Network Effects and Technology Licensing

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Abstract

Information technology innovations that lead to new products/services exhibiting network effects form an increasingly important driver of economic growth. A paramount question faced by such innovators is whether to offer the innovation to other firms that compete with them in the same market. In this paper, we consider a firm's licensing choice in presence of network effects. The economics literature has found that producer-innovators should use royalties instead of fixed fees when licensing. We find, however, that as the intensity of the network effect increases, the choice of licensing mechanism shifts from a royalty-based regime to a fee-based regime. Furthermore, in each regime, the optimal royalty rate or the optimal fee is influenced by the intensity of the network effect, the investment needed to replicate the innovation, and the size of the potential market. Our results provide valuable insights in formulating licensing decisions in industries that exhibit network effects.

1 Introduction

Cooperation between competitors has become a growing trend in modern business. Referred to as coopetition by Brandenburger and Nalebuff [1], this phenomenon is most prevalent in information technology-based innovations where the success of resulting goods and services depend on the establishment of standards. Innovating firms must look ahead to consider strategies for deployment and value capture. On the one hand, the technology could be deployed in a proprietary manner within a vertically integrated firm. On the other hand, it can be shared with others including competitors. The sharing can be achieved either via the sale of a product or a component module that embodies the technology or through licensing [24]. Licenses will convey the right to manufacture a component (or the entire product) to a firm that competes in the product market. While our model captures the spirit of both component sales and licenses, it fits best to cases such as software and intellectual property rights where the production costs are negligible.

Our focus is on technological innovations that have the potential to be developed into standards. Sometimes the innovation is the final product itself, where standards are formed by the adoption by many users to create a large installed base [2], [8]. Most often, however, standards are built around intermediate modules (components, algorithms, architectural layers) that are embedded in a larger system. In such cases, attracting suppliers of complementary assets reinforces the standard. For example, Qualcomm authorizes infrastructure and mobile phone suppliers such as Lucent, Motorola, Nokia, Sony, and TCL to design, manufacture, and sell products using its CDMA technology [18]. Another example is General Motors' OnStar system, which provides a wide range of in-vehicle safety, communication and information services, and is attempting to forge a worldwide standard for automobile telematics. Originally offered in only a few high-end Cadillac models, OnStar is now in most GM models as well as Acura, Audi, Volkswagen, and Subaru [22].

The establishment of technology standards affects the economics of the product market by creating network effects -- the value to each user increases, as more users adopt the standard. In some networks, users gain utility not only from the standalone use, but also from the ability to connect (e.g. email) and collaborate (e.g., word processes) with other users. In other networks, the network value is derived from attracting an ecosystem of suppliers who innovate around the network standard and increase the variety of complementary products and services (e.g., operating systems). See [4], [6], [13], and [20] for extensive discussions regarding the economic implications of network effects resulting from standards.

Often a single firm enjoys a temporary leadership in developing a standard around its innovative technology due to previous knowledge, technological breakthroughs, or familiarity with the market. Such firms must then decide whether to maintain a proprietary standard, or to allow competitors access to it via interfaces and thereby establish an industry-wide standard. Licensing a

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technology to others can promote wider adoption of the technology and build a de facto standard, which creates substantial network effects. Allowing other firms to build compatible products and services will prompt more use of the standard, ultimately realizing higher network value. Establishing a standard can also provide a strategic advantage by dissuading the development of competing standards and enticing users to switch away from current standards.

Licensing a standard to potential competitors can be crucial to the success of a standard. Just as a successful licensing strategy may help a firm dominate a market, a poor licensing strategy can spell its doom. Google licensed its search results to other search engines such as Yahoo in the late 1990s, which helped to build Google's instant popularity. Compare this to Sony, which had a head start in developing videocassette recorders and invited Matsushita and JVC to license its Betamax technology in December 1974. JVC and Matsushita declined the offer. Although Sony enjoyed a virtual monopoly in the VCR market for a year, in 1976 JVC's introduction of the VHS format launched a VCR standards war, which eventually established VHS as the global standard [3]. Similar battles surrounding standards have occurred (and continue to be fought) in computer operating systems, high-definition television, web services, instant messaging, and various other technologies.

