_E\) due to nonexclusive licensing without introducing a distortion in the pricing decisions of firm 1. Joint profits are the same as under exclusive licensing.

18. Under nonexclusive licensing, a royalty \(r^* = p_{E1}^d - c_2\) eliminates firm 2’s incentive to compete in the enhanced product for \(p_{B1} = p_{B1}^d\) and \(p_{B1} = p_{B1}^d\), without introducing any distortion in the pricing decisions of firm 1, if and only if (1) \(|D_E| \geq |D_{BE}|\), (2) \(p_{B1}^d = c_2\), and (3) \(p_{E1}^d = c'_2\) (the superscript \(r^*\) indicates equilibrium under nonexclusive licensing with \(r = r^*\)). This result is shown in Appendix B. Under these conditions, the optimal licensing contract includes a royalty \(r = r^*\). For example, when consumers’ preferences are described by \(U = \theta q - p\) if the consumer consumes one unit of quality \(q\) and pays price \(p\) and by \(0\) otherwise (where the parameter \(\theta\) of taste for quality is uniformly distributed between \(\theta' \geq 0\) and \(\theta' + 1\)), a royalty \(r^*\) eliminates firm 2’s incentive to compete in the enhanced product for \(p_{B1} = p_{B1}^d\) and \(p_{B1} = p_{B1}^d\), without introducing any distortion in the pricing decisions of firm 1. This preferences structure was first proposed by Gabszewicz and Thissen (1979) and Shaked and Sutton (1982) (see also Tirole, 1988, p. 296).
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*Check whether \( x \) signifies exclusive licensing.

Cost Advantage

- Minor Cost Disadvantage
- Significant Cost Disadvantage
- Extreme Cost Disadvantage

Innovator's Cost Position

\[ \text{Cost Advantage} \]

IV. Conclusion

This paper uses a game-theoretic model to study how competitive considerations affect the deployment of quality-improving innovations, comparing captive use, independent selling, and licensing. We identify three underlying concerns that influence the choice among these deployment strategies: achieving cost-efficient production, ensuring coordinated pricing of the basic and enhanced products, and mitigating competition within products. We show that, as a result of the interplay of these efficiency and competitive forces, both licensing and independent selling may be profit-maximizing strategies. Furthermore, it can easily be verified that, even though the effect of licensing and independent selling on equilibrium prices and, hence, on consumer surplus is unclear, these deployment strategies may well increase social welfare.

Figure 2 summarizes the results regarding the profit-maximizing deployment strategy. In our model, captive use is optimal in only one case, where the innovating firm is also the most cost-efficient manufacturer. It is far from clear that the same firm, in general, excels in both dimensions. According to Porter (1980), successful firms usually have to compete either on the basis of low costs or product differentiation: Firms that attempt to pursue both types of advantage simultaneously are almost guaranteed low profitability. As Caves (1984) puts it, “a sufficient source of exclusivity lies in managerial coordinating capacity and the need to select a system of internal organization, evaluation, and reward that is designed for optimal pursuit of the chosen strategy” (p. 127).

19. Porter’s argument has provoked a vigorous debate, for both empirical and conceptual reasons. The empirical evidence is mixed. In some industries, successful firms possess either a differentiation or cost leadership strategy, not both (e.g., Hambrick 1983; Dess and Davis 1984). However, several empirical studies suggest that cost and differentiation advantages...
The Strategic Deployment of Quality-Improving Innovations

To the extent that Porter's argument is correct, our model suggests that captive use may often be dominated by the other deployment options. Put differently, in all cases where quality-improving innovations are generated by firms that are not the most cost-efficient producer in their industries, licensing or independent selling may be the optimal deployment option.

More specifically, our model indicates that, when the innovating firm is inefficient, exclusive licensing should be preferred whenever it is possible. When it is not possible to draw up exclusive licensing contracts, the choice between nonexclusive licensing and independent selling depends on the cost position of the firm. It should be pointed out, however, that, in such cases, the firm should always verify whether or not a special type of licensing agreement \( (L^*) \) can be devised, which enables the innovator to effectively replicate an exclusive license. Indeed, under specific conditions, an optimal royalty rate \( r^* \) can be set that enables the firm to credibly and costlessly commit itself not to use the quality-improving innovation. Since such an agreement replicates an exclusive license, it is preferable, whenever possible, to nonexclusive licensing or independent selling. Finally, if the cost disadvantage of the innovating firm becomes very big, this firm is no longer able to compete with the licensee, ensuring that the license is de facto exclusive.

