NETWORK EFFECTS AND TECHNOLOGY LICENSING: MANAGERIAL DECISIONS FOR FIXED FEE, ROYALTY, AND HYBRID LICENSING

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Last revised: April 24, 2006

ABSTRACT

A paramount question faced by technology innovators is whether to license an innovation to other firms, and if so, what type of license it should use. Information technology innovations often have the unique feature of leading to new products and services that exhibit network effects. This paper addresses the question whether the presence of network effects changes an innovator' licensing choice. The literature suggests that without network effects, a royalty license is preferred by producer-innovators. We find, however, in a market with high intensity of network effects, a fixed fee license is optimal. For low intensity of network effects, the optimal license uses a royalty rate, either alone or in combination with a fee. We further derive the terms of the optimal license and discuss the impact of the investment needed to replicate the innovation and the size of the potential market. Our results provide insights for licensing decisions in industries that exhibit network effects.

Keywords: Economic analysis, fixed fees, hybrid charging schemes, IT value, licensing policy, network effects, royalty, technology innovations

1 Introduction

Technological innovations often have the potential to be developed into standards. In information and telecommunication industries, establishing standards has proved vital for the success of products and services built around innovations [2, 8]. Therefore, a firm deciding how to deploy its innovations should consider capturing value not only from its own use of the innovations, but also from the resulting standards [24].

There are two different strategies to establish an innovation-based standard. First, a firm can deploy an innovation within its boundary, and subsequently develop a proprietary standard. When a standard is built around an innovative module, the firm must be vertically integrated in order to keep the standard proprietary. The conventional wisdom for such a strategy is that the firm can sustain a competitive advantage and earn monopolistic profits. However, it is questionable whether the firm can become or remain a monopolist: other firms may achieve substitutable innovations and develop competing standards. Another risk for building a proprietary standard is that without the support from others, the new technology may fail to generate enough interest among users or fail to satisfy growing market demand.

An alternative strategy is to allow others including competitors to adopt one's technology. This strategy acts as a double-edge sword. On the one hand, the more others adopt the technology, the more likely it is to become the dominant standard, which helps defeat competing standards and dissuade potential competitors from developing new standards. On the other hand, however, this strategy invites others to compete with one's own product. Recent research and business practice have shown that the potential to own and establish a standard tends to outweigh the concerns of competition in the product market. Brandenburger and Nalebuff [1] notice a growing trend in modern business where competitors engage in cooperative

activities, which they call "coopetition." Allowing competitors access to one's innovation is a special form of coopetition most prevalent in industries (such as information technology and telecommunication industries) where it is critical to establish standards based on innovations. In fact, many innovating firms make tremendous efforts to persuade potential competitors to adopt their technology, hoping to establish an industry-wide standard.[1] Innovators usually also encourage vendors of complementary goods to build compatible products and services, further prompting use of the standard.

Why are firms so keen on establishing a standard? One of the key reasons is that the owner of a standard can reap higher economic benefits by creating network value for its users.[2] Users gain utility from the ability to connect (e.g., email) and collaborate (e.g., word processors) with more users, in addition to the standalone use of the product. This is called a *direct network effect*. When many firms adopt a standard and produce compatible products, users of these products form a large network and are willing to pay a higher price, allowing each provider to earn higher profits. A large network of users also attracts an ecosystem of suppliers who innovate around the standard and increase the variety of complementary products and services (e.g., operating systems), which further increases the network value for users. Such network value, called an *indirect network effect*, plays an important role in most standards.

The next question that arises is how to establish a standard. Numerous cases illustrate that convincing potential competitors to adopt one's standard can be crucial for the success of a standard. In the history of VCR standards, Sony had a head start in developing videocassette recorders. Little known is that Sony invited Matsushita and JVC to license its Betamax

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[1] For example, the Bluetooth technology was first developed by Ericsson in 1994. Instead of keeping the standard proprietary, it invited five other companies including its competitor Nokia to jointly form the Bluetooth Special Interest Group (SIG) in 1998.
[2] See [5, 6, 14, 24] for extensive discussions regarding the economic implications of network effects resulting from standards.

technology in December 1974. However, 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 [4]. As a counter-example, General Motors was the leader in the automobile telematics market and attempted to forge a worldwide standard by selling its OnStar system to other automobile manufacturers [25]. OnStar provides a wide range of in-vehicle safety, communication and information services. Although it might be too early to declare a winner, Honda, Volkswagen, and Subaru have now adopted OnStar as their telematics standard, and suspended development of their own standards. OnStar is now available not only in most GM models, but also in such makes as Acura, Audi, Volkswagen, and Subaru. 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. Of these ongoing standards wars, the battle between Blu-Ray and HD-DVD over the next generation DVD standard is in many ways similar to the Betamax vs. VHS case. Both camps are trying to license their technology to optical media manufacturers and are seeking support from content providers. In all these examples, one key issue the leading firm must resolve is the terms of the contract for technology use (most often a licensing agreement).

In practice, establishing a standard and negotiating with other parties are highly complex decisions involving not only economic but also technological, legal, and public policy issues. In this paper, we do not attempt to capture all the nuances of a standards strategy. Instead, we focus on the economic issues and in particular, address the following questions: 1) should an innovator develop a proprietary standard or should it allow others to adopt its technology? 2) if it allows others access to its technology, how much should it charge for the access? We develop a game-

theoretic duopoly model in which an innovating firm faces the choice to either keep its technology proprietary or allow another firm to adopt its technology. If the technology is kept proprietary, the other firm can achieve a substitutable innovation at a cost and establish its own standard. If the firm allows adoption of its technology, it then needs to decide on a pricing mechanism acceptable to the other firm (i.e., effectively preempting a substitutable innovation).

Before we generalize the pricing mechanisms for technology sharing, we discuss different forms of innovations and the manner in which users can gain access to them. An innovation may come in the form of a new product, and a standard is established when many users adopt the product, creating a large installed base. The innovator then can license its technology, conveying the right of manufacturing similar products to licensees. However, single-product standards are rare, and most often a standard involves a system consisting of multiple complementary products and services.[3] In these cases, the owner of a system may let others offer one of the products or services, and just charge for access to the system. For example, carmakers that have adopted OnStar pay GM subscription fees to access the OnStar network, and buyers of cars with OnStar installed pay for the services on a monthly basis. For another example, Qualcomm licenses its CDMA technologies by authorizing infrastructure and mobile phone suppliers such as Lucent, Motorola, Nokia, Sony, and TCL to design, manufacture, and sell products compatible with the CDMA standard [22]. In fact, most innovations in information and communication technologies (ICT) occur in a module (component, algorithm, architectural layer, etc.) of a larger system, leading to new systems with the innovations embedded. Over the years, ICT innovations have been achieved at different architectural layers (hardware, operating systems, applications, telecommunication protocols, business processes, etc.) and led to