When a firm is considering licensing its technology and establishing a standard, it needs to decide on the form of licensing arrangement. For example, licensees pay Qualcomm royalties for producing CDMA equipment and mobile phones. In the case of OnStar, adopters pay GM subscription fees to access the OnStar network, and buyers of cars with OnStar installed pay a subscription fee on a monthly basis for OnStar services. The patent licensing literature has studied three licensing methods: auction, fixed-fee per license, and royalty per unit of output. The optimal licensing method, however, depends critically on whether the inventor is an outsider or an industry incumbent. Our model deals with the latter case when the patent holder is also a producer in the industry, where royalty licensing is preferred to the other two methods, because the inventor-producer is interested in not only the licensing revenue but also its profits from production [12], [23]. Empirical evidence shows that both royalties and fixed fees are used in practical, though royalties are used more often than fixed fees. In a survey of technology licenses, [19] finds that 39% of the licensing contracts use royalty alone, 13% fixed fee alone, and 46% down payment plus running royalty.

While the licensing game in our model follows the standard structure in this literature, there are two important points of departure in our approach (representative papers in the licensing literature include [5], [10], [11], [14], [15], [16], and [21], and [9] is a survey of the literature up to 1992). First, we consider innovations that lead to new products/services that exhibit network effects. Second, we grant a competing firm an option to develop its own technology standard. One of our key results shows that for an inventor-producer, as the intensity of network effect increases, the optimal licensing strategy shifts from a royalty-based regime of a fee-based regime. The result in the previous literature that royalty licensing is optimal for an insider inventor becomes a special case of our model, where the intensity of network effect is zero.

2 Model

2.1 Model Setup

We consider an industry where two competing firms generate innovations that can be developed into a new product or service that exhibit network effect. Suppose one of the firms, M, has achieved a licensable innovation (M's decisions and investments that led to the innovation are in the past and not the focus of this paper.) The other firm N, temporarily lagging behind, can achieve a substitute innovation by investing the amount of K. M can either retain its innovation as proprietary, or license the innovation to its competitor N. Given M's decision N decides whether or not to invest K in its own innovation.

First, consider the case where M retains its innovation as proprietary. If N invests in its own technology, the two firms will engage in Cournot competition, producing perfectly substitutable but incompatible products (services) under competing standards. We only consider the firms' Cournot profits and ignore any intermediate cash flow M may earn before N produces (the intermediate cash flow is negligible compared to the profits both firms make in the life cycle of the products). If N does not invest, M becomes a monopolist.

Next, consider the case where M licenses its innovation to N. If M decides to allow N to license the standard, it makes a take-it-or-leave-it (TIOLI) offer to N. The license may take two different forms: a fixed fee, or a quantity-based royalty rate. Firm N then has the choice of whether to accept or reject the offer. By accepting the licensing offer, N adopts M's technology and will not invest K. The two firms then engage in Cournot competition in the product market. Unlike the case where M keeps its innovation proprietary and N invests in its own innovation, in this case, there is only one standard, i.e. M's technology, in the market. If N rejects the licensing offer, however, N's investment will result in two competing standards.

Firms may incur some cost in producing the network product. For information goods such as software, the marginal cost is close to zero. Since our focus is on the network effects, we assume zero production cost. The real world, of course, is inherently more complex than our stylized model. There can be multiple players, possibility of coordination, and complementary networks. Our model is intended to isolate licensing as an important mechanism through which firms establish network standards. Next, we discuss the demand function in a market that exhibits network effect and where firms can establish standards. We also discuss how firms' licensing decisions impact demand in such a market.