The results summarized in figure 2 suggest that captive use of a quality-improving innovation is often not the optimal deployment option. Therefore, according to the predictions of our model, in reality captive use should be a rare exception. These predictions seem to be at odds with reality. Firms often use their product enhancements captively in an attempt to differentiate their products. How can we explain this mismatch between the model's implications and the realities of asset deployment?

The distance between the model and reality is explained, first of all, by a number of modeling choices. Our objective, in this paper, is to analyze how competitive considerations affect the deployment of quality-improving innovations. Therefore, even though our model captures cost differences and market competition, it does not take into account a number of important factors that have been identified in the literature. Specifically, we ignore several insights from the transaction cost perspective (e.g., Williamson 1975, 1985; Teece 1986, 1987; Hill 1992). For example, there may be uncertainty about the value of the innovation, which could make licensing more problematic. Furthermore, it are not incompatible (e.g., Phillips, Chang and Buzzell 1983; Miller and Friesen 1986; and White 1986). Two related factors may weaken the trade-off between cost and differentiation positions in an industry (e.g., Hill 1988; Porter 1996). On the one hand, a firm with a differentiation advantage may increase market share, which then allows it to benefit from economies of scale, scope, and learning. On the other hand, the idea that higher quality or better performing products involve higher costs ignores the possibility that firms may be producing inefficiently.
may be difficult to license an innovation without diffusing the general knowledge underlying the innovation to be transferred. This may allow the licensee to improve on the licensed innovation or to apply it to products for which it was not licensed. If these types of costs are significant, they may reduce firms' incentives to choose a licensing strategy, even if exclusive licensing is possible.

In addition, our model assumes very specific cost and demand structures. In particular, we assume that firms have constant marginal costs and that products $x_B$ and $x_E$ are vertically differentiated. While these assumptions are justified in a first effort to analyze how competitive considerations affect the deployment of quality-improving innovations, an important issue for further research is to verify to what extent our results depend on these assumptions. Two obvious extensions to the paper would be to consider a range of cost functions exhibiting increasing marginal costs or a more general demand with horizontal and vertical components.

The mismatch between the model's implications and the realities of asset deployment may also be explained by a managerial bias towards captive use (e.g., Gabel 1984; Dierickx and Cool 1994). As pointed out by several strategy researchers, this bias may result, first of all, from the persistence of strategies narrowly focused on pursuing competitive advantage in product markets. If the firm's ultimate objective is to achieve a strong product market position, a captive use strategy is the natural choice. In such a strategy, the firm uses its valuable assets to enhance its products only in an attempt to create a competitive advantage in product markets. In addition, a captive use strategy may result from the failure to correctly identify the real source of the firm's above-normal returns. Unless the specific assets responsible for the firm's superior earning potential have been explicitly identified and the different deployment alternatives carefully compared, competitive strategy is likely to be biased towards captive use.

The following example illustrates this point. As reported by Business Week (December 27, 1999, p. 20), many major automakers have relied at some time or other on the automotive engineering capabilities of Porsche, the German producer of luxury sports cars. For example, Porsche engineers helped DaimlerChrysler solve the instability problems suffered by its compact A-Class cars and to develop its Smart microcar model; and Zafira, the compact van of Opel, General Motors German subsidiary, was engineered under contract by Porsche. At any time, one third of Porsche's designers and engineers are doing outside contract work for other companies, mostly carmakers. Providing automotive engineering services has become a pillar of Porsche's business and a key part of its growth strategy. Why have Porsche's executives been able to identify this profitable strategy? First of all, because they understood that Porsche is on the cutting edge of automotive engineering. More
importantly, because they realized that a captive use strategy (i.e., the strategy of using the company’s engineering capabilities only to build Porsche’s luxury sports cars) would not be a profit maximizing strategy. They understood that the identification of the optimal deployment option requires firms to think beyond product market positioning and to address the broader question of how to fully exploit the potential rents associated with their valuable assets.

Whether the distance between the model and reality is explained by our modeling choices or by a managerial bias toward captive use can be assessed only empirically. Unfortunately, the deployment of quality-improving innovations has not received sufficient attention in the empirical literature. Hence, the empirical validation of the results presented in this paper could be an interesting topic for further research.

