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Product Strategy for Innovators in Markets with Network Effects

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This paper examines four alternative product strategies available to an innovating firm in markets with network effects: single-product monopoly, technology licensing, product-line extension, and a combination of licensing and product-line extension. We address three questions. First, what factors affect the attractiveness of each of the four product strategies? Second, under what conditions will any particular strategy dominate the others? Third, what is the impact of licensing fees on the profitability of a licensing strategy? We show that offering a product line utilizes consumer heterogeneity to increase the total user base and is superior to free licensing when the innovator's cost of producing a low-quality product is low and network effects are weak. However, because of the advantage of licensing in generating a larger installed base, free licensing can dominate line extension when network effects are strong, even if the innovator suffers no cost disadvantage compared to the competitor. We also show that paid licensing trumps free licensing when the clone product has a high quality or a low cost, regardless of network effect. Finally, strong network effects make a lump-sum fee more profitable than a royalty fee (or a combination of both) because a royalty fee reduces the licensee's production.

Key words: network effects; new product strategy; innovation management; licensing; product line; competitive strategy; technological standards; installed base
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1. Introduction

Many industries are characterized by a network effect, under which the value of a product to each user increases with the number of users (Katz and Shapiro 1985, 1994; Farrell and Saloner 1985; Liebowitz and Margolis 1999; Shapiro and Varian 1999). Examples of markets with a network effect include communication devices (e.g., fax machines and modems), communication services (e.g., telephone, e-mail, and Internet online services), and complementary products (e.g., VCRs, PCs, video-game players, CD players, and DVD players). Several recent papers have addressed some important strategic issues involving the network effect, such as pricing (Dhebar and Oren 1985, Xie and Sirbu 1995), discontinuous innovation (Dhebar 1995), indirect network effects (Gupta et al. 1999, Basu et al. 2003), product upgrades (Padmanabhan et al. 1997), knowledge management (Ofek and Sarvary 2001), success of high-tech products (Yin 2001), advertising strategy in the presence of standards competition (Chakravarti and Xie 2004), asymmetric network effects (Shankar and Bayus 2003), cross-market network effects (Chen and Xie 2003), and effect of network effects on pioneer survival (Srinivasan et al. 2004). This paper addresses innovating firms' product strategies in the presence of a network effect.

In markets without network effects, innovating firms often use legal attacks or technological power to combat or deter imitation (Porter 1980, Teece 1986). However, in markets with a strong network effect, many firms that develop new products have lowered entry barriers by licensing their technologies to competitors or by making their design or system "open" (Graud and Kumaraswamy 1993). Several recent studies demonstrate the counterintuitive effect of encouraging compatible entries in markets with a network effect. For example, Conner (1995) finds that with a strong network effect, the innovator may benefit from having a clone competitor even if the innovator can (costlessly) foreclose such competition. By incorporating a network effect into a diffusion model, Xie and Sirbu (1995) show that an innovating firm can achieve faster diffusion of its product and gain a higher profit by having a compatible competitor enter the market at an early stage rather than by being a monopolist. Economides (1996) suggests that an innovator may have incentives to share or even subsidize its technology with competitors.

Building on this branch of research, this paper addresses some important unanswered questions. For example, if the innovator can benefit from the existence of a "clone" product, should the innovator produce the clone product internally via product-line extension (self-cloning) or externally via the licensing of its technology to competitors? Are external and internal cloning strategies substitutable? Is it possible for the innovator to achieve a higher profit by simultaneously pursuing both technology licensing and line-extension strategies than by pursuing each pure strategy alone? Different alternative strategies have frequently been observed in markets with network effects. For example, manufacturers of video game players have adopted a single-product-monopoly strategy—each generation of video game player (e.g., Microsoft's Xbox, Nintendo's N64) has been produced by only one manufacturer and offered in only one quality. Many software vendors, however, have adopted a line-extension strategy—introducing different versions of their application software that remain compatible but vary in quality. For example, TreeAge Software offers a full version of its decision-analysis software DATA at $495 and a student version that limits the size of models to 125 nodes at only $50. Some software vendors create multiple products to expand their installed base by separating their product's creation and consumption features (e.g., Adobe's free versions of Adobe Reader, a component of Adobe Acrobat). Finally, the combination strategy—simultaneously offering a product line and licensing technology—has been observed in markets with network effects, such as VCRs, CD players, PCs, and PDAs. For example, Palm licenses its operating system, Palm OS, to competitors such as Handspring, Sony, Nokia, Samsung, and Acer while at the same time offering a wide range of its own products. Given the array of feasible product strategies, it is important for innovating firms competing in markets with a network effect to understand the trade-offs between different product strategies along with their strategic implications.

Most of the past research on innovating firms' incentives to facilitate compatible entry (e.g., Baake and Boom 2001, Conner 1995, Esser and Leruth 1988, Katz and Shapiro 1985) has assumed a zero licensing fee. In markets with a network effect, however, we observe both free and paid licensing policies. For example, in the PDA industry, both Palm and Microsoft charge other manufacturers a per-unit licensing fee to use their operating system (Palm OS or Windows CE). The impact of a licensing fee is important because it can affect the size of the installed base of the clone products and, thus, the overall attractiveness of a technology-licensing strategy.

To better understand these issues, this paper examines four alternative product strategies available to an innovating firm: (1) a *single-product-monopoly* strategy, under which the innovator is the exclusive seller of the product based on its technological standard, (2) a *technology-licensing* strategy, under which the innovator creates compatible products externally by licensing its technology to competitors, (3) a *product-line-extension* strategy, under which the innovator internally creates compatible products with multiple qualities, and (4) a *combination* strategy, under which the innovator simultaneously licenses its technology and expands its product line. We address three specific questions. First, what factors affect the attractiveness of each of the four product strategies? Second, under what conditions will each of these strategies dominate? Third, what is the impact of licensing fees on the profitability of a licensing strategy? To answer these questions, we first develop a basic model to examine the innovator's optimal product strategy in markets with a network effect. Then, we generalize the basic model to allow different licensing-fee structures.

While previous research has analyzed the benefits of encouraging compatible entry, our results reveal that such a strategy is neither the only way nor always the best way for the innovator to realize a larger installed base and a higher profit. We show that, under some conditions, product-line extension can be the optimal strategy in the presence of a network effect. In the marketing literature, product-line decisions traditionally have been driven by consumer heterogeneity (Dobson and Kalish 1988, Lilien et al. 1992, Preyas 2001). We show that a network effect creates interdependence among consumers with different preferences because the valuation of their preferred product is determined by the joint demand for the full line. In the presence of a network effect, manufacturers that offer a product line not only tailor their products to consumers' preferences but also utilize consumer heterogeneity to increase the total user base. This, in turn, increases all buyers' consumption utility. We also show that while a licensing fee generates revenue for the innovator, a free-licensing contract can lead to a higher profit. With strong network effects, a lump-sum fee is more profitable for the innovating firm than a royalty fee or a combination of the two because a royalty fee increases the licensee's marginal cost and, thus, reduces its production. Furthermore, some of our results are counterintuitive. For example, we show that it is possible for a free-licensing strategy to generate a higher profit than a line-extension strategy even if internal and external clone production have the same costs. While a licensing fee generates revenue for the innovator, a free-licensing contract can lead to a higher profit. We also show that the strength of a network effect is not always the dominant factor in determining the superiority of a paid-licensing contract versus a free-licensing contract. Network effects become a key factor only when the value of the clone product is low or its cost is high.

This paper is organized as follows. Section 2 presents a model to analyze the alternative product strategies. Section 3 derives conditions under which each strategy dominates the others. Section 4 examines the impact of licensing fees, and §5 summarizes our conclusions.