2.2 Demand for Network Goods and the Intensity of Network Effect

A canonical linear demand function for a normal good can be represented by:

$$P(q,\theta)=\theta - q$$

where q is the quantity demanded for the good. Both firms know the demand parameter, θ. Though θ is treated as certain in this model, it can also be interpreted as the expected value of maximum potential demand.

In the case of a network good, users derive added value from the presence of others in the network. Although network effects are the easiest to visualize when users derive value from connecting to other users, they also arise in systems of complementary goods (e.g., video game consoles and games, cars, gas stations, and repair shops). The literature characterizes the former as direct network effects and the latter as indirect network effects. The value in complementary systems comes from increased variety in future periods, but there is a similar network effect in that as the total number of users increases, so does the value to each user. The mechanism of the network effect is indirect in that the more users of a standard the greater the incentives for complementors to create more variety.

This additional value, which we call network value, depends on the number of other users of this good. Even though users make their purchasing decisions independent of each other, and join the network at different times, they do not base their decisions on the actual number of users at the time they join the network, but rather on the *expected* size of the network.

We assume expectations are exogenously given. We also assume users are homogeneous in their valuation of network benefits, and the network value compounds the standalone value of the good. There is both good reason and empirical evidence that indicates different consumers will contribute different amounts of network value. For instance, one might derive substantial value from having close friends, family, and colleagues who use the same standard word processor or instant messaging system. The total number of consumers will induce other firms to develop a greater variety of complementary products and thereby enhance the indirect network effects.

We can write the demand function for a network good as:

$$P(q,q^e,\theta)=\theta+v(q^e)-q$$

where q^e is users' expectation regarding the size of the network. Katz and Shapiro use a similar specification for the demand function [13]. The term $v(q^e)$ represents an individual user's willingness to pay for the network value of the good, and is an increasing function of q^e, i.e., $v'>0$. θ now represents the maximum market demand for the standalone use of the network good.

According to the well-known Metcalfe's law, the total value of a network increases in proportion to the square of the number of users in the network [7]. That is, The total value of the network is $q\,v(q)=\beta q^2$. It implies that for each consumer, the network value of a product can be represented by:

$$v(q)=\beta q$$

More generally, we know that network benefits tend to level off after a network reaches a large enough size. In fact, in some cases very large networks may even become cumbersome to navigate and create congestion, so that user benefits may decline beyond a certain scale. These effects can be modeled by a more general function of the form, $v(q)=\beta q^{\alpha}$.

The parameter β reflects an intrinsic property of a network. That is, for two networks with equal size, the network with a higher β endows its users with higher network benefits. We define β as the intensity of the network effect. At one extreme where β=0, $v(q)$=0, and the demand collapses to that for a normal good where users realize only the standalone value. At the other extreme, in order to maintain the downward-sloping property of the demand function, we restrict $\beta<1$. Leibenstein [17] shows how to derive the demand curve in presence of network effect under fulfilled expectation equilibrium (FEE). We explain the notion of FEE in Section 4.1.

Networks are different with regard to intensity of network effect. There is a more intense network effect for a network of online game players, for example, than for users of an online bookstore. Players of online games benefit from the presence of other players because they can interact with more players, and it is more likely they will meet players with similar skill levels. While customers of the same online bookstore may benefit from each other's reviews of the store and the books, the network effect is not likely as strong. In other words, a network of online game players has a higher β than a network of online bookstore consumers.

Providers of network goods and services may also change the intensity of network effects through business decisions. Wireless service providers often offer services that apply only to their own customers, which in effect create their own networks. Sprint PCS, for example, offers free PCS-to-PCS calls, so each PCS subscriber gains from the existence of other PCS subscribers. Sprint further offers a service that allows "walkie-talkie-style" communication, and users who have added this service receive even higher network value among them. By offering more services, a provider can increase the intensity of the network effect.