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[3] For example, Apple's digital media standard is built largely on its innovative device, the iPod family, but Apple also provides complementary products and services, namely the iTunes software and digital contents through iTunes Music Store.

numerous standards. Innovators can offer the technology to others either through licensing the right of providing a device/service, or via the sale of a key component module that embodies the technology, or by sharing application programming interfaces (API) for a fee [28].[4]

While access to innovations may take various forms, there are two basic types of pricing mechanisms: a fixed fee, or a per unit charge. For example, a firm using a licensing strategy can charge either a fixed fee per license or a royalty rate per unit of output. In a survey of technology licenses, Rostoker [23] finds that 39% of the licensing contracts used royalties alone, 13% fixed fees alone, and 46% down payments plus a running royalty. From the pricing perspective, sale of a component, volume-based service charges, and royalty-based licenses are all forms of per unit charges, while lump sum sale or service charges, and fee-based licenses are variations of fixed-fee pricing. In the rest of this paper, we discuss pricing choices in terms of fixed-fee licensing and royalty licensing. Note that our results also apply to cases of sales and service charges.[5]

We obtain several interesting results. First, a firm with an innovation should license its technology to its competitor in presence of network effects. While previous results show that without network effects, the leading firm does not license when the market demand is low [18] we find that with a network effect, it is always optimal to license one's technology. The intuition is that without a network effect, the prospects of earning monopolistic profits outweigh licensing revenues in some cases, but even a slight network effect will make a licensing strategy always preferred to a keeping-it-proprietary strategy.

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[4] Details regarding access to specific layers, modules, and architectural control points are technical decisions with important implications. Our research, however, focuses on the economic aspects.

[5] Since we study the pricing choice for sharing technological innovations, our research is closely related to and contributes to the patent licensing literature. Another strand of literature that studies contracting choices between fixed fees and royalties is the research on franchising. Empirical evidence shows that most franchisors collect both a fixed fee and sales royalties (see, e.g., [9, 19]). Incentive concerns play an important role in determining the terms of the franchise contract [17, 21]. This is due to the central role of the trademark in franchising, which is not present in technology licensing [3, 19].

Second, the optimal licensing structure depends on the intensity of network effects. We compare the two licensing methods, fixed fees vs. royalties, and find that a royalty license is preferred when the intensity of the network effect is low, while a fixed fee should be used when the intensity of the network effect is high. Our results make previous findings in the patent licensing literature a special case. The literature suggests that when the patent holder is also a producer in the industry, royalty licensing should be preferred to fixed-fee licensing, because the inventor-producer is interested in not only the licensing revenues but also its profits from production [13, 26, 27]. Our results show that a royalty license is optimal when network intensity equals zero, which is the case studied in the literature. We further show that as the intensity of the network effect increases, the optimal licensing strategy shifts from a royalty-based regime to a fee-based regime. The reason for this shift is as follows. With a royalty license, the leading firm limits the quantity its competitor provides while a fixed-fee license allows the competitor to produce as much as it wants. With increasing network intensity, in order to take advantage of the network effects, it is in the best interest of the leading firm to let the competitor to produce more. Therefore, it should not use a royalty rate to restrict the competitor's production, but use a fixed-fee license instead.

As an extension to our model, we allow the firm to offer not only a pure-fee or pure-royalty license, but also a hybrid license that consists of both a fixed-fee component and a royalty rate. We find that a pure fixed-fee license should always be used when the network intensity is high, and the rationale is again to encourage the production of the competitor in order to take advantage of network effects. When the network intensity is low, a royalty rate should be used alone when the market demand is high and combined with a fixed-fee component when the market size is small. The reason is as follows. A royalty rate confers quantity leadership onto the

licensor; however, it has a negative effect on the size of the network. Therefore, a pure royalty license should be used only when the market is sufficiently large such that the negative effect on network size is dominated by the positive effect of quantity leadership.

In addition to the introduction of network effects, the licensing game in our model also has two important points of departure from the standard setup of the licensing literature.[6] First, we consider drastic innovations that lead to new products and services while the literature focuses on incremental innovations that reduce costs. Second, we grant a competing firm an option to develop its own technology standard, which has not been considered in previous research.

Kulatilaka and Lin [18] study the licensing of drastic innovations in an uncertain environment without network effects. It is found that a royalty license is optimal in absence of uncertainty, while a royalty cap contract can be used as a financing vehicle in face of uncertainty.

The rest of this paper is organized as follows. In Section 2, we set up the model and describe how we model network effects. Section 3 studies the three choices faced by a firm with an innovation: (1) no licensing or sharing of the technology, and sharing with either (2) a fixed fee-based license, or (3) a royalty-based license, and derives the optimal decisions. Section 4 extends the model by allowing a hybrid license. Section 5 provides concluding remarks.

2   Model

2.1   Model Setup

We consider an industry where two competing firms achieve innovations that can be developed into a new product or service exhibiting a network effect. Suppose one of the firms, Firm 1, has achieved a licensable innovation. The other firm, Firm 2, temporarily lagging behind, can achieve a substitute innovation by investing K. Firm 1 can either retain its innovation as a

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[6] See, for example, [11, 12, 15, 16, 26, 27]. See [10, 13] for surveys of the literature.

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proprietary technology, or license the innovation to Firm 2. Based on Firm 1's strategy, Firm 2 decides whether to invest K in its own innovation (see Table 1 for a complete list of notations).

First, consider the case where Firm 1 retains its innovation as proprietary. If Firm 2 invests in its own technology, the two firms will engage in Cournot competition, producing perfectly substitutable but incompatible products under competing standards.[7] We only consider the firms' Cournot profits and ignore any intermediate cash flow Firm 1 may earn before Firm 2 produces (the intermediate cash flow is negligible compared to the profits both firms make in the life cycle of the products). If the market demand is low and Firm 2 decides not to invest, Firm 1 becomes a monopolist.

Next, consider the case where Firm 1 licenses its innovation to Firm 2. If Firm 1 decides to license to Firm 2, it makes a take-it-or-leave-it (TIOLI) offer to Firm 2. The license may take one of two different forms: a fixed fee, or a quantity-based royalty rate. Firm 2 then has the choice of whether to accept or reject the offer. By accepting the licensing offer, Firm 2 adopts Firm 1's technology and will not invest K. The two firms then engage in Cournot competition in the product market. Unlike the case where Firm 1 keeps its innovation proprietary and Firm 2 invests in its own innovation, in this case, there is only one standard (i.e., Firm 1's technology) in the market. If Firm 2 rejects the licensing offer, however, Firm 2'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, possible coordination, mergers and acquisitions,

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[7] We discuss the case where Firm 2 can also invest to achieve a standard compatible with Firm 1's in Section 5.

and complementary networks. Our model is intended to isolate licensing as an important

strategy through which firms establish network standards.