As already mentioned, the model presented in this paper should be seen as a first effort to study how competitive considerations influence the deployment of quality-improving innovations. As suggested previously, two obvious extensions to the paper would be to consider a range of cost functions exhibiting increasing marginal costs or a more general demand with horizontal and vertical components. In addition, this work could be enriched by incorporating additional insights from the transaction cost perspective. Our model can also be extended in several other ways.

First, while the model involves only two firms, it can easily be extended to three or more firms. The main results carry through without modification. Two clarifications are necessary, however. When exclusive licensing is possible, the model suggests that a high-cost firm should license the quality-improving innovation exclusively to only one firm, the one with the lowest cost position in the production of the basic product. Furthermore, captive use is optimal if and only if the innovator has the lowest cost position of all firms in the market. In our model, all innovating firms that are not the most cost-efficient producer have the incentive to follow a licensing or independent selling strategy.

Second, this paper identifies incentives to share a quality-improving innovation with competitors or follow an independent selling strategy ex-post, that is, after the development of the innovation has been concluded. An interesting extension of the paper would be to study the deployment decision ex-ante, that is, while R&D efforts are still taking place. This seems to be a promising area for further research, because R&D and deployment decisions are clearly linked. For example, by licensing an innovation to other firms or by following an independent selling strategy, the innovating firm may be able to influence competitors’ incentives to develop a similar innovation.

Third, an important extension of the paper would be to formally model a broader range of collaborative arrangements (e.g., exclusive sourcing, joint ventures). Note, however, that these extensions can only
further restrict the domain of optimality of captive use, reinforcing a key conclusion of this paper: In the case of quality-improving innovations, the interplay of production efficiency and competitive considerations tends to favor other deployment strategies relative to captive use.

Appendix A

Captive Use vs. Independent Selling

Assume that firm 2 uses the innovation captively. For a given pair of equilibrium prices \((p_{B1}^c, p_{E1}^c)\), firm 2’s equilibrium profit is given by

\[
\Pi_2^c = D_E(p_{E1}^c, p_{B1}^c) \cdot (p_{B1}^c - c_2).
\]

Consider now that firm 2 follows an independent selling strategy. Assume that, for \(p_{B1} = p_{B1}^i\), firm 2 sets a price \(p_{E1}^i = p_{E1}^c - c_2\). Its profit is then given by

\[
\Pi_2^i = D_E(p_{B1}^i + p_{E1}^i, p_{B1}^i) \cdot p_{E1}^i
= D_E(p_{B1}^c + p_{B1}^i - c_2, p_{B1}^i) \cdot (p_{B1}^c - c_2).
\]

To compare \(\Pi_2^c\) and \(\Pi_2^i\), we distinguish three cases, \(p_{B1}^c = p_{B1}^i\), \(p_{B1}^c > p_{B1}^i\), and \(p_{B1}^c < p_{B1}^i\):

(a) \(p_{B1}^c = p_{B1}^i\). In this case, \(\Pi_2^c \leq \Pi_2^i\) and \(\Pi_2^c \leq \Pi_2^i\), because \(p_{B1}^c \leq c_2\). Note that if \(p_{B1}^c = p_{B1}^i = c_2\), then \(p_{E1}^i = p_{E1}^c\) and \(\Pi_2^c = \Pi_2^i = \Pi_2^i\).

(b) \(p_{B1}^c < p_{B1}^i\). In this case, \(\Pi_2^c < \Pi_2^i\) and \(\Pi_2^c < \Pi_2^i\), because \(D_{EE} > 0\).

(c) \(p_{B1}^c > p_{B1}^i\). In this case, since \(p_{B1}^c < p_{B1}^i \leq c_2\), we know that

\[
c_2 - p_{B1}^c \geq p_{B1}^i - p_{B1}^i > 0.
\]

We also know that \(|D_{EE}| \geq |D_{EB}|\). Therefore, \(\Pi_2^c \leq \Pi_2^i\) and \(\Pi_2^c \geq \Pi_2^i\).

One can easily verify that \(\Pi_2^c < \Pi_2^i\), except if (1) \(p_{B1}^c = p_{B1}^i = c_2\) or if (2) \(p_{B1}^c < p_{B1}^i = c_2\) and \(|D_{EE}| = |D_{EB}|\). In these two cases, \(\Pi_2^c = \Pi_2^i\).

Appendix B

Royalty \(r^*\) as a Costless Commitment Device

We first show sufficiency. The proof of sufficiency consists of two steps.