The presence of network effects plays a vital role in M's licensing decisions and in N's adoption decision. When M does not license its innovation, or the two firms cannot reach a licensing agreement, N's investment will result in a competing standard. In this case, each firm will make its production decisions knowing that buyers of its products will belong to different networks, and that the network will be less valuable than if the two firms had adopted the same standard and effectively formed one network. This path is probably best illustrated by the VCR standards war and Apple Computer keeping its Macintosh technology proprietary.

If M successfully licenses its technology to N, users of both products form one single large network instead of two smaller incompatible networks, allowing users to enjoy higher network benefits. The firms are then in a position to charge a higher price and earn higher profits for the product because of users' increased willingness to pay. By using an appropriate licensing strategy, M can establish its standard as the industry standard *and* collect licensing revenues from N, all the while it is producing a good with a higher network value. OnStar exemplifies such a case.

3 Optimal Decisions under Different Licensing Strategies

M has three strategies regarding licensing: 1) Does not license its innovation; 2) License the innovation to N by means of a fixed fee; 3) License by means of a royalty. For each strategy, we solve for the firms' optimal production decisions. For the two strategies that involve licensing, we further solve for the optimal licensing fee and the optimal royalty rate..

3.1 No Licensing

Suppose M does not offer a license to N. If N invests K, M and N will have incompatible standards. Since the two firms' products are perfect substitutes in their standalone value, the prices for the products are given by (we use subscripts 1 and 2 to represent M and N respectively):

$$P_i = \theta + v\left(q_i^e\right) - q_1 - q_2, \quad i = 1,2$$

The profits are given by:

$$\pi_i = q_i\left[\theta + v\left(q_i^e\right) - q_1 - q_2\right] \quad i = 1,2$$

We use the functional form $v(q) = \beta q$. We now determine the firms' optimal production decisions. We solve M's and N's profit maximization problems and impose a fulfilled expectation equilibrium (FEE) condition.

Under FEE, M and N choose the optimal quantity of the network good by maximizing profits and setting the quantity equal to corresponding expected quantities. Solving for the equilibrium quantities, prices, and profits as functions of θ under FEE, we see that the two firms engage in symmetric Cournot competition and produce identical quantities.

$$q_1^* = q_2^* = \frac{\theta}{3-\beta}$$

$$\pi_1^* = \pi_2^* = \left(\frac{\theta}{3-\beta}\right)^2$$

For N, the net payoff from developing its own standard is: $\Pi_2 = \pi_2^* - K$. Since staying out of the market yields zero payoff, N will enter only when $\theta > (3-\beta)\sqrt{K}$. This means that the market demand must exceed a threshold level for N's entry to be profitable. We call $\theta \equiv (3-\beta)\sqrt{K}$ the entry threshold. The resulting N's payoff function is:

$$\Pi_2^{NL} = \begin{cases} 0 & \text{when } \theta \le \theta \\ \frac{1}{(3-\beta)^2}\theta^2 - K & \text{when } \theta > \theta \end{cases}$$

Since N stays out of the market when the demand is below the entry threshold, M becomes the monopolist. Maximizing $\pi_1 = q_1\left(\theta + \beta q_1^e - q_1\right)$ under FEE yields the monopoly quantity $q_1^* = \frac{1}{2-\beta}\theta$. Thus, M's payoff as a function of realized demand is given by:

$$\Pi_1^{NL} = \begin{cases} \frac{1}{(2\text{-}\beta)^2}\theta^2 & \text{when } \theta \le \theta \\ \frac{1}{(3-\beta)^2}\theta^2 & \text{when } \theta > \theta \end{cases}$$

3.2 Licensing by Means of Fixed Fee

If N does not invest to develop its own standard, but instead licenses M's standard by paying M a fixed fee, *F*, the firms then engage in Cournot competition. With licensing, M and N conform to the same standard, and the customers of both firms form one large network, leading to higher network value. The market price is given by:

$$P = \theta + v\left(q_1^e + q_2^e\right) - q_1 - q_2$$

The firms' profits are:

$$\pi_i = q_i\left[\theta + v\left(q_1^e + q_2^e\right) - q_1 - q_2\right] \quad i = 1, 2$$