2.2 Demand for Network Goods and the Intensity of Network Effect

We now discuss the demand function in a market that exhibits network effects and how

firms' licensing decisions impact demand in such a market.

A linear inverse 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. 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.[8] Therefore, 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. The term $v(q^e)$ represents an

individual user's willingness-to-pay for the network value of the good, and is an increasing

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[8] 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.

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 Metcalfe's law, the total value of a network increases in proportion to the square of the number of users in the network [7]. It implies that for each consumer, the network value of a product can be represented by[9]

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

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 network effects*. When $\beta = 0$, $v(q)=0$, and the demand degenerates to that for a normal good where users realize only the standalone value. In order to maintain the downward-sloping property of the demand function, we restrict $\beta < 1$. Therefore, the range of valid β values is [0, 1).

Networks are different with regard to the intensity of the network effect. For example, a network of online game players has a more intense network effect than the network consisting of 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.

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[9] The total value of the network is therefore $q\,v(q) = \beta q^2$, which corresponds to Metcalfe's law. 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 presence of network effects plays a vital role in Firm 1's licensing decisions and in

Firm 2's adoption decision. When Firm 1 does not license its innovation, or the two firms cannot

reach a licensing agreement, Firm 2's investment will result in a competing standard. In this

case, only users who have purchased the product from the same firm can interact with each other,

forming their own network. Therefore, the users are not willing to pay as much for the network

value than they would if the products were compatible. The firms must consider this effect when

making licensing decisions. The case of two competing standards is probably best illustrated by

the VCR standards war and the competition between the two operating systems, Windows and

Macintosh.

If Firm 1 successfully licenses its technology to Firm 2, users of both products form one

single large network instead of two smaller incompatible networks, allowing them 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, Firm 1 can establish its standard as the industry standard *and* collect licensing

revenues from Firm 2, while it is producing a good with a higher network value. OnStar

exemplifies such a case. As more carmakers adopt the OnStar system, more services that are

complementary to the system will be available, resulting in higher network value for car owners.

This allows OnStar to charge a higher price for its system as well as earn higher licensing

revenues.

While the intensity of network effects depends largely on the nature of the market,

providers of network goods and services may influence the intensity of network effects through

business decisions.[10] This paper focuses on the impact of network effects on a firm's licensing

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[10] For instance, Sprint PCS 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

choice; therefore, the intensity of network effects is treated as exogenously given. This implies that the assessment of the intensity of network effects and any decisions that may influence the intensity should precede the licensing decision. It also means that when the network intensity changes, a firm should modify its licensing strategies accordingly.

3 Optimal Licensing Decisions: Fixed fee vs. Royalty

We compare the following three strategies of Firm 1: (1) no licensing or sharing of the technology, and sharing with either (2) a fixed fee license, or (3) a royalty license. The literature has studied the choice between the two licensing methods, fixed fee vs. royalty, extensively. Here we explore how these two licensing methods differ in presence of network effects. 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. We then find the optimal licensing decision.

3.1 No Licensing

Suppose Firm 1 does not offer a license to Firm 2. If Firm 2 invests K, the two firms will have incompatible standards. Therefore, each firm's customers form their own network. 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 Firms 1 and 2 respectively):

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

The profits are given by:

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

To determine the firms' optimal production decisions, we solve the firms' profit maximization problems and impose a fulfilled expectation equilibrium (FEE) condition [14].

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service receive even higher network value. Thus by offering more services, Sprint has increased the intensity of the network effect.

Under FEE, each firms chooses the optimal quantity of the network good by maximizing its profits and setting the quantity equal to corresponding expected quantities. We use the functional form $v(q) = \beta q$. Leibenstein [20] shows how to derive the demand curve in presence of network effects under FEE.

$$q_1^* = q_2^* = \frac{\theta}{3-\beta} \ , \qquad \pi_1^* = \pi_2^* = \left(\frac{\theta}{3-\beta}\right)^2$$

We see that the two firms engage in symmetric Cournot competition and produce identical quantities. Firm 2's net payoff from developing its own standard is: $\Pi_2 = \pi_2^* - K$. Assuming a zero reservation payoff for Firm 2, Firm 2 will enter only when $\theta > (3-\beta)\sqrt{K}$. We call $\hat{\theta} \equiv (3-\beta)\sqrt{K}$ the entry threshold of demand for Firm 2. When Firm 1 does not license, Firm 2's payoff function is given by:

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

When the demand is below the entry threshold, Firm 2 stays out of the market, making Firm 1 a monopolist. The profit-maximizing monopolistic quantity under FEE is given by $q_1^* = \frac{1}{2-\beta}\theta$. Thus, we obtain Firm 1's payoff function:

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

3.2 Licensing by Means of Fixed Fee

When Firm 1 licenses its technology to Firm 2 by means of a fixed fee, F, the two firms again engage in Cournot competition. However, since the two firms now conform to the same

standard, the customers of both firms form one large network, leading to higher network value. The market price is therefore given by:

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

The firms' profits are:

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

The two firms' optimal production decisions yield the following equilibrium quantities:

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

The firms' payoffs under a fixed fee license are given by:

$$\Pi_1^F = \frac{1}{(3-2\beta)^2}\theta^2 + F, \quad \Pi_2^F = \frac{1}{(3-2\beta)^2}\theta^2 - F$$

Next, we examine how Firm 1 should set the licensing fee. Recall the assumption that Firm 1 makes a TIOLI offer to Firm 2. Therefore, the optimal fee should maximize Firm 1's payoff while ensuring that Firm 2 will agree to the term of the license. We assume that Firm 2 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:

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

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

Obviously, Firm 1 wants to charge the highest possible fixed fee, which is constrained by Firm 2's acceptance. This means that the constraint is binding and the optimal fee F^* is determined by $\Pi_2^F = \Pi_2^{NL}$, as follows:

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

We can then derive Firm 1's payoff under the optimal fixed fee, Π_1^{F*} (see Table 2). This is the maximum payoff that Firm 1 can achieve with a fixed-fee license. Firm 2's payoff is trivial when Firm 1 charges the optimal fee, because by definition $\Pi_2^{F*} = \Pi_2^{NL}$.