2. The Model

Consider an innovating firm that has developed a new product based on its proprietary technology. To build a larger installed base of users of its standard, the innovator may want to create a vertically differentiated but compatible product. Following the literature on network effects (e.g., Conner 1995), we call such a product a "clone" product, which differs from the innovator's current product in quality and performance, but is compatible in interface either with the user or with the complimentary software or hardware.[1]

2.1. Assumptions

Previous research has generally accepted the assumption of a fulfilled consumer expectation (e.g., Katz and Shapiro 1985, Economides 1996, Bental and Spiegel 1995). To capture the dependence between consumers' expected network sizes and their purchase decisions in a static model, previous research has assumed that consumers make their purchase decisions before the actual network size is known (e.g., Katz and Shapiro 1985, Economides 1996). Quantity competition has also been widely used in the economics and marketing literature to model markets with network effects (e.g., Belleflamme 1998, De Palma and Leruth 1996, Economides 1996, Economides and Flyer 1997, Katz and Shapiro 1985). We adopt these same assumptions with one notable variation: we allow the innovator to consider multiple strategic alternatives. If an internal-cloning strategy (line extension) is adopted, the innovator chooses the quantity of its high- and low-quality product by maximizing the total profit. If an external-cloning strategy (licensing) is adopted, firms choose their quantity by playing a Cournot-Nash game.

[1] See Purohit (1994) for competition between innovating firms and clones in the absence of network effects.

We assume the existence of a continuum of consumers. Each consumer is characterized by a parameter, $\theta \in [-M, 1]$, representing her preference for quality, and θ is distributed uniformly with the population density normalized to one.[2] The reservation price of a consumer, θ, for a given product j is defined by $U(\theta, K_j, Q_j) = \theta K_j + \gamma K_j Q_j$, where K_j is the product quality, Q_j is the expected network size, and γ measures the strength of the network effect.[3] Furthermore, γ is assumed to be less than one to ensure a downward-sloping demand function. Each consumer demands either zero or one unit of the product. An individual will buy the product if the resulting surplus is nonnegative, and if there are multiple products available she will choose the product that offers the highest surplus.

Let K and K_c denote the quality of the innovator's current product and of the clone product, respectively, where $K \geq K_c$. For the ease of exposition, we normalize $K = 1$. We allow a cost difference between internal and external clone production. We assume a zero licensing fee in §3 and allow a positive licensing fee in §4.

2.2. The Alternative Product Strategies

In this section, we present a basic model to examine the alternative product strategies.

(1) *Single-Product-Monopoly Strategy.* Let p_{im} and Q_{im} be the price and the expected installed base of the monopolist's product, where the subscript, m, is used to denote the case of a single-product monopoly. Define θ_{im} as the preference parameter of the consumer who is indifferent about adopting the product:

$$(\theta_{im} + \gamma Q_{im}) - p_{im} = 0. \tag{1}$$

Because all individuals who have a higher preference for quality, $\theta > \theta_{im}$, will adopt the product, the total number of adopters is $q_{im} = 1 - \theta_{im} = 1 + \gamma Q_{im} - p_{im}$. Let c be the marginal cost. The innovator's profit is

$$\pi_{im} = (p_{im} - c) q_{im}. \tag{2}$$

(2) *Technology-Licensing Strategy.* We use the subscript, l, to denote all the variables for the licensing strategy. By licensing technology to the competitor, the innovator creates competition for its own product. When multiple products with varying quality are available, consumers with a higher θ will buy the innovator's product, while those with a lower θ will buy the clone product. Let θ_{cl} be the preference

[2] Following Katz and Shapiro (1985), M is assumed to be sufficiently large to avoid having to consider corner solutions, where all consumers enter the market.

[3] See Baake and Boom (2001) for more detailed discussions on this assumption.

parameter of the consumer who is indifferent about buying a product, and let θ_{il} be the preference parameter of the consumer who is indifferent about which product to buy. A consumer with preference parameter, θ, will buy the innovator's product if $\theta \geq \theta_{il}$, the clone product if $\theta_{il} > \theta \geq \theta_{cl}$, and nothing if $\theta < \theta_{cl}$. The market is thus segmented as $I_0 = [-M, \theta_{cl})$, $I_c = [\theta_{cl}, \theta_{il})$, and $I_i = [\theta_{il}, 1]$, where I_0 is the set of nonpurchasers, I_c is the set of consumers who will purchase the clone product, and I_i is the set of consumers who will purchase the innovator's product.

Let p_{il} and p_{cl} denote the prices of the innovator's and clone product, respectively. Let q_{il} and q_{cl} denote the quantities of the two products, respectively. Let Q_{il} denote the expected network size. Then, θ_{il} and θ_{cl} are given by

$$(\theta_{cl} + \gamma Q_{il})K_c - p_{cl} = 0, \tag{3}$$

$$(\theta_{il} + \gamma Q_{il}) - p_{il} = (\theta_{il} + \gamma Q_{il})K_c - p_{cl}. \tag{4}$$

A consumer with preference parameter θ_{cl} is indifferent between nonpurchase and the clone product. Similarly, a consumer with preference parameter θ_{il} is indifferent between the clone product and the innovator product. The total user base and the innovator's user base are given by the following two equations:

$$q_{il} + q_{cl} = 1 - \theta_{cl} = 1 + \gamma Q_{il} - p_{cl}/K_c, \tag{5}$$

$$q_{il} = 1 - \theta_{il} = 1 + \gamma Q_{il} - \frac{p_{il} - p_{cl}}{1 - K_c}, \tag{6}$$

where K_c is the quality of the clone product.

Let c_{cl} and c_{fl} denote the marginal and fixed costs of the clone product. To ensure the feasibility of the licensing strategy, we consider the case in which the costs of external cloning are sufficiently low so that the clone maker will produce a positive quantity under the licensing strategy. The innovator and the clone maker maximize their profits, π_{il} and π_{cl}:

$$\pi_{il} = (p_{il} - c)q_{il}, \tag{7}$$

$$\pi_{cl} = (p_{cl} - c_{cl})q_{cl} - c_{fl}. \tag{8}$$

(3) *Product-Line-Extension Strategy.* We use the subscript e to denote all the variables for the line-extension strategy. When the innovator adopts an internal-cloning strategy, it faces a product-line profit-maximization problem. As in the case with the licensing strategy, the market is segmented into three sets; however, unlike the licensing strategy, the innovator offers both products. Let p_{ie} and q_{ie} denote the price and quantity, respectively, of the innovator's existing (high-quality) product. Let p_{ce} and q_{ce} denote the price and quantity, respectively, of the internal clone (low-quality) product. Let Q_{ie} denote the expected network size. Let c_{ce} and c_{fe} denote the marginal and fixed cost, respectively, of the low-quality product. The innovator maximizes its total profit, π_{ie}:

$$\pi_{ie} = (p_{ie} - c)q_{ie} + (p_{ce} - c_{ce})q_{ce} - c_{fe}. \tag{9}$$

(4) *Combination Strategy.* Unlike the three pure strategies discussed above, the combination strategy creates direct competition between the innovator and the clone maker in the low-quality product market. We present the equilibrium analysis of the combination strategy in the Appendix.

Lemma 1 summarizes the optimal quantities under the three pure strategies. (See the Appendix for proofs of the lemma and propositions.)