Firms' optimal production decisions yield the following equilibrium quantities:

$$q_1^* = q_2^* = \frac{\theta}{3-2\beta}.$$

Firms' payoffs with a fixed fee license are given by:

$$\Pi_1^F = \tfrac{1}{(3-2\beta)^2}\theta^2 + F;$$

$$\Pi_2^F = \tfrac{1}{(3-2\beta)^2}\theta^2 - F.$$

Next, we examine how M should set the licensing fee. Recall the assumption that M makes a TIOLI offer to N. Therefore, the optimal fee should maximize M's payoff while ensuring that N will agree to the term of the license. We assume that N agrees to license when it is indifferent between licensing and not licensing, or achieves higher payoff by licensing. In other words, the optimal fee is the solution to the following constrained maximization problem:

$$\underset{F}{Max} \quad \Pi_1^F = \tfrac{1}{(3-2\beta)^2}\theta^2 + F$$

$$s.t. \quad \Pi_2^F = \tfrac{1}{(3-2\beta)^2}\theta^2 - F \geq \Pi_2^{NL}$$

Obviously, M wants to charge the highest possible fee, which is constrained by N's acceptance. This means that the constraint is binding and the optimal fee F^* is determined by $\Pi_2^F = \Pi_2^{NL}$. We have,

$$F^* = \begin{cases} \tfrac{1}{(3-2\beta)^2}\theta^2 & \text{when } \theta \leq \theta \\ \tfrac{3\beta(2-\beta)}{(3-\beta)^2(3-2\beta)^2}\theta^2 + K & \text{when } \theta > \theta \end{cases}$$

We can then derive M's payoff under the optimal fee, Π_1^{F*} (see Table 1). This is the maximum payoff that M can achieve with a fixed-fee license. N's payoff is trivial when M charges the optimal fee, because by definition $\Pi_2^{F*} = \Pi_2^{NL}$.

3.3 Licensing by Means of Royalty

If N licenses M's standard by means of royalty, it pays M a royalty, r, for each unit it produces. M's payoff thus consists of two parts: profits from selling its own product, and royalties from N:

$$\Pi_1^r = q_1\left[\theta + v\left(q_1^e + q_2^e\right) - q_1 - q_2\right] + q_2 r$$

N's payoff is given by:

$$\Pi_2^r = q_2\left[\theta + v\left(q_1^e + q_2^e\right) - q_1 - q_2 - r\right]$$

The equilibrium quantities under optimal production decisions are:

$$q_1^* = \frac{\theta + (1-\beta)r}{3-2\beta}$$

$$q_2^* = \frac{\theta - (2-\beta)r}{3-2\beta}$$

The firms' payoffs under equilibrium quantities are:

$$\Pi_1^r = \frac{\theta^2 + (5-4\beta)\theta r - \left(\beta^2 - 5\beta + 5\right)r^2}{(3-2\beta)^2}$$

$$\Pi_2^r = \left[\frac{\theta - (2-\beta)r}{3-2\beta}\right]^2$$

What is the optimal royalty rate for M? Again, the optimal rate should maximize M's payoff as long as N agrees to license. In other words, the optimal rate r^* should solve:

$$\underset{r}{Max} \quad \Pi_1^r = \frac{\theta^2 + (5-4\beta)\theta r - \left(\beta^2 - 5\beta + 5\right)r^2}{(3-2\beta)^2}$$

$$s.t. \quad \Pi_2^r = \left[\frac{\theta - (2-\beta)r}{3-2\beta}\right]^2 \geq \Pi_2^{NL}$$

The expression of Π_1^r, however, suggests that unlike the case of fee licensing, it may not be in M's best interests to charge the highest rate acceptable to N. In other words, N's acceptance constraint may not be binding. We use a three-step approach to solve the above constrained maximization problem and determine the optimal royalty rate. First, we solve the unconstrained maximization problem and we derive the rate that maximizes M's payoff *regardless of* N's acceptance, which we denote by r_1^*. Second, we find the royalty rate where N's acceptance constraint is binding, denoted by r_2^*. Because N's payoff decreases with the royalty rate,

r_2^* is the maximum royalty rate N will agree to. Lastly, the optimal rate is determined by taking the minimum of the above rates, i.e. $r^* \equiv \min\left(r_1^*, r_2^*\right)$.