3.3 Licensing by Means of Royalty

If Firm 2 licenses Firm 1's technology by means of a royalty, it pays Firm 1 a royalty, r, for each unit it produces. Firm 1's payoff thus consists of two parts: profits from selling its own product, and royalties from Firm 2:

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

Firm 2'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 the optimal production decisions are:

$$q_1^* = \frac{\theta + (1-\beta)r}{3-2\beta}, \qquad q_2^* = \frac{\theta - (2-\beta)r}{3-2\beta}$$

The firms' payoffs under equilibrium quantities are:

$$\Pi_1^r = \frac{\theta^2 + (5-4\beta)\theta r - (\beta^2 - 5\beta + 5)r^2}{(3-2\beta)^2}, \qquad \Pi_2^r = \left[\frac{\theta - (2-\beta)r}{3-2\beta}\right]^2$$

What is the optimal royalty rate for Firm 1, given the equilibrium output? Again, the optimal rate should maximize Firm 1's payoff as long as Firm 2 agrees to license. In other words, the optimal rate r^* should solve:

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

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

We call the constraint Firm 2's *acceptance constraint*. The expression of Π_1^r, however, suggests that unlike the case of fee licensing, it may not be in Firm 1's best interest to charge the highest rate acceptable to Firm 2. 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, deriving the rate that maximizes Firm 1's payoff *regardless of* Firm 2's acceptance, which we denote by r_1^*.

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

Second, we find the royalty rate where Firm 2's acceptance constraint is binding (i.e., $\Pi_2^r = \Pi_2^{NL}$), denoted by r_2^*. Because Firm 2's payoff decreases with the royalty rate, r_2^* is the maximum royalty rate Firm 2 will agree to. We have,

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

Last, the optimal rate is determined by taking the minimum of the above rates, that is, $r^* \equiv \min(r_1^*, r_2^*)$. This is because whenever $r_1^* < r_2^*$, it is in Firm 1's best interest to charge r_1^* instead of r_2^*, and when $r_1^* \geq r_2^*$ Firm 1 is forced to charge r_2^* due to Firm 2's acceptance constraint.

We first note that when $\theta \le \hat{\theta}$, $r_1^* < r_2^*$ for any valid value of β. Therefore,

$r^* \equiv \min\left(r_1^*, r_2^*\right) = r_1^*$ when $\theta \le \hat{\theta}$. Next, for $\theta > \hat{\theta}$, we find that $r_1^* = r_2^*$ when

$\theta = \frac{2(3-\beta)(5-5\beta+\beta^2)}{\sqrt{(1-\beta)(2-\beta)(5-\beta)(10-3\beta)}}\sqrt{K}$. We define $\tilde{\theta} \equiv \frac{2(3-\beta)(5-5\beta+\beta^2)}{\sqrt{(1-\beta)(2-\beta)(5-\beta)(10-3\beta)}}\sqrt{K}$. Furthermore, $r_1^* < r_2^*$ when

$\hat{\theta} < \theta < \tilde{\theta}$, and $r_1^* > r_2^*$ when $\theta > \tilde{\theta}$. Therefore, $r^* = r_1^*$ when $\hat{\theta} < \theta \le \tilde{\theta}$, and $r^* = r_2^*$ when $\theta > \tilde{\theta}$.

In sum, the optimal royalty rate is given by:

$$r^* \equiv \min\left(r_1^*, r_2^*\right) = \begin{cases} r_1^* = \frac{5-4\beta}{2(5-5\beta+\beta^2)}\theta & \text{when } \theta \le \tilde{\theta} \\ r_2^* = \frac{1}{2-\beta}\theta - \frac{3-2\beta}{2-\beta}\sqrt{\frac{\theta^2}{(3-\beta)^2} - K} & \text{when } \theta > \tilde{\theta} \end{cases}$$

Figure 1 depicts how the optimal royalty rate is determined. Overall, the optimal rate is determined purely by Firm 1's payoff maximization when $\theta \le \tilde{\theta}$, and Firm 2's acceptance condition is binding and determines the rate Firm 1 charges only when $\theta > \tilde{\theta}$. The result for $\theta > \tilde{\theta}$ is easy to understand, but it is surprising that when $\theta \le \tilde{\theta}$, it is optimal for Firm 1 to offer a royalty rate lower than what Firm 2 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 Firm 2 is unwilling to enter the market, due to the network effect, it is in the best interest of Firm 1 to entice Firm 2 to produce and help grow the network. Then why would Firm 1 charge a rate lower than the maximum rate acceptable to Firm 2? With a fee licensing structure, Firm 1 produces the same amount as Firm 2 does, and thus Firm 1 charges the highest fee Firm 2 is willing to pay. With a royalty licensing structure, however, Firm 1 produces a higher quantity than Firm 2 does. Therefore, to take full advantage of network effects, it is optimal for Firm 1 to charge a rate lower than what Firm 2 is willing to pay to further encourage Firm 2's production activity when demand is relatively low.

We can also derive Firm 1's payoff under the optimal royalty rate, Π_1^{r*} (see Table 2), which is the maximum payoff Firm 1 can get by offering a royalty-based license.

3.4 Optimal Licensing Decision

For each of the three strategies: no licensing, fee licensing, and royalty licensing, we have discussed firms' optimal decisions and derived Firm 1's maximum payoff (see Table 2). Based on these results, what is Firm 1's optimal decision? To answer this question, we simply need to compare the payoff functions under different strategies for given parameter values and choose the payoff-maximizing strategy.

We define the following notation. For given parameter values, if the payoffs for two licensing strategies A and B satisfy $\Pi_1^A > \Pi_1^B$, we say *A dominates B*, or *B is dominated by A*, denoted by $A \succ B$. With slight abuse of notation, we use *NL*, F^*, and r^*, to denote Firm 1'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.

Obviously, the optimal strategy has to be determined for different ranges of demand and different β values. First, when demand is within Firm 2's entry threshold (i.e., $\theta \leq \hat{\theta}$), 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. Comparison between Π_1^{r*} and Π_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 $\theta \leq \hat{\theta}$. Furthermore, royalty licensing dominates fee licensing (i.e., $r^* \succ F^*$) for $\beta < \beta_1$, while fee dominates royalty (i.e., $F^* \succ r^*$) for $\beta > \beta_1$.

When demand is above Firm 2's entry threshold (i.e., $\theta > \hat{\theta}$), 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 two licensing strategies. We first compare Π_1^{r*} and Π_1^{F*} for the demand range of $\hat{\theta} < \theta \le \tilde{\theta}$. We find that for each $\theta \in \left(\hat{\theta}, \tilde{\theta}\right]$, there exists a unique level of the network intensity 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., $r^* \succ F^*$) for $\beta < \beta_e(\theta)$, while fee dominates royalty (i.e., $F^* \succ r^*$) for $\beta > \beta_e(\theta)$.