Lemma 1. *The optimal quantities under different strategies are:*

(1) *Single-product monopoly:*

$$q_{im}^* = \frac{1-c}{2-\gamma}.$$

(2) *Licensing:*

$$q_{il}^* = \frac{(1-c)(2-\gamma) - (1-c_{cl}/K_c)(K_c-\gamma)}{(2-\gamma)^2 - (1-\gamma)(K_c-\gamma)},$$

$$q_{cl}^* = \frac{(1-c_{cl}/K_c)(2-\gamma) - (1-c)(1-\gamma)}{(2-\gamma)^2 - (1-\gamma)(K_c-\gamma)}.$$

(3) *Line extension:*

$$q_{ie}^* = \frac{2(1-K_c)(1-c_{ce}/K_c) - (2-\gamma)(c-c_{ce}/K_c)}{2(2-\gamma)(1-K_c)},$$

$$q_{ce}^* = \frac{c - c_{ce}/K_c}{2-2K_c}.$$

3. Optimal Product Strategy

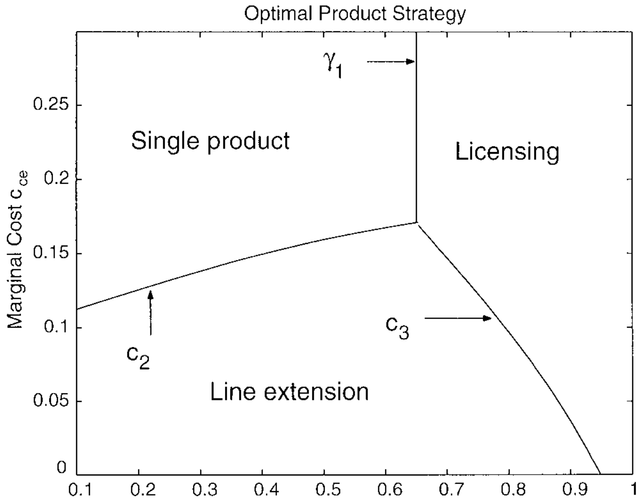
Lemma 1 allows us to derive firms' maximum profits under different product strategies. Comparing these profits leads to Proposition 1.

Proposition 1. *The conditions under which each strategy dominates the others are given below:*

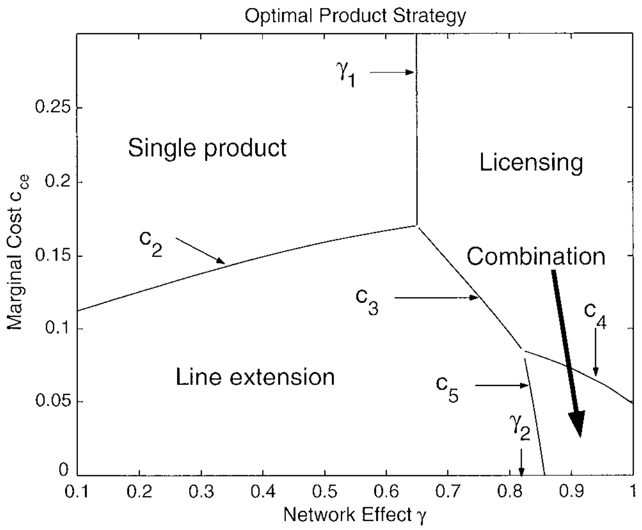
	Internal cloning cost (c_{ce})	*Optimal strategy*
Weak network effect ($\gamma < \gamma_1$)	*Large* ($c_{ce} > c_2$)	*Single-product monopoly*
	Small ($c_{ce} \leq c_2$)	*Line extension*
Strong network effect ($\gamma \geq \gamma_1$)	*Large* ($c_{ce} > c_3$)	*Licensing*
	Small ($c_{ce} \leq c_3$)	*Line extension*

where $\gamma_1 \equiv K_c$, *and* c_2 *and* c_3 *are functions of cost, quality, and network effect parameter (see the Appendix for their definitions).*

Figure 1 **Conditions of Optimal Strategies** ($K_c = 0.65$, $c = 0.3$, $c_{fe} = c_{fl} = 0.01$, $c_{cl} = 0.25$)



(a) Single-Product Monopoly, Licensing, and Line Extension



(b) Combination vs. Other Strategies

We graphically present Proposition 1 in Figure 1(a). As shown in the figure, two key conditions jointly determine the optimal strategy: the strength of the network effect, γ, and the variable cost of internal clone production, c_{ce}. The two conditions divide the plane into three areas, each representing the conditions under which one strategy is optimal.

Figure 1(a) illustrates several interesting results. First, the single-product-monopoly strategy is optimal in markets with a weak network effect and a high cost of internal clone production. A weak network effect ($\gamma < \gamma_1$) implies a negative net gain from sharing one's technology with the competitor, while a high cost of internal clone production ($c_{ce} > c_2$) implies inefficiency in introducing a low-quality product. Hence, in markets with a weak network effect and a high cost of internal clone production, the single-product monopoly can outperform both licensing and line-extension strategies. As shown in Figure 1(a), the cost condition above in which single-product monopoly dominates line extension, c_2, increases with network effect, suggesting that the stronger the network effect, the more likely it is for the line-extension strategy to dominate the single-product-monopoly strategy.

Second, line extension can be the optimal strategy in the presence of either a strong or a weak (or absent) network effect. The key condition deterring the superiority of line extension is the cost of internal clone production. In conventional markets without a network effect, line extension has two diametrical effects on a firm's profit: a positive segmentation effect and a negative cannibalization effect. Hence, line extension can be an optimal strategy in markets without a network effect if the segmentation effect dominates the cannibalization effect. In markets with a network effect, the line-extension strategy has an additional positive installed-base effect. Because the low-quality product is compatible with the innovator's high-quality product, line extension will increase the total installed base of the innovator's standard, thereby increasing the value of both products. It is interesting to note that the cost condition under which line extension is superior to the other two strategies first increases (see c_2) and then decreases (see c_3) with network effect. When the network effect is weak ($\gamma < \gamma_1$), the innovator chooses between line-extension and single-product-monopoly strategies. In this case, the stronger the network effect, the more likely it is for line extension to dominate the single-product-monopoly strategy, because under such conditions there is a significant benefit to gain from creating a compatible low-quality product (i.e., c_2 increases with γ). When the network effect is strong ($\gamma \geq \gamma_1$), the innovator chooses between line-extension and licensing strategies. In this case, the stronger the network effect, the more the innovator can benefit from having a larger network. Due to a competition effect, the licensing strategy contributes more than the line-extension strategy to the innovator's installed base; therefore, a stronger network effect favors licensing over line extension (i.e., c_3 decreases with γ).

Third, unlike line extension, a free-licensing strategy is most favorable only in markets with a strong network effect ($\gamma \geq \gamma_1$). The innovator faces different market structures under these two different product strategies. Under line extension, the innovator benefits from the revenues of both products, whereas under licensing, the low-quality product is offered by a competitor that competes directly with the innovator for sales. Therefore, free licensing cannot improve the innovator's profit unless the innovator can somehow benefit from the sales of its competitor. Network effects establish a positive relationship between the competitor's installed base and the value of the innovator's product. This positive relationship allows the innovator that adopts a free-licensing strategy to earn a profit that exceeds the (single- or multiproduct) monopoly profit. In the absence of a network effect, the innovator suffers a complete loss by giving the competitor free access to its technology.

Note that c_3 intersects with the horizontal axis in Figure 1(a), which implies that giving a competitor free access to technology can be more profitable in the presence of a very strong network effect, even if the cost of internal clone production is zero. Intuitively, if there is no cost disadvantage involved, the innovator should always introduce the clone product itself and never allow the competitor into the market. However, intuition in this case proves to be false, as Proposition 2 shows.

Proposition 2. *When there is no cost differentiation (i.e., $c_{ce} = c_{cl}$ and $c_{fe} = c_{fl}$), (1) the line-extension strategy generates a smaller network size than the licensing strategy (i.e., $q^*_{ie} + q^*_{ce} < q^*_{il} + q^*_{cl}$), and (2) it is possible for the licensing strategy to dominate the line-extension strategy.*

Proposition 2 suggests that licensing offers the advantage over line extension in generating a large network size. It is this advantage that makes it possible for the innovator to earn a higher profit under licensing than under line extension even if there is no cost disadvantage to the innovator. This advantage of licensing points to a drawback of monopoly markets that has been noted in previous research on the network effect in which it is assumed that all firms sell the same product (e.g., Katz and Shapiro 1985, Economides 1996). As Katz and Shapiro explain (1985, p. 431), "a monopolist will exploit his position with high prices and consumers know that. Thus, consumers expect a smaller network and are willing to pay less for the good." Proposition 2 shows that the monopolist's disadvantage in generating network size occurs even if quality differentiation is possible.[4]

Thus far we have considered two alternative strategies for building the installed base: licensing and line extension. These two strategies do not necessarily have to be exclusive. As Proposition 3 shows, under some conditions it is more beneficial to adopt both strategies simultaneously. Let π^*_{i+} denote the innovator's profit under the combination strategy.