We derive r_1^* by maximizing Π_1^r.

$$r_1^* = \frac{5-4\beta}{2\left(\beta^2 - 5\beta + 5\right)}\theta$$

The maximum rate N will agree to, r_2^*, is derived by solving $\Pi_2^r = \Pi_2^{NL}$. We have

$$r_2^* = \begin{cases} \frac{1}{2-\beta}\theta & \text{when } \theta \leq \theta \\ \frac{1}{2-\beta}\theta - \frac{3-2\beta}{2-\beta}\sqrt{\frac{\theta^2}{(3-\beta)^2} - K} & \text{when } \theta > \theta \end{cases}$$

The optimal rate is the minimum of r_1^* and r_2^*. This is because whenever $r_1^* < r_2^*$, it is in M's best interest to charge r_1^* instead of r_2^*, and when $r_1^* \geq r_2^*$ M is forced to charge r_2^* due to N's acceptance constraint. We first note that when $\theta \leq \theta$, $r_1^* < r_2^*$ for any valid value of β. Therefore, $r^* \equiv \min\left(r_1^*, r_2^*\right) = r_1^*$, which means that when $\theta \leq \theta$, the optimal royalty rate is determined purely by M's payoff maximization and that N's acceptance constraint is not binding. In other words, when the demand is below N's entry threshold, it is optimal for M to offer a royalty rate lower than what N is willing to pay! The reason for this counter-intuitive result is as follows. The rationale for licensing, by either fixed fee or royalty, is that when the demand is low and N is unwilling to enter the market, due to the network effect, it is in the best interest of M to entice N to produce and help grow the network. Then why would M charge a rate lower than the maximum rate acceptable to N? With a fee licensing structure, M produces the same amount as N does, and thus M charges the highest fee N is willing to pay. With a royalty licensing structure, however, M produces higher quantity than N does. Therefore, to take full advantage of network effects, it is optimal for M to charge a rate lower than what N is willing to pay to further encourage N's production activity.

For $\theta > \theta$, we first define $\theta \equiv \frac{2(3-\beta)\left(5-5\beta+\beta^2\right)}{\sqrt{(1-\beta)(2-\beta)(5-\beta)(10-3\beta)}}\sqrt{K}$ (note that $\theta > \theta$). We find that $r_1^* < r_2^*$ when $\theta < \theta < \theta$, $r_1^* = r_2^*$ when $\theta = \theta$, and $r_1^* > r_2^*$ when $\theta > \theta$. Therefore, $r^* = r_1^*$ when $\theta < \theta \leq \theta$, and $r^* = r_2^*$ when $\theta > \theta$.

Overall, the optimal rate is determined purely by M's payoff maximization when $\theta \leq \theta$, and N's acceptance condition is binding and determines the rate M charges only when $\theta > \theta$. In sum, the optimal royalty rate is given by:

$$r^* = \begin{cases} \frac{5-4\beta}{2\left(5-5\beta+\beta^2\right)}\theta & \text{when } \theta \leq \theta \\ \frac{1}{2-\beta}\theta - \frac{3-2\beta}{2-\beta}\sqrt{\frac{\theta^2}{(3-\beta)^2} - K} & \text{when } \theta > \theta \end{cases}$$

We can also derive M's payoff under the optimal royalty rate, $\Pi_1^{r^*}$ (see Table 1), which is the maximum payoff M can get by offering a royalty-based license.

4 Optimal Licensing Strategy

For each of the three strategies: no licensing, fee licensing, and royalty licensing, we have discussed firms' optimal decisions and derived M's maximum payoff. Table 1 lists M's payoffs under these strategies, as well as the optimal fee and royalty rate, for different ranges of demands.