Applying this notation to the results we obtained earlier for the range of $\theta \le \hat{\theta}$, clearly, we have $\beta_e(\theta) = \beta_1$ for $\theta \le \hat{\theta}$. For $\hat{\theta} < \theta \le \tilde{\theta}$, however, there is no closed-form expression for $\beta_e(\theta)$. We can construct $\beta_e(\theta)$ numerically though. We can also prove that $\beta_e(\theta)$ is continuous and increasing in θ, and that $\beta_e\left(\hat{\theta}\right) = \beta_1$ and $\beta_e\left(\tilde{\theta}\right) \equiv \beta_2 \cong 0.319$.[11]

Last, we compare Π_1^{r*} and Π_1^{F*} for the demand range of $\theta > \tilde{\theta}$. Again, for any $\theta \in \left(\tilde{\theta}, +\infty\right)$, there exists a unique level of the network intensity β, denoted by $\beta_e(\theta)$, such that Firm 1 is indifferent between fee and royalty licensing, and $r^* \succ F^*$ for $\beta < \beta_e(\theta)$ while $F^* \succ r^*$ for $\beta > \beta_e(\theta)$. Similar to the case where $\hat{\theta} < \theta \le \tilde{\theta}$, $\beta_e(\theta)$ can only be numerically

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[11] 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 $[0, 1)$.

constructed for $\theta > \tilde{\theta}$. $\beta_e(\theta)$ is also continuous and monotonically increasing in θ in this range.

Furthermore, $\beta_e(\theta)$ has an upper bound. Define $\lim_{\theta \to \infty} \beta_e(\theta) \equiv \beta_3$. Numerically, $\beta_3 \cong 0.468$.[12]

We obtain the following proposition.

Proposition 1 (The Pure Fixed Fee and Pure Royalty Proposition). With only pure fee and pure royalty licensing for any level of demand θ, there exists a unique intensity of the 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 $\beta > \beta_e(\theta)$.

Figure 2 depicts the above result in the β–θ space (note that $\hat{\theta}$ and $\tilde{\theta}$ are functions of β). The function $\beta_e(\theta)$ divides the space into two regimes: below $\beta_e(\theta)$ is the *royalty regime* where a royalty-based license is optimal, while above $\beta_e(\theta)$ is the *fixed fee regime* where it is optimal to charge a fixed fee per license.

This result has interesting implications for firms' licensing strategy. First, for any positive network intensity, it is always optimal to license one's technology. It is understandable that when demand is high, the strategy of being a monopolist is not sustainable because of competing standards, and therefore a licensing strategy benefits the leading firm more than a no-licensing strategy does. When the market demand is low ($\theta < \hat{\theta}$), however, Firm 1 can actually be the monopolist by not licensing its technology to Firm 2. Our results show that even in such a case, due to network effects, the strategy of becoming a monopolist and earning monopolistic profits is no longer optimal. Instead, the firm should allow others to produce competing yet compatible

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[12] 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 $[0, 1)$.

products. This yields a total quantity higher than that in a monopolistic market, resulting in a larger network. Thus, it creates higher network value for both firms' customers, leading to higher profits for the licensor.

Second, as the network effect intensifies, the leading firm with an innovation should switch from a royalty license to a fee license. When considering pure licenses only, royalty licensing should always be used if the intensity of the network effect is below β_1, while fee licensing is always optimal for a network with intensity higher than β_3.

To understand the intuition behind the above result, we need to compare the two licensing methods in more detail. Under a fee licensing structure, the two firms produce the same amount.[13] When using a royalty licensing structure, however, Firm 1 acts as a Stackleberg leader, producing a higher quantity than Firm 2 does. In fact, Firm 1 produces more under a royalty-based license than it would do under a fee-based license, while the opposite is true for Firm 2.[14] The total quantity under a royalty license, however, is lower than that under a fee license.[15] An increase in the total quantity has two countervailing effects on the price of the network good: on the one hand, the price will decrease when the total quantity supplied is higher due to the economics of normal goods; on the other hand, firms can charge a higher price for the network good because the users now derive higher network value. The second effect is obviously the network effect, which stems from the demand side. In contrast, the first effect arises from the supply side, and thus we call it a *supply-side effect*. When network intensity is low, the supply-side effect dominates the network effect, therefore being a Stackleberg leader in quantity and

---

[13] Recall that under a fee license, $q_1^* = q_2^* = \frac{\theta}{3-2\beta}$.

[14] We know that $r^* > 0$. Therefore, for Firm 1, $\frac{\theta+(1-\beta)r^*}{3-2\beta} > \frac{\theta}{3-2\beta}$; for Firm 2, $\frac{\theta-(2-\beta)r^*}{3-2\beta} < \frac{\theta}{3-2\beta}$

[15] The total quantity under royalty licensing is $\frac{2\theta-r^*}{3-2\beta}$, while the total quantity under fee licensing is $\frac{2\theta}{3-2\beta}$.

keeping the total supply low is more important for Firm 1, which suggests that it should use a royalty license instead of a fee license. When network intensity is high, however, the network effect dominates the supply-side effect, and creating a large network is in Firm 1's best interest. By using a fee-based license, even though Firm 1 gives up its leadership in quantity, it benefits from capturing higher network value.

The key difference between a royalty license and a fee license is that a royalty license leads to asymmetric quantities produced by the two firms and results in a lower total quantity than that under a fee license. A royalty license not only generates licensing revenues, but also confers quantity leadership onto the licensor. While leadership in quantity is desirable for a non-network good or a network good with low network intensity, it is no longer true for a network good with high intensity. In the latter case, being a quantity leader prevents it from taking full advantage of the network effect. Therefore, a firm seeking to license its new technology in a market that exhibits high network intensity should use a fee license because it generates licensing revenue without discouraging other firms' production activities. Also for network goods with high intensity, the disadvantage of being a quantity leader is not due to the cost of production, since we assume zero production cost – instead, it is merely due to foregone network effects on the demand side.

The choice of the licensing strategy may also be influenced by the size of the market. When the intensity of the network effect is in the medium range (i.e., $\beta_1 < \beta < \beta_3$), the choice of licensing strategy depends on the size of the market. When market size is small, the firm switches from royalty to fee licensing at a lower level of network intensity, while the change of regime happens at a higher level of network intensity for a large market. The intuition is that the reduced total quantity resulted from a royalty license has a more significant effect in a smaller

market, and therefore, royalty licensing becomes suboptimal at a low level of network intensity. On the other hand, a royalty license's effect on quantity is less significant in a large market. Therefore, firms with innovations should stop licensing by royalty and switch to a fee license at a lower level of network intensity (in the medium range) for a small market, while the switch happens at a higher level of network intensity for a large market.

Within each regime, the term of the optimal license is given by the following corollaries.