Proposition 3. *The combination strategy is optimal in markets with a very strong network effect and an intermediate variable cost of internal clone production. Mathematically, there exist γ_2, c_4, and c_5 such that $\pi^*_{i+} > \max(\pi^*_{im}, \pi^*_{ie}, \pi^*_{il})$, when $\gamma > \gamma_2$ and $c_5 < c_{ce} < c_4$, where $\gamma_2 \geq \gamma_1$ (γ_1 is given in Proposition 1).*

Figure 1(b) graphically presents the results in Proposition 3. It shows that the minimum network effect required for the combination strategy to be optimal is $\gamma > \gamma_2$, whereas the minimal network effect required for the licensing strategy is $\gamma > \gamma_1$, where $\gamma_2 > \gamma_1$. This suggests that a stronger network effect is required for the combination strategy to be optimal than for the pure licensing strategy. The combination strategy creates competition between the high- and low-end markets and within the low-end market, while the licensing strategy creates the former but not the latter; hence, a stronger positive network effect is necessary for the combination strategy to ensure the profitability of introducing additional competition. Figure 1(b) also shows that a combination strategy requires an intermediate variable cost of internal clone production, c_{ce}. The upper-bound cost condition, $c_{ce} < c_4$, is necessary to ensure the superiority of the combination strategy over the pure licensing strategy and the lower-bound cost condition, $c_{ce} > c_5$, is necessary to ensure the superiority of the combination strategy over pure line extension.

4. Impact of Licensing Fee

Innovating firms often have a choice between a free- and a paid-licensing strategy. In this section, we assume that the licensor can charge a fee for the use of its technology.[5] We consider two fee structures: (a) a royalty of f per unit of production of the licensee, and (b) a fixed lump sum fee of F. We examine the impact of a licensing fee on the innovators' product strategy. Given the licensing fee, the firms engage in a Courtnot-Nash game as described in §2. We add a "check" on all variables of a paid-licensing strategy. To ensure the feasibility of a paid-licensing strategy, we consider the case in which the royalty fee is low enough to lead to a positive quantity of clone production. To simplify the exposition and focus on the comparison between monopoly and licensing strategies, we assume that $c_{fl} = 0$ and $c_{ce} \geq c_2$.

4.1. Royalty Fee

With a royalty fee per unit sold by the clone maker, f, the innovator's profit is the sum of the profit from its own sales and the royalty payment. For the clone

[4] As pointed out by Katz and Shapiro (1985), the monopolist's disadvantage found in their model (as well as in our Proposition 2) is derived based on "a model where a firm's announcement of its planned level of output has no effect on consumer expectation." To illustrate the generality of our findings given in Proposition 2, we further relax the assumption of fixed consumer expectation by developing a two-period model in which consumer expectation is affected by the observed market output. The two-period model leads to the same conclusion as that given in Proposition 2. The analysis of the two-period model can be obtained by contacting the authors.

[5] Economides (1996) discusses the effects of licensing fees but focuses on products without vertical differentiation and assumes that the demand can be upward sloping.

maker, a royalty is equivalent to an increase in the variable cost. The firms' profits are

$$\check{\pi}_{il} = (\check{p}_{il} - c)\check{q}_{il} + f\check{q}_{cl}, \tag{10}$$

$$\check{\pi}_{cl} = (\check{p}_{cl} - (c_{cl} + f))\check{q}_{cl}. \tag{11}$$

Proposition 4 describes conditions under which a paid-licensing strategy dominates a single-product-monopoly strategy and a line-extension strategy.

Proposition 4. *A positive royalty fee weakens the conditions under which a licensing strategy dominates* (1) *a single-product-monopoly strategy, and* (2) *a line-extension strategy. Formally,* (1) *there exists* $\check{\gamma}_1 < \gamma_1$ *and* $f > 0$ *such that* $\check{\pi}_{il} \geq \pi_{im}$ *if* $\gamma \geq \check{\gamma}_1$, *and* (2) *there exists* $\check{c}_3 \leq c_3$ *and* $f > 0$ *such that* $\check{\pi}_{il} \geq \pi_{ie}$ *if* $c_{ce} \geq \check{c}_3$.

Proposition 1 shows that sharing its technology freely with the competitor will hurt the innovator if the network effect is weak (i.e., $\gamma < \gamma_1$). Proposition 4 implies that, when combined with a positive royalty fee, the licensing strategy can dominate the single-product monopoly even in markets with a weak network effect (i.e., $\gamma_1 > \gamma > \check{\gamma}_1$). A paid-licensing strategy requires a weaker network effect condition because with a positive royalty fee, the innovator benefits from clone production not only from the installed base effect but also from the royalty payment. For the same reason, to dominate a line-extension strategy, a paid-licensing strategy requires a weaker cost condition (i.e., $c_{ce} > \check{c}_3$) than a free-licensing strategy (i.e., $c_{ce} > c_3$, where $c_3 \geq \check{c}_3$).

Next, we compare the innovator's profit under a paid-licensing strategy ($\check{\pi}_{il}$) with that under a free-licensing strategy (π_{il}). Proposition 5 follows.

Proposition 5. *When the quality of the clone product is sufficiently high and the cost of the clone product is sufficiently low, a paid-licensing strategy is always more profitable than a free-licensing strategy. Otherwise, a free-licensing strategy can be more profitable when the network effect is very high.*

On the one hand, a positive royalty fee can help the innovator, who receives a direct royalty payment from the licensee. On the other hand, a positive royalty fee may also hurt the innovator because a royalty fee decreases the profit margin of the clone product. As a result, the licensee will choose to sell a smaller quantity of the clone product at a higher price under a paid-licensing contract than it would under a free-licensing contract. The net impact of a royalty fee depends on the trade-off of the two opposite effects.

When the clone product has both a sufficiently high quality and a sufficiently low cost, the profit margin of the clone product is sufficiently high and the clone production may not be unduly sensitive to the royalty fee. When the clone product has either a low quality or a high cost, its profit margin is low, and therefore the clone production will be more sensitive to the royalty fee. However, the impact of reduced clone production on the innovator's profit depends on the strength of the network effect. Strong network effects favor the free-licensing strategy while weak network effects favor the paid-licensing strategy. This is because the installed base generated by the clone maker is more important to the innovator when network effects are strong than when they are weak.

4.2. Lump-Sum Licensing Fee

We now allow the innovator to charge a lump-sum licensing fee in addition to a royalty fee per unit sold. Let $\check{\pi}_{il}(f, F)$ denote the innovator's profit under a royalty fee, f, and a lump-sum fee, F. In Proposition 6 we show that in the presence of strong network effects, the innovator prefers to charge a zero royalty fee but a positive lump-sum fee.

Proposition 6. *In the presence of strong network effects, when a lump-sum licensing fee is feasible, the innovator will benefit by charging a lump-sum fee with no royalty fee. Formally, when* $\gamma \geq \gamma_1$, *for any given lump-sum fee* $F > 0$, *and royalty fee,* $f > 0$, *there exists a lump-sum fee,* $F' > 0$, *such that* $\check{\pi}_{il}(0, F') \geq \check{\pi}_{il}(f, F)$.