Based on the above results, what is M's optimal strategy for a given demand parameter? To answer this question, we simply need to compare the payoff functions under different strategies for any given demand parameter and choose the payoff-maximizing strategy.

We define the following notation. For two licensing strategies *A* and *B*, if $\Pi_1^A > \Pi_1^B$ for some level of θ, we say *A* dominates *B*, or $A \quad B$, for this value of θ. With slight abuse of notation, we use *NL*, F^*, and r^*, to denote M's three strategies: no license, a fixed-fee license, and a royalty-based license, respectively. The strategies F^* and r^* imply that the fee and the royalty rate are set optimally, as given in Section 4 and Table 1.

First, when demand is within N's entry threshold, i.e. $\theta \leq \theta$, we find that $\Pi_1^{r^*} > \Pi_1^{NL}$ for any θ and any valid β. It means that the strategy of no licensing is dominated by royalty licensing, and therefore we only need to compare the two strategies that involve licensing to find the optimal strategy. Comparison between $\Pi_1^{r^*}$ and $\Pi_1^{F^*}$ yields the following results. When $\beta = \beta_1 \equiv \frac{5-\sqrt{10}}{6} \cong 0.306$, the optimal fee license and the optimal royalty license yield the same payoff for any $\theta \leq \theta$. Furthermore, royalty licensing dominates fee licensing (i.e. $r^* \quad F^*$) for $\beta < \beta_1$, while fee dominates royalty (i.e. $F^* \quad r^*$) for $\beta > \beta_1$.

When demand is above N's entry threshold, i.e. $\theta > \theta$, we find that $\Pi_1^{F*} > \Pi_1^{NL}$ for any θ and any valid β. Again we can ignore the no licensing strategy and focus on the other two strategies. We first compare Π_1^{r*} and Π_1^{F*} for the demand range of $\theta < \theta \le \theta$. We find that for each $\theta \in \left(\theta, \theta\right]$, there exists a unique level of β such that fee and royalty licenses (terms set optimally) yield the same payoff. We define these levels of β as β_e, which is a function of θ, denoted by $\beta_e(\theta)$. Furthermore, royalty licensing dominates fee licensing (i.e. $r^* \quad F^*$) for $\beta < \beta_e(\theta)$, while fee dominates royalty (i.e. $F^* \quad r^*$) for $\beta > \beta_e(\theta)$. Applying this notation to the results we obtain earlier for the range of $\theta \le \theta$, clearly, we have $\beta_e(\theta) = \beta_1$. For $\theta < \theta \le \theta$, however, there is no closed-form expression for $\beta_e(\theta)$. We can construct $\beta_e(\theta)$ numerically. We can prove that $\beta_e(\theta)$ is continuous and increasing in θ, and that $\beta_e(\theta) = \beta_1$ and $\beta_e(\theta) \equiv \beta_2 \cong 0.319$. β_2 is defined as the root of the equation $4\beta^3 - 18\beta^2 + 21\beta - 5 = 0$ that falls in the range of [0, 1).

Lastly, we compare Π_1^{r*} and Π_1^{F*} for the demand range of $\theta > \theta$. Again, for any $\theta \in (\theta, +\infty)$, there exists a unique level of β, denoted by $\beta_e(\theta)$, such that M is indifferent between fee and royalty licensing, and $r^* \quad F^*$ for $\beta < \beta_e(\theta)$ while $F^* \quad r^*$ for $\beta > \beta_e(\theta)$. Similar to the case of $\theta < \theta \le \theta$, $\beta_e(\theta)$ can only be numerically constructed for $\theta > \theta$. $\beta_e(\theta)$ is also continuous and monotonically increasing in θ for $\theta \ge \theta$. Furthermore, $\beta_e(\theta)$ has an upper bound. Define $\lim_{\theta \to \infty} \beta_e(\theta) \equiv \beta_3$. β_3 is defined as the root of the equation $\beta^3 - 6\beta^2 + 9\beta - 3 = 0$ that falls in the range of [0, 1), and numerically, $\beta_3 \cong 0.468$.