Corollary 1.1 (Optimal Fixed Fee License Condition). When $\beta > \beta_e(\theta)$, the optimal license is a fixed fee given by:

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

Corollary 1.2 (Optimal Royalty Rate License Condition). When $\beta < \beta_e(\theta)$, the optimal license is a royalty rate given by:

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

The above results are also depicted in Figure 2. The fixed fee regime is further split by the entry threshold for network intensity into two regions: in Region A, the fee is set to make Firm 2 indifferent between licensing and staying out of the market, while in Region B the fee makes Firm 2 indifferent between licensing and entry by developing its own technology. While in both regions the optimal fee increases with the demand θ for any given β, it increases at a lower rate in Region B where Firm 2 has incentive to develop its own technology. This means that Firm 2's credible threat to develop an alternative standard limits Firm 1's ability to charge a high licensing fee.

The royalty regime is split into Regions C and D by $\tilde{\theta}$. In Region C where the demand is above the entry threshold (note that $\tilde{\theta} > \hat{\theta}$), the royalty rate determined by Firm 2's acceptance constraint decreases with demand first; it then increases with demand, but at a lower rate than in Region D, where the rate is determined by Firm 1's payoff-maximization (see also Figure 1). The fact that royalty rate be reduced facing higher demand implies that Firm 2's incentive to develop an alternative standard reduces Firm 1's bargaining power severely.

4   Extension: Optimal Licensing Decisions Allowing for Hybrid Licenses

In this section, we allow for a hybrid license consisting of a fixed-fee component and a royalty per unit of output. We find that in many situations, the leading firm should still use a pure-fee or pure-royalty license; a hybrid license does achieve higher payoffs when the intensity of network effect is low and the market size is small.

When the leading firm can use any combination of a fixed fee and a royalty rate to license, it solves the following problem:

$$\underset{F_c, r_c}{Max} \quad \Pi_1^c = \frac{\theta^2 + (5-4\beta)\theta r_c - (\beta^2 - 5\beta + 5)r_c^2}{(3-2\beta)^2} + F_c$$

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

$$F_c, r_c \geq 0$$

Solving the above problem yields the following proposition.

Proposition 2 (The Hybrid Licensing Charge Proposition). Assuming that a license can use any combination of a fixed fee and a royalty rate, when $\beta \geq 0.5$, a pure fixed-fee license is optimal for any level of demand θ. When $\beta < 0.5$, a pure royalty license is optimal for $\theta \geq \bar{\theta}$

and a hybrid license consisting of both a fixed-fee component and a per-unit royalty is optimal

for $\theta < \overline{\theta}$, where $\overline{\theta} \equiv \frac{2(3-\beta)(1-\beta)}{\sqrt{(1+\beta)(2-\beta)\left(2-5\beta+\beta^2\right)}}\sqrt{K}$. (See the Appendix for the proof.)

The results in Proposition 2 are illustrated in Figure 3. Similar to Figure 2, the β–θ space is divided into two regimes: above the horizontal line $\beta = 0.5$ is the fixed fee regime where a pure fixed-fee license is optimal, while below is the royalty regime where the optimal license uses a royalty rate, either alone or in combination with a fee. The intuition for this result is just as we have explained in Section 3: a royalty has the effect of limiting the licensee's output, and therefore should be avoided when the network intensity is high. In such cases, the licensor should use a pure fixed-fee license, which allows it to take full advantage of the network effects.

We consider the space below $\beta = 0.5$ as the royalty regime because any positive royalty rate, combined with a fee or not, leads to asymmetric output quantities and a smaller network overall. Our result indicates that when the intensity of network effects is low, it is optimal for the innovating firm to keep a quantity leadership via a positive per-unit royalty rate. The royalty regime is further divided into three regions: Region C' where a pure royalty license is optimal, and Regions D' and E' where a hybrid license should be used. It suggests that in markets with low network intensity, a royalty rate should be used alone when the demand is high while it should be combined with a fixed fee component when the demand is low or the network intensity is not too low. Again, the intuition is the same as what we have developed in Section 3. We know that using a royalty leads to a smaller network. This effect is less important when the market is sufficiently large, and therefore a pure royalty license is optimal. For a smaller market, however, the effect is rather significant, therefore, the innovating firm should lower the royalty rate to alleviate the negative effect of a royalty; in the meantime, it can add a fixed-fee component to the license to compensate for the lost licensing revenue.

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We also derive the optimal licenses for each regime.

Corollary 2.1 (Pure Fixed Fee Licensing Condition). When $\beta \geq 0.5$, the optimal

license is a pure fixed-fee license given by:

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

We notice that two regions in the fee regime, A' and B' in Figure 3, are subsets of

Regions A and B in Figure 2, respectively. Furthermore, the optimal fee for Regions A' and B'

are the same as those for Regions A and B. We also find that in both regions, the optimal fee

increases with the intensity of network effects for any given demand. This simply means that

higher network intensity allows the leading firm to charge a higher fee.

Corollary 2.2 (Pure Royalty Licensing Condition). When $\beta < 0.5$ and $\theta \geq \bar{\theta}$, the

optimal license is a pure royalty license and the rate is given by:

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

The above corollary shows that in Region C', the optimal pure-royalty license is the same

as that in Region C of Figure 2. In fact, Region C' is a subset of Region C.[16]

Corollary 2.3 (Hybrid Licensing Condition). When $\beta < 0.5$ and $\theta < \bar{\theta}$, the optimal

license is a hybrid license consisting of a fixed-fee component and a per-unit royalty, denoted by

$\left(F_c^*, r_c^*\right)$. The royalty rate is given by $r_c^* = \frac{1-2\beta}{2(1-\beta)}\theta$. The fixed fee is given by:

---

[16] Region C' is a subset of Region C. It can be proved analytically that $\bar{\theta} > \tilde{\theta}$ and shown numerically that $\bar{\theta}$ lies below $\beta_e(\theta)$.

$$
F_c^* = \begin{cases} \left[\dfrac{\beta}{2(1-\beta)}\theta\right]^2 & \text{when } \theta < \hat{\theta} \\[4mm] \left[\dfrac{(2-\beta)(1+\beta)(5\beta-2-\beta^2)}{4(1-\beta)^2(3-\beta)^2}\right]\theta^2 + K & \text{when } \hat{\theta} \le \theta < \overline{\theta} \end{cases}
$$

Based on Corollary 2.3, we find that for an optimal hybrid license, as the intensity of network effect increases, the royalty rate declines while the fee rises, at a given θ.[17] This is consistent with the intuition that increasing network intensity suggests more use of fee and less use of royalty. As the intensity of network effects rises, the switch from a royalty to a fee occurs suddenly if only pure licensing methods are considered, whereas when hybrid licenses are also allowed, the transition from a pure royalty to a pure fee happens gradually via a hybrid-license zone.[18]

In sum, a hybrid license makes a difference only in small markets with low network intensity (Region D') and large markets with medium network intensity (Region E'). In such cases, by combining two types of licensing structure, the innovating firm is able to create and extract higher surplus than it does with a pure fee or royalty license, while keeping Firm 2 indifferent.