(i) We first show that, for (1) \(|D_{EE}| \geq |D_{EB}|\), (2) \(p_{B1}^c = c_2\) and (3) \(p_{E1}^c = c_2\), if licensing occurs and \(r = r^* = p_{E1}^c - c_2\), firm 1 can charge \(p_{B1} = p_{B1}^c = c_2\) and \(p_{E1} = p_{E1}^c\) without facing competition from firm 2 in \(X_E\). Under these conditions, firm 1 can charge the pair of prices \(p_{B1} = p_{B1}^c = c_2\) and \(p_{E1} = p_{E1}^c\) without facing competition of firm 2 in \(X_E\), if and only if

\[
RP = (p_{E1}^c - c_2) \cdot D_E(p_{E1}^c, p_{B1}^c) \geq \Pi_2^c = (p_{E1} - c_2) \cdot D_E(p_{E1}^c, p_{B1}^c).
\]
for all \( p_{E2} < p^d_{E1} \). Since \( (p_E - c_2) \cdot D_E(p_E, p_B) \) is, by assumption, differentiable and concave in \( p_E \), \( RP \geq \Pi_2^E \) if and only if

\[
D_E(p^d_{E1}, c_2) + D_{EE} \cdot (p^d_{E1} - c_2) \geq 0.
\]

This condition implies that, by competing in the enhanced product with a price \( p_{E2} \) slightly lower than \( p^d_{E1} \), firm 2 (weakly) decreases its profit. Since, by assumption, \( p^*_{B1} = c_2, p^d_{E1} \) is determined by the first-order condition

\[
\frac{\partial \Pi_1 + 2}{\partial p_{E1}} = D_E(p^d_{E1}, c_2) + D_{EE} \cdot (p^d_{E1} - c_1) + D_{BE} \cdot (c_2 - c_1) = 0.
\]

This condition can be written as

\[
D_E(p^d_{E1}, c_2) + D_{EE} \cdot (p^d_{E1} - c_2) + D_{BE} \cdot (c_2 - c_1) = 0.
\]

(iii) We now verify that, in fact, \( p^*_{E1} = p^d_{E1} \). In equilibrium, firm 1 sets the price \( p_{E1} \) that maximizes

\[
\Pi_1 = D_E(p_{E1}, c_2) \cdot (p_{E1} - c_1 - r^*) + D_B(c_2, p_{E1}) \cdot (c_2 - c_1),
\]

so that

\[
p_{E1} \leq p^d_{E1} = c_2 + r^*.
\]

Ignore for a moment the restriction on \( p_{E1} \). For \( p^*_{E1} = p^d_{E1} = c_2, p_{E1} \) is given by the corresponding first-order condition

\[
\frac{\partial \Pi_1}{\partial p_{E1}} = D_{EE} \cdot (p_{E1} - c_1 - r^*) + D_E(p_{E1}, c_2) + D_{BE} \cdot (c_2 - c_1) = 0.
\]

From the first-order condition, it is easy to verify that, without the restriction on \( p_{E1} \), for any royalty \( r > 0 \), and in particular for \( r = r^* \), firm 1 would charge a price \( p_{E1} > p^d_{E1} \). Consider now the restriction \( p_{E1} \leq p^d_{E1} \). Due to the concavity of firm 1’s profit on \( p_{E1} \), the best firm 1 can do is to set \( p^*_{E1} = p^d_{E1} \).

The proof of necessity is straightforward and therefore simply sketched here. First relax the assumption \( p^d_{B1} = c_2 \). If \( p^d_{B1} < c_2 \), two things may happen: (a) \( p^*_{B1} = c_2 \) and (b) \( p^*_{B1} < c_2 \). In case (a), we have \( p^*_{E1} = p^d_{E1} \). In case (b), one can easily verify by inspection of the first-order conditions that \( p^*_{B1} < p^d_{B1} \). In both cases, licensing introduces a distortion in the pricing decisions of the licensee. A similar argument can be developed for the assumption \( p^d_{B1} = c_2 \).

Clearly, if \( |D_{EE}| > |D_{BE}| \), a royalty \( r = r^* \) cannot be used as a means for firm 2 to credibly commit not to use the licensed technology if firm 1 charges a price \( p^d_{E1} \). For \( p_{E1} = p^d_{E1} \), firm 2 has the incentive to produce \( x_E \).
References