Proposition 6 implies that a lump-sum fee structure is superior to a royalty fee structure in markets with a strong network effect. This is because the licensor enjoys two benefits from its licensing contract in the presence of a network effect: a direct monetary benefit from the licensee's payment and an indirect network benefit from the licensee's installed base. The stronger the network effect, the more important the latter benefit. A royalty fee decreases the licensee's production level and, hence, the network benefit, whereas a lump-sum fee has no impact on the licensee's production level. For this reason, in markets with a strong network effect, the licensor will always benefit from a lump-sum fee structure (when feasible) more than from a royalty fee structure (or a lump-sum fee plus a royalty fee).

5. Conclusions and Implications

This paper presents several new findings regarding innovating firms' product-strategy decisions in the presence of network effects that have a number of managerial implications. First, we show that a single-product-monopoly strategy can be optimal in markets where the network effect is not overwhelming and the innovator's cost to produce a low-quality product is high. Video game players represent one such market. Before the very recent advent of Internet-connected game players, the dominant network effect for game players was the effect of user base on the supply of game software titles (Shankar and Bayus 2003). In the game player market, the network effect seems to be relatively weak compared to other markets with network effects created by the coupling of hardware and software (such as VCR or DVD markets) in which each consumer uses purchased hardware with hundreds of software titles (i.e., movies). Video game players, however, typically buy fewer than a dozen game titles (Dhebar 1994, Coughlan 2001), but these few are played repeatedly. Moreover, in the video game market, the most popular games comprise a large proportion of total game sales (e.g., 15 of the 185 games produced for Nintendo Entertainment System sold more than 500,000 copies each, at which level a game is designated a "hit" (Dhebar 1994)), suggesting that consumer utility of a given game platform is primarily derived from a small number of game titles. Network effects in the video game industry may also be weakened by a manufacturer's tight controls over the games' creation, reproduction, and marketing (Dehbar 1994). Furthermore, because the main consumption utility of a game player is excitement, video game software is designed to take full advantage of the game player's processing power and memory capacity (Brandenburger 1995). Hence, the perceived quality of a low-end player with less speed and memory will be very low. For this reason, the cost of a low-end player relative to its perceived quality can be very high.

Second, our results reveal that when the cost of producing a lower-quality version of the innovator's product is low, a multiproduct-monopoly strategy can be more attractive than either a single-product-monopoly or a licensing strategy. Such a product line-extension strategy is common in the software industry. Software products often exhibit network effects because the extent to which a user can exchange files with others depends on the number of people using the same software. Many software vendors have adopted a line-extension strategy—introducing different versions of their application software (e.g., professional versus student version) that are compatible but vary in quality. Another way that software monopolists create multiple products to expand their installed base is by separating their products' creation and consumption features. Thus, Adobe gives away free versions of Adobe Reader, a component of Adobe Acrobat. Because these reduced-function versions are based on existing products, their development costs are very low. Moreover, because these products are software, their marginal production costs are low. Our findings suggest that in these markets, a multiproduct-monopoly strategy can be more profitable than either a licensing or a single-product-monopoly strategy.

Third, we show that line-extension and licensing strategies are not necessarily exclusive. Under certain conditions, that is, when network effect is very strong and the innovator's cost to produce a low-quality product is neither too low nor too high, a combination strategy is optimal. Such a combination strategy has been observed in various markets with network effects (Grindley 1995), such as VCRs, CD players, PCs, and PDAs.

Fourth, our analysis of the strategic implications of licensing fees shows that a positive royalty fee can have both a positive and a negative effect on the licensee's profit because it not only brings revenue to the licensor but also leads to a lower installed base of the licensee's product. Contrary to our expectations, however, the strength of network effect is not the sole dominating factor in determining the superiority of a paid-licensing contract versus a free-licensing contract. Network effects will become a key factor only if either the value of the clone product is low or the cost is high. The innovating firm should demand a royalty fee for the use of its technology in high-value and low-cost clone products even if the market exhibits strong network effects. Yet, a free-licensing contract should be offered for low-value or high-cost clone products only when the network effect is strong. Furthermore, when it is feasible, the innovator should seek to charge a lump-sum fee rather than a royalty fee. A lump-sum fee does not affect the licensee's production level, whereas a royalty fee increases the licensee's marginal cost and, thus, reduces its production.

5.1. Limitation and Future Research

First, like most past research on markets with network effects, this paper is based on a static model that is unable to address the dynamics of firms' strategic decisions. In practice, innovating firms may adopt different product strategies during different market-development stages (Bayus 1992, Dockner and Jørgensen 1988, Kopalle et al. 1999). A dynamic model will allow us to examine whether there is a window for successful technology licensing and how the timing of technology licensing may affect the innovating firms' short- and long-term profitability (Putsis 1993). Second, this paper assumes a vertically differentiated market. Considering both vertical and horizontal differentiation will better capture consumers' adoption behavior (Gupta and Loulou 1998) and the relative attractiveness of firms' strategies. Third, like most previous research of network effect, this paper assumes an exogenous level of product quality. While we show in a research note[6] that our key results about the relative attractiveness of licensing and line-extension strategies can still hold when the quality of the clone product is an endogenous variable, the interaction between product quality and strategies

[6] Available upon request from the authors.

deserves further attention. Finally, an important subject for future investigation would be to empirically test the effects of the strength of network effect, production cost, standards competition, licensing fee, and other factors on innovating firms' product-strategy choices.

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Appendix
Proof of Lemma 1. (1) *Single-Product Monopoly.* The innovator's profit is given in Equation (2). Setting marginal revenue equal to marginal cost, we have $1+\gamma Q_{im}^* - 2q_{im}^* - c = 0$. Consumers' expectation is fulfilled in the equilibrium, $Q_{im}^* = q_{im}^*$. The optimal quantity and profit are

$$q_{im}^* = \frac{1-c}{2-\gamma}, \qquad \pi_{im}^* = [q_{im}^*]^2 = \frac{(1-c)^2}{(2-\gamma)^2}. \tag{A.1}$$

(2) *Licensing.* Following Equations (5) and (6), we have

$$\begin{aligned} p_{cl} &= K_c[1+\gamma Q_{il} - (q_{il}+q_{cl})], \\ p_{il} &= 1+\gamma Q_{il} - q_{il} - K_c q_{cl}. \end{aligned} \tag{A.2}$$

Firms' profit functions are given in (7) and (8). The first-order conditions are

$$\begin{aligned} 1+\gamma Q_{il}^* - 2q_{il}^* - K_c q_{cl}^* - c &= 0, \\ 1+\gamma Q_{il}^* - q_{il}^* - 2q_{cl}^* - c_{cl}/K_c &= 0. \end{aligned} \tag{A.3}$$

Solving for the optimal quantities and profits, we have

$$\begin{aligned} q_{il}^* &= \frac{(1-c)(2-\gamma) - (1-c_{cl}/K_c)(K_c-\gamma)}{(2-\gamma)^2 - (1-\gamma)(K_c-\gamma)}, \\ q_{cl}^* &= \frac{(1-c_{cl}/K_c)(2-\gamma) - (1-c)(1-\gamma)}{(2-\gamma)^2 - (1-\gamma)(K_c-\gamma)}, \end{aligned} \tag{A.4}$$

$$\begin{aligned} \pi_{il}^* &= (p_{il}^* - c)q_{il}^* = [q_{il}^*]^2, \\ \pi_{cl}^* &= (p_{cl}^* - c_{cl})q_{cl}^* - c_{fl} = K_c[q_{cl}^*]^2 - c_{fl}. \end{aligned} \tag{A.5}$$

Note that for the clone firm to earn a positive profit, we must have

$$c_{cl} < c_1 \equiv \left\{ c + \frac{1-c}{2-\gamma} - \frac{\sqrt{c_{fl}}[4-K_c-(3-K_c)\gamma]}{\sqrt{K_c}(2-\gamma)} \right\} K_c. \tag{A.6}$$

(3) *Line Extension.* Firms' profit functions are given in (9). The first-order conditions are

$$\begin{aligned} 1+\gamma Q_{ie}^* - 2q_{ie}^* - 2K_c q_{ce}^* - c &= 0, \\ 1+\gamma Q_{ie}^* - 2q_{ce}^* - 2q_{ie}^* - c_{ce}/K_c &= 0. \end{aligned} \tag{A.7}$$