In practice, however, a hybrid license tends to be more costly to negotiate and implement than a pure fee or pure royalty license. Therefore, when a firm faces market conditions that fall in Regions D' or E', it should trade off the benefit and cost of a hybrid license, and when the cost exceeds the benefit, the firm should choose a pure fee or pure royalty license instead.

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[17] Based on the comparative statics of r_c^* and F_c^* with respect to β.

[18] Note that the horizontal axis $\beta=0$ is in the pure-royalty region. The optimal license when $\beta=0$ is a pure royalty rate given by $r^* = \frac{1}{2}\theta$ when $\theta \le \hat{\theta}$ and $r^* = \frac{1}{2}\theta - \frac{3}{2}\sqrt{\frac{\theta^2}{9}-K}$ when $\theta > \hat{\theta}$.

5   Discussion and Concluding Remarks

This paper considers a firm's licensing choice when it has achieved an innovation that leads to a network product. We find that in presence of network effects, it is always optimal to license one's technology, even when it is possible to become and remain a monopolist in the market. We also find that as the intensity of the network effect increases, the optimal licensing mechanism shifts from a royalty regime to a fee regime. We further derive the terms of the optimal license as functions of the intensity of the network effect, the investment needed to replicate the innovation, and the size of the potential market.

One of the key insights we gain from the results is that the presence of network effects changes the optimal market structure for firms. With positive network effects, a firm should no longer seek to act in a proprietary way and charge monopoly prices that limit output. Rather, it should make room for competition to grow the market by licensing its technology. For networks with less intensity, it is optimal to retain quantity leadership and restrict other firms' production using a contractual mechanism. When the intensity of network effects is high, however, the leading firm should give up its quantity leadership to allow the market to grow even further – in this case, the benefits of making a larger pie outweigh that of getting a big slice of a smaller pie.

Our results have implications for firms that are trying to establish a standard and to reach agreements with other parties. First, to successfully license a technology, the leading firm should choose the licensing mechanism and terms of the contract based on relevant information of the market. When parties fail to reach a licensing agreement, it is often the case that the innovating firm charges too high a fee or royalty, not offering other parties enough incentive to adopt its technology.

Second, parties may fail to reach an agreement due to different estimates of parameters. Each party may have its own estimate of the intensity of the network effect and expectations about the size of the market, leading to different opinions of a fair contract. Such discrepancies may lead to either failure of negotiation, or agreements that significantly benefit or cost some of the parties. For example, if the leading firm's estimate of the network intensity is higher than that of other party's, no agreement can be reached, while in the opposite situation the parties will agree on a contract that benefits the other party more.

Our model can be further extended in several ways. Here we assume that the parameters are common knowledge. While the intensity of network effects and market size are parameters that can be estimated based on publicly available information, the investment required to achieve a comparable innovation is often private information known only to firms capable of such an innovation. Therefore, asymmetric information may play an important role in making licensing agreements. Our results show that the lower the required investment, the lower the fee or the royalty rate. The information asymmetry may lead to the well-known adverse selection problem, where a potential competitor accepts a licensing contract only when its technology development is not promising and more threatening competitors will decline an offer.

When the cost of achieving a comparable innovation is common knowledge, it is worth exploring the possibility of the leading firm utilizing this knowledge to deter entry. Specifically, instead of licensing, the leading firm can adopt a predation strategy, choosing a quantity that makes entry unprofitable. A comparison between the predation strategy and the licensing strategy yields an interesting finding: when demand is above the competitor's entry threshold, licensing is preferred for any intensity greater than 0.12 ($\beta > 0.12$); for lower demand, licensing

still dominates predation for sufficiently high network intensity (β>0.38).[19] This result reinforces the insight that in markets exhibiting strong network effects, firms switch their strategy from gaining and keeping market power to a strategy of coopetition, such as forging business partnerships using licenses or other contracts.

The comparison between licensing and predation shows that for medium-sized markets with low network intensity, the leading firm does have an incentive to deter entry by predation. Despite the deterrence, however, a potential competitor may still enter the market with its own technology, expecting future profits to more than compensate for temporary losses (in a sub-game perfect equilibrium, the incumbent will accommodate the entrant after the entry). To further investigate the tradeoffs between deterrence and licensing, a multi-stage game is necessary, which is an interesting direction for future research.

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 the 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, 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.

Our model assumes that a potential competitor may invest to achieve a technology incompatible with the leading firm's. Is it possible for the competitor to achieve a compatible technology (supposedly at a higher cost) without licensing it from the leading firm? For this to happen, the leading firm's technology must be accessible to some extent. For example, software companies can develop programs compatible with open source software, but it is almost

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[19] Detailed analytical results are available upon request.

impossible to develop applications compatible with proprietary software unless the proprietary

software vendor provides some APIs, either free or for a fee. Our model covers firms that charge

for access to its standard. When a firm provides free access to its technology, it is then up to

potential competitors whether to develop a compatible or incompatible technology. A compatible

technology benefits users of both technologies, leading to an externality competitors cannot fully

internalize. It is no longer a pricing issue (the price for access to a technology is already set at

zero), but research in this direction may provide interesting implications for open standards.

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Table 1. Notation

Notation	Description
K	The investment required for Firm 2 to achieve a substitute innovation
β	The intensity of network effects
θ	The maximum market demand for the standalone use of the network good.
q_i	The quantity of output produced by Firm i, $i = 1, 2$
F	The fixed fee that Firm 1 charges to Firm 2
F^*	The optimal pure fixed fee that Firm 1 charges to Firm 2
F_c^*	The optimal fixed fee component when Firm 1 shares its innovation with a hybrid license (i.e., a combination of a royalty rate and a fixed fee component)
r	The royalty rate that Firm 1 charges per unit of Firm 2's output
r_1^*	The pure royalty rate that maximizes Firm 1's payoff regardless of Firm 2's acceptance constraint
r_2^*	The maximum pure royalty rate that satisfies Firm 2's acceptance constraint (i.e., the maximum pure royalty rate Firm 2 is willing to pay to Firm 1)
r^*	The optimal pure royalty rate that Firm 1 charges per unit of Firm 2's output
r_c^*	The optimal royalty rate when Firm 1 shares its innovation with a hybrid license (i.e., a combination of a royalty rate and a fixed fee component)
Π_i^{NL}	Firm i's payoff when Firm 1 does not license or share its innovation
Π_i^{F}	Firm i's payoff when Firm 1 shares its innovation with a fixed fee license;
Π_i^{r}	Firm i's payoff when Firm 1 shares its innovation with a royalty license
Π_i^{c}	Firm i's payoff when Firm 1 shares its innovation with a hybrid license (i.e., a combination of a royalty rate and a fixed fee component)