Based on the above results, we obtain the following propositions.

Proposition 1: For any level of demand θ, there exists a unique intensity of network effect $\beta_e(\theta)$ such that the optimal fee license and the optimal royalty license yield the same payoff, and royalty licensing dominates fee licensing for $\beta < \beta_e(\theta)$ while fee licensing dominates royalty licensing for $\beta > \beta_e(\theta)$.

Proposition 2: When $\beta < \beta_e(\theta)$, the optimal licensing strategy is a royalty-based license where the royalty rate is given by:

$$r^* = \begin{cases} \frac{5-4\beta}{2\left(5-5\beta+\beta^2\right)}\theta & \text{when } \theta \le \theta \\ \frac{1}{2-\beta}\theta - \frac{3-2\beta}{2-\beta}\sqrt{\frac{\theta^2}{(3-\beta)^2} - K} & \text{when } \theta > \theta \end{cases}$$

Proposition 3: When $\beta > \beta_e(\theta)$, the optimal licensing strategy is a fee-based license where the fee is given by:

$$F^* = \begin{cases} \frac{1}{(3-2\beta)^2}\theta^2 & \text{when } \theta \le \theta \\ \frac{3\beta(2-\beta)}{(3-\beta)^2(3-2\beta)^2}\theta^2 + K & \text{when } \theta > \theta \end{cases}$$

5 Concluding Remarks

This paper considers a firm's licensing choice when it has achieved an innovation that leads to network product. The economics literature on licensing has found that producer-innovators should use royalties instead of fixed fees when licensing. We find, however, that as the intensity of the network effect increases, the optimal licensing mechanism shifts from royalty-based to a fee-based. We further derive the optimal royalty rate and the optimal fee as functions of the intensity of the network effect, the investment needed to replicate the innovation, and the size of the potential market.

Although our results provide insights in strategic investment and licensing, there are several caveats that must be attached. First, by considering a linear function of network value, we preclude the possibility of well-documented network saturation effect. However, when the network value can be approximated by a piece-wise linear function, the qualitative nature of our results holds true. Second, by limiting the form of licensing to a fixed-fee and a single royalty rate, we do not address the full spectrum of licensing possibilities. Furthermore, the simple structure of our model does not reflect the impact of contract duration. However, a most sophisticated model that considers these features can be developed along similar lines.

6 References

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Table 1				
		$0<\theta\le\theta$	$\theta<\theta\le\theta$	$\theta>\theta$
No Licensing	Π_1^{NL}	$\frac{1}{(2\text{-}\beta)^2}\theta^2$	$\frac{1}{(3-\beta)^2}\theta^2$	
Fixed Fee Licensing	F^*	$\frac{1}{(3-2\beta)^2}\theta^2$	$\frac{3\beta(2-\beta)}{(3-\beta)^2(3-2\beta)^2}\theta^2+K$	
	Π_1^{F*}	$\frac{2}{(3-2\beta)^2}\theta^2$	$\frac{9-2\beta^2}{(3-\beta)^2(3-2\beta)^2}\theta^2+K$	
Royalty Licensing	r^*	$\frac{5-4\beta}{2(5-5\beta+\beta^2)}\theta$		$\frac{1}{2-\beta}\left[\theta-(3-2\beta)\sqrt{\frac{\theta^2}{(3-\beta)^2}-K}\right]$
	Π_1^{r*}	$\frac{5}{4(5-5\beta+\beta^2)}\theta^2$		$\frac{1}{(2-\beta)^2}\left[\frac{4-\beta}{(3-\beta)^2}\theta^2+\beta\theta\sqrt{\frac{\theta^2}{(3-\beta)^2}-K}+(5-5\beta+\beta^2)K\right]$