In equilibrium, we have $Q_{ie}^* = q_{ie}^* + q_{ce}^*$, and

$$\begin{aligned} q_{ie}^* &= \frac{2(1-K_c)(1-c_{ce}/K_c) - (2-\gamma)(c - c_{ce}/K_c)}{2(2-\gamma)(1-K_c)}, \\ q_{ce}^* &= \frac{c - c_{ce}/K_c}{2(1-K_c)}. \end{aligned} \tag{A.8}$$

The innovator's profit under product extension is

$$\begin{aligned} \pi_{ie}^* &= (p_{ie}^* - c)q_{ie}^* + (p_{ce}^* - c_{ce})q_{ce}^* - c_{fe} \\ &= (q_{ie}^* + K_c q_{ce}^*)^2 + K_c(1-K_c)[q_{ce}^*]^2 - c_{fe}. \quad \square \end{aligned} \tag{A.9}$$

Proof of Proposition 1. (1) *Licensing vs. Single-Product Monopoly.* From (A.1) and (A.4), we get

$$q_{il}^* - q_{im}^* = \frac{(\gamma - K_c)q_{cl}^*}{2-\gamma}. \tag{A.10}$$

Thus, $q_{il}^* > q_{im}^*$ iff $\gamma > K_c$. Because $\pi_{il}^* = [q_{il}^*]^2$ (see (A.5)), $\pi_{im}^* = [q_{im}^*]^2$ (see (A.1)), we have $\pi_{il}^* > \pi_{im}^*$ iff $\gamma > \gamma_1 \equiv K_c$.

(2) *Line-Extension vs. Single-Product Monopoly.* From (A.1) and (A.8), we have

$$q_{ie}^* + K_c q_{ce}^* = q_{im}^* + q_{ce}^* \frac{\gamma(1-K_c)}{2-\gamma}. \tag{A.11}$$

Substituting (A.11) into (A.9), we get

$$\begin{aligned} \pi_{ie}^* &= \left[q_{im}^* + q_{ce}^* \frac{\gamma(1-K_c)}{2-\gamma} \right]^2 + K_c(1-K_c)[q_{ce}^*]^2 - c_{fe} \\ &= A_0[q_{ce}^*]^2 + B_0 q_{ce}^* + \pi_{im}^* - c_{fe}, \end{aligned} \tag{A.12}$$

where

$$\begin{aligned} A_0 &\equiv \left[\frac{\gamma(1-K_c)}{2-\gamma} \right]^2 + K_c(1-K_c) > 0, \\ B_0 &= q_{im}^* \frac{2\gamma(1-K_c)}{2-\gamma}. \end{aligned} \tag{A.13}$$

Thus, the condition $\pi_{ie}^* > \pi_{im}^*$ reduces to $q_{ce}^* > (2A_0)^{-1}[-B_0 + \sqrt{B_0^2 + 4A_0 c_{fe}}]$. Using the expression of q_{ce}^* in (A.8), the condition $\pi_{ie}^* > \pi_{im}^*$ further reduces to

$$\begin{aligned} c_{ce} < c_2 &\equiv K_c\left[c - \frac{(1-K_c)[-B_0 + \sqrt{B_0^2 + 4A_0 c_{fe}}]}{A_0} \right] \\ &= K_c\left[c - \frac{4(1-K_c)c_{fe}}{B_0 + \sqrt{B_0^2 + 4A_0 c_{fe}}} \right]. \end{aligned} \tag{A.14}$$

(3) *Licensing vs. Line Extension.* From (A.12), the condition $\pi_{ie}^* > \pi_{il}^*$ reduces to

$$q_{ce}^* > \frac{-B_0 + \sqrt{B_0^2 + 4A_0(\pi_{il}^* - \pi_{im}^* + c_{fe})}}{2A_0}. \tag{A.15}$$

This is equivalent to

$$\begin{aligned} c_{ce} < c_3 \equiv cK_c - \frac{1}{A_0}\Big\{ & K_c(1-K_c) \\ & \cdot\left[-B_0 + \sqrt{B_0^2 + 4A_0(\pi_{il}^* - \pi_{im}^* + c_{fe})} \right] \Big\}. \quad \square \end{aligned} \tag{A.16}$$

Proof of Proposition 2. (1) When there is no cost differentiation, from (A.4) and (A.8), we get

$$(q_{il}^* + q_{cl}^*) - (q_{ie}^* + q_{ce}^*) = \frac{q_{il}^*}{2-\gamma} > 0. \tag{A.17}$$

(2) Let $c_{ce} = c_{cl} = c_c, c_{fe} = c_{fl} = c_f$. Note that at $c = 0$, $c_c = 0$, $c_f = 0$, and $c_3 < 0$. Thus, there exists an open ball in the neighborhood of $c = 0, c_c = 0$, and $c_f = 0$ such that $c_3 < 0 < c_{ce}$ and the licensing strategy dominates the line-extension strategy. □

Proof of Proposition 3. (a) *The Optimal Quantities Under the Combination Strategy* (we use a "+" subscript to denote the variables for the combination strategy). Let q^*_{cl+} denote the quantity of the clone product, and q^*_{ce+}, q^*_{i+} denote the quantity of the innovator's low- and high-quality product, respectively. The first-order conditions are

$$\begin{aligned} &1 + \gamma Q^*_{i+} - 2K_c q^*_{ce+} - 2q^*_{i+} - K_c q^*_{cl+} - c = 0, \\ &1 + \gamma Q^*_{i+} - 2q^*_{ce+} - 2q^*_{i+} - q^*_{cl+} - c_{ce}/K_c = 0, \end{aligned} \tag{A.18}$$

$$1 + \gamma Q^*_{i+} - q^*_{ce+} - q^*_{i+} - 2q^*_{cl+} - c_{cl}/K_c = 0. \tag{A.19}$$

Solving the first-order conditions, we have

$$\begin{aligned} q^*_{cl+} &= q^*_{ce+} + q^*_{i+} + (c_{ce} - c_{cl})/K_c, \\ q^*_{i+} &= \frac{3 - [\gamma c_{cl} + (3-\gamma)c_{ce}]/K_c}{2(3-2\gamma)} - \frac{c - c_{ce}/K_c}{2 - 2K_c}, \end{aligned} \tag{A.20}$$

$$q^*_{ce+} = \frac{c - c_{ce}/K_c}{2 - 2K_c} - \frac{1 + [(1-\gamma)c_{ce} - (2-\gamma)c_{cl}]/K_c}{2(3-2\gamma)}. \tag{A.21}$$

The profit of the innovator under the combination strategy is

$$\begin{aligned} \pi^*_{i+} &= (p^*_{i+} - c)q^*_{i+} + (p^*_{ce+} - c_{ce})q^*_{ce+} \\ &= (1-K_c)[q^*_{i+}]^2 + K_c(q^*_{i+} + q^*_{ce+})^2 - c_{fe} \\ &= (q^*_{i+} + K_c q^*_{ce+})^2 + K_c(1-K_c)[q^*_{ce+}]^2 - c_{fe} \\ &= \left[q^*_{il} + \frac{(1-K_c)[\gamma(1-K_c)+K_c]}{(2-\gamma)^2 - (1-\gamma)(K_c-\gamma)} q^*_{ce+}\right]^2 \\ &\quad + K_c(1-K_c)[q^*_{ce+}]^2 - c_{fe}. \end{aligned} \tag{A.22}$$

(b) *Combination vs. Licensing.* From (A.22) and (A.5), the condition $\pi^*_{i+} > \pi^*_{il}$ reduces to $A_2[q^*_{ce}]^2 + B_2 q^*_{ce} - c_{fe} > 0$, where

$$\begin{aligned} A_2 &= K_c(1-K_c) + \left[\frac{(1-K_c)[\gamma(1-K_c)+K_c]}{(2-\gamma)^2 - (1-\gamma)(K_c-\gamma)}\right]^2, \\ B_2 &= \frac{(1-c)(2-\gamma) - (1-c_{cl}/K_c)(K_c-\gamma)}{(2-\gamma)(2-\gamma) - (1-\gamma)(K_c-\gamma)} \\ &\quad \cdot \frac{(1-K_c)[\gamma(1-K_c)+K_c]}{(2-\gamma)^2 - (1-\gamma)(K_c-\gamma)}. \end{aligned}$$

With further algebra, the condition $\pi^*_{i+} > \pi^*_{il}$ reduces to

$$\begin{aligned} c_{ce} < c_4 \equiv \Bigg[& cK_c(3-2\gamma) - (1-K_c)(K_c - (2-\gamma)c_{cl}) \\ & - 2(1-K_c)(3-2\gamma)\frac{c_{fe}K_c}{B_2 + \sqrt{B_2^2 + A_2 c_{fe}}}\Bigg] \\ & \cdot \frac{1}{3 - 2\gamma + (1-K_c)(1-\gamma)}. \end{aligned}$$

(c) *Combination vs. Line Extension.* From (A.12) and (A.22), we have

$$\begin{aligned} \pi^*_{i+} - \pi^*_{ie} &= K_c(q^*_{i+} + q^*_{ce+})^2 + (1-K_c)[q^*_{i+}]^2 \\ &\quad - \{K_c(q^*_{ie} + q^*_{ce})^2 + (1-K_c)[q^*_{ie}]^2\}. \end{aligned} \tag{A.23}$$

The condition $\pi^*_{i+} > \pi^*_{ie}$ reduces to

$$\begin{aligned} &\left[(1-K_c)q^*_{ie}\frac{\gamma}{2-\gamma} - K_c(q^*_{ie} + q^*_{ce})\frac{2-2\gamma}{2-\gamma}\right] \\ &\quad + \left[(1-K_c)\left(\frac{\gamma}{4-2\gamma}\right)^2 + K_c\left(\frac{1-\gamma}{2-\gamma}\right)^2\right] q^*_{cl+} > 0. \end{aligned}$$

Further simplification reduces the condition to $c_{ce} > c_5 \equiv A_3/B_3$, where

$$\begin{aligned} A_3 &= \frac{2K_c(1-\gamma)}{(2-\gamma)^2} - \frac{\gamma[2(1-K_c)K_c - (2-\gamma)cK_c]}{2(2-\gamma)^2 K_c} \\ &\quad - \frac{(1-K_c)\gamma^2 + 4K_c(1-\gamma)^2}{4K_c(3-2\gamma)(2-\gamma)^2/[K_c - (2-\gamma)c_{cl}]}, \\ B_3 &= \frac{2(1-\gamma)}{(2-\gamma)^2} + \frac{\gamma(2K_c - \gamma)}{2(2-\gamma)^2 K_c} \\ &\quad + \frac{[(1-K_c)\gamma^2 + 4K_c(1-\gamma)^2](1-\gamma)}{4K_c(3-2\gamma)(2-\gamma)^2}. \end{aligned}$$

(d) *Optimality Condition for the Combination Strategy.* Note that from (A.8), (A.20), and (A.21), we have

$$\begin{aligned} q^*_{i+} + q^*_{ce} &= q^*_{ie} + q^*_{ce} - q^*_{cl+}\frac{1-\gamma}{2-\gamma}, \\ q^*_{i+} &= q^*_{ie} + q^*_{cl+}\frac{\gamma}{2(2-\gamma)}. \end{aligned} \tag{A.24}$$

In the neighborhood of $\gamma = 1$, following Equations (A.23) and (A.24), we have $\pi^*_{i+} > \pi^*_{ie}$. Hence, there is an open ball around $\gamma = 1$ such that $\pi^*_{i+} > \pi^*_{ie}$. Taking this together with the condition $c_5 \le c_{ce} \le c_4$, we know that there exists $c_4, c_5, \gamma_2 > \gamma_1$ such that for $\gamma > \gamma_2, c_5 \le c_{ce} \le c_4$, the combination strategy dominates both the licensing and line-extension strategies. Note that under these conditions, the combination strategy also dominates the single-product-monopoly strategy because licensing dominates the single-product strategy when $\gamma > \gamma_2 > \gamma_1$. □

Proof of Proposition 4. The profit function given the licensing fee is

$$\check{\pi}_{il} = (\check{p}_{il} - c)\check{q}_{il} + f\check{q}_{cl}, \quad \check{\pi}_{cl} = (\check{p}_{cl} - (c_{cl} + f))\check{q}_{cl}. \tag{A.25}$$

The first-order conditions are

$$\begin{aligned} &1 + \gamma\check{Q}^*_l - 2\check{q}^*_{il} - K_c\check{q}^*_{cl} - c = 0, \\ &1 + \gamma\check{Q}^*_l - \check{q}^*_{il} - 2\check{q}^*_{cl} - (c_{cl} + f)/K_c = 0, \end{aligned} \tag{A.26}$$

$$\begin{aligned} \check{q}^*_{il} &= \frac{(1-c)(2-\gamma) - [1 - (c_{cl}+f)/K_c](K_c - \gamma)}{(2-\gamma)^2 - (1-\gamma)(K_c-\gamma)}, \\ \check{q}^*_{cl} &= \frac{[1 - (c_{cl}+f)/K_c](2-\gamma) - (1-c)(1-\gamma)}{(2-\gamma)^2 - (1-\gamma)(K_c-\gamma)}. \end{aligned} \tag{A.27}$$

For the $\check{q}^*_{cl}$ to be positive, we must have

$$f < f_1 \equiv K_c\frac{(1 - c_{cl}/K_c)(2-\gamma) - (1-c)(1-\gamma)}{2-\gamma}.$$

The equilibrium profit as a function of the licensing fee is

$$\begin{aligned} \check{\pi}^*_{il}(f) &= (\check{p}^*_{il}(f) - c)\check{q}^*_{il}(f) + f\check{q}^*_{cl}(f) \\ &= [\check{q}^*_{il}(f)]^2 + f\check{q}^*_{cl}(f) = -\frac{A_4 f^2}{K_c^2} + \frac{B_4 f}{K_c} + \pi^*_{il}, \end{aligned} \tag{A.28}$$

where π_{il}^* is the profit under the free-licensing strategy and

$$A_4 = \frac{K_c(2-\gamma)[4-K_c-(3-K_c)\gamma]-(K_c-\gamma)^2}{[4-K_c-(3-K_c)\gamma]^2} > 0, \quad (A.29)$$

$$B_4 = \left\{\frac{2(K_c-\gamma)[(1-c)(2-\gamma)-(1-c_{cl})(K_c-\gamma)]}{4-K_c-(3-K_c)\gamma} + K_c[(1-c_{cl}/K_c)(2-\gamma)-(1-c)(1-\gamma)]\right\} \cdot \frac{1}{4-K_c-(3-K_c)\gamma}. \quad (A.30)$$

(1) *Paid Licensing vs. Single-Product Monopoly.* First, consider $\gamma = K_c$. In this case, $\pi_{il}^* = \pi_{im}^*$ (see (A.1), (A.5), and (A.11)), and

$$B_4|_{\gamma=K_c} = \frac{\gamma[(1-c_{cl})(2-\gamma)-(1-c)(1-\gamma)]}{(2-\gamma)^2} > 0. \quad (A.31)$$

From (A.28) and (A.29), there exists an $f > 0$ such that $\check{\pi}_{il}^*(f) > \pi_{il}^* = \pi_{im}^*$. Because the profit functions are a continuous function of γ, there exists an $\epsilon > 0$ such that paid licensing strictly dominates the single-product strategy for $K_c \geq \gamma > K_c - \epsilon$. Second, consider $\gamma > K_c$. In this case, we have

$$\check{\pi}_{il}^*(0) = \pi_{il}^* > \pi_{im}^*. \quad (A.32)$$

Because $\pi_{il}^*(f)$ is continuous, there exists an f such that $\pi_{il}^*(f) > \pi_{im}^*$. Thus, there exists $\check{\gamma}_1 < \gamma_1$ for $K_c > \check{\gamma}_1$, $\pi_{il}^*(f) > \pi_{im}^*$ for some $f > 0$.

(2) *Paid Licensing vs. Line Extension.* Let f^* denote the optimal royalty fee. From (A.16), we know that the condition $\check{\pi}_{il}^*(f^*) > \pi_{ie}^*$ requires

$$c_{ce} < \check{c}_3 \equiv cK_c - \frac{1}{A_0}\left\{K_c(1-K_c) \cdot \left[-B_0+\sqrt{B_0^2+4A_0(\check{\pi}_{il}^*(f^*)-\pi_{im}^*+c_{fe})}\right]\right\}. \quad (A.33)$$

Because $\check{\pi}_{il}^*(f^*) \geq \check{\pi}_{il}^*(0) = \pi_{il}^*$, we have $\check{c}_3 \leq c_3$. □

Proof of Proposition 5. First, we know from (A.28) and (A.29), when $B_4 > 0$, there is a $\check{f} > 0$ such that $\check{\pi}_{il}^*(\check{f}) > \pi_{il}^*$; when $B_4 \leq 0$, $\check{\pi}_{il}^*(f) < \pi_{il}$ for all $f > 0$. Next, we determine the sign of B_4. Note that

$$B_4 = \frac{A_5(1-c_{cl}/K_c)-(1-c)B_5}{[4-K_c-(3-K_c)\gamma]^2},$$

where $A_5 = K_c(2-\gamma)[4-K_c-(3-K_c)\gamma]-2(K_c-\gamma)^2$ and $B_5 = 2(\gamma-K_c)(2-\gamma)+K_c(1-\gamma)[4-K_c-(3-K_c)\gamma]$. Let $F(\gamma) \equiv A_5(1-c_{cl}/K_c)-(1-c)B_5$. Then, the sign of B_4 is the same as the sign of $F(\gamma)$. It is easy to show that

$$F(\gamma) = F(1)\gamma^2 + F(0)(1-\gamma), \quad (A.34)$$

where $F(1) = (2-K_c)(2K_c-1)(1-c_{cl}/K_c)-2(1-K_c)(1-c)$ and $F(0) = 4K_c(2-K_c)(1-c_{cl}/K_c)+(1-c)[K_c^2] > 0$. Note first that $F(0) > 0$. Thus, if $F(1) > 0$, then $F(\gamma) > 0$ for $\gamma \in [0,1]$. If $F(1) < 0$, then there exists a $\check{\gamma}_2 \in (0,1)$ such that $F(\check{\gamma}_2) = 0$. Because $F(\gamma)$ is a quadratic function of γ and crosses zero only once as γ increases from the positive side, we have $F(\gamma) > 0$ for $0 < \gamma < \check{\gamma}_2$ and $F(\gamma) \leq 0$ for $\check{\gamma}_2 \leq \gamma \leq 1$.

Finally, we discuss the sign of $F(1)$. Let

$$\check{c}_{cl} \equiv K_c\left\{1 - \frac{2(1-K_c)(1-c)}{(2-K_c)(2K_c-1)}\right\}.$$

When $K_c > 0.5$ and $c_{cl} < \check{c}_{cl}$, we have $F(1) > 0$. From the above discussion we know that $F(\gamma) > 0$ for $\gamma \in [0,1]$. Hence, it is always optimal to charge a licensing fee.

When $K_c \leq 0.5$ or $c_{cl} \geq \check{c}_{cl}$, we have $F(1) \leq 0$. From the above discussion we know that there exists a $\check{\gamma}_2$ such that a positive licensing-fee policy is optimal for $0 \leq \gamma < \check{\gamma}_2$ and a free-licensing policy is optimal for $\gamma > \check{\gamma}_2$. □

Proof of Proposition 6. Let $f > 0$ be the royalty fee per unit of production and let F be the lump-sum fee. Consider an arbitrary licensing policy (f, F) under which the licensee earns a nonnegative profit. Let $(0, F')$ be an alternative licensing-fee policy such that $F' = F + f\check{q}_{cl}(f, F)$. From (A.1) and (A.27), we have $\check{q}_{il}^*(f, F) = q_{im}^* + \check{q}_{cl}^*(f, F)(\gamma - K_c)/(2-\gamma)$. Note that $\check{q}_{cl}^*(f, F)$ decreases with f but q_{im}^* does not depend on f. Thus, $\check{q}_{il}^*(f, F)$ also decreases with f when $\gamma > K_c$. Consequently, $\check{q}_{cl}^*(0, F') > \check{q}_{cl}^*(f, F)$ and $\check{q}_{il}^*(0, F') > \check{q}_{il}^*(f, F)$.

First, we show that the innovator earns a higher profit under $(0, F')$ than under (f, F). The profit under $(0, F')$ is $\check{\pi}_{il}^*(0, F') = (\check{p}_{il}^*(0, F') - c)\check{q}_{il}^*(0, F') + F' = [\check{q}_{il}^*(0, F')]^2 + F + f\check{q}_{cl}^*(f, F)$. The profit under (f, F) is $\check{\pi}_{il}^*(f, F) = [\check{q}_{il}^*(f, F)]^2 + F + f\check{q}_{cl}(f, F)$. The difference is $\check{\pi}_{il}^*(0, F') - \check{\pi}_{il}^*(f, F) = [\check{q}_{il}^*(0, F')]^2 - [\check{q}_{il}^*(f, F)]^2 > 0$.

Second, we show that the licensee earns a higher profit under $(0, F')$ than (f, F). The profit under $(0, F')$ is

$$\begin{aligned}\check{\pi}_{cl}^*(0, F') &= [\check{p}_{cl}^*(0, F') - c_{cl}]\check{q}_{cl}^*(0, F') - F' \\ &= [\check{p}_{cl}^*(0, F') - c_{cl}]\check{q}_{cl}^*(0, F') - F - f\check{q}_{cl}^*(f, F) \\ &= K_c[\check{q}_{cl}^*(0, F')]^2 - F - f\check{q}_{cl}^*(f, F).\end{aligned}$$

The profit under (f, F) is $\check{\pi}_{cl}^*(f, F) = [\check{p}_{cl}^*(f, F) - (c_{cl} + f)] \cdot \check{q}_{cl}^*(f, F) - F = K_c[\check{q}_{cl}^*(f, F)]^2 - F$. The difference is

$$\begin{aligned}&\check{\pi}_{cl}^*(0, F') - \check{\pi}^*(f, F) \\ &= K_c\{[\check{q}_{cl}^*(0, F')]^2 - [\check{q}_{cl}^*(f, F)]^2\} - f\check{q}_{cl}^*(f, F) \\ &= \frac{f(2-\gamma)}{(2-\gamma)^2 + (1-\gamma)(\gamma - K_c)}[\check{q}_{cl}^*(0, F') + \check{q}_{cl}^*(f, F)] - f\check{q}_{cl}^*(f, F) \\ &> \frac{2(2-\gamma)}{(2-\gamma)^2 + (1-\gamma)(\gamma - K_c)} f\check{q}_{cl}^*(f, F) - f\check{q}_{cl}^*(f, F) \\ &= \left[1 + \frac{\gamma(2-\gamma) - (\gamma - K_c)(1-\gamma)}{(2-\gamma)^2 + (1-\gamma)(\gamma - K_c)}\right] f\check{q}_{cl}^*(f, F) - f\check{q}_{cl}^*(f, F) > 0. \quad \square\end{aligned}$$

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