Notes: Within a context, Π_i^{F} may also denote Firm i's payoff when Firm 1 charges its optimal fixed fee. Similarly, Π_i^{r} may also denote Firm i's payoff when Firm 1 charges its optimal royalty rate and, Π_i^{c} may denote Firm i's payoff when Firm 1 uses the optimal hybrid license.
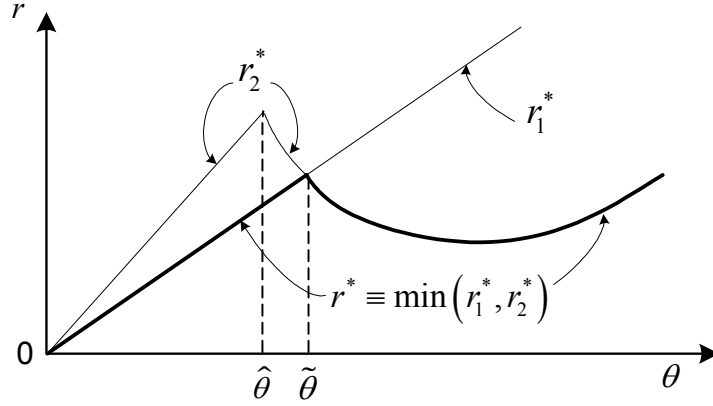
Table 2.
Firm 1's Maximum Payoffs under No Licensing, Fixed Fee Licensing, and Royalty Licensing

Range of Demand		$0 < \theta \le \hat{\theta}$	$\hat{\theta} < \theta \le \tilde{\theta}$	$\theta > \tilde{\theta}$
(1) No Licensing	Π_1^{NL}	$\frac{1}{(2-\beta)^2}\theta^2$		$\frac{1}{(3-\beta)^2}\theta^2$
(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*}	$\frac{2}{(3-2\beta)^2}\theta^2$		$\frac{9-2\beta^2}{(3-\beta)^2(3-2\beta)^2}\theta^2 + K$
(3) 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*}	$\frac{5}{4(5-5\beta+\beta^2)}\theta^2$		$\frac{1}{(2-\beta)^2}\left[\frac{4-\beta}{(3-\beta)^2}\theta^2 + \beta\theta\sqrt{\frac{\theta^2}{(3-\beta)^2} - K} + (5-5\beta+\beta^2)K\right]$

Notes: The table lists Firm 1's maximum payoffs under three strategies: (1) no licensing or sharing of the technology, and sharing with either (2) a fixed fee-based license, or (3) a royalty-based license. These payoffs are based on the firm's optimal quantities and optimal licensing terms. The optimal strategy can be derived by comparing these payoffs.
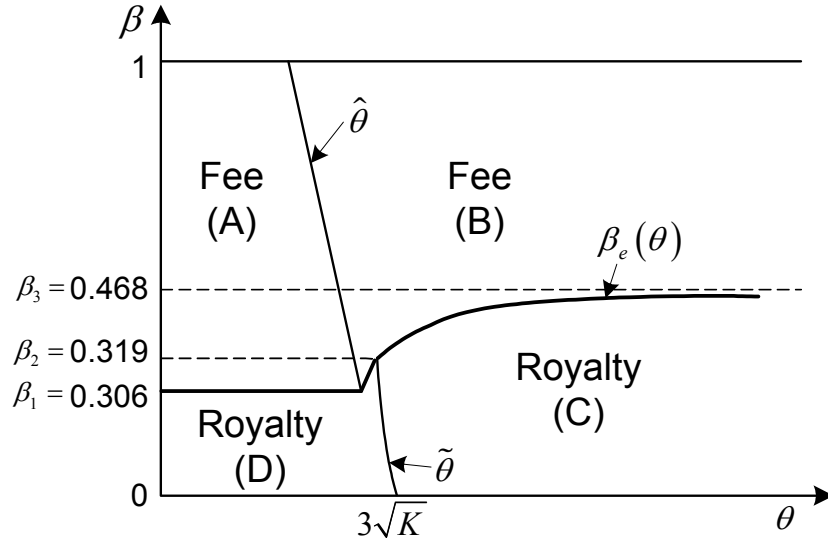
Figure 1: Optimal Royalty Rate

$$\hat{\theta} \equiv (3-\beta)\sqrt{K} \qquad \tilde{\theta} \equiv \frac{2(3-\beta)(5-5\beta+\beta^2)}{\sqrt{(1-\beta)(2-\beta)(5-\beta)(10-3\beta)}}\sqrt{K}$$

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

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

$$r^* = \min\left(r_1^*, r_2^*\right)$$

Figure 2: Optimal License: Fixed Fee vs. Royalty

$$\hat{\theta} \equiv (3-\beta)\sqrt{K} \qquad \tilde{\theta} \equiv \frac{2(3-\beta)(5-5\beta+\beta^2)}{\sqrt{(1-\beta)(2-\beta)(5-\beta)(10-3\beta)}}\sqrt{K}$$

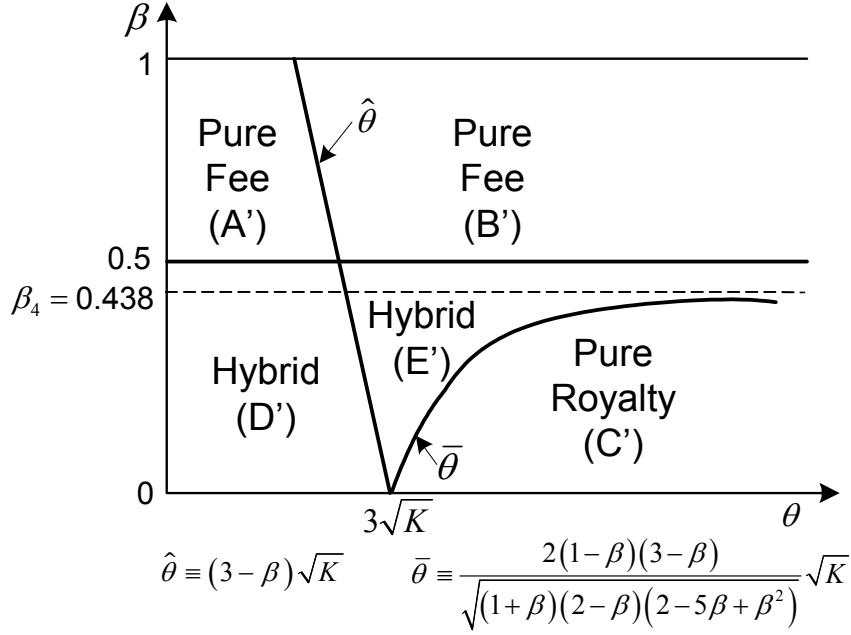Region A: $\quad F^* = \frac{1}{(3-2\beta)^2}\theta^2$

Region B: $\quad F^* = \frac{3\beta(2-\beta)}{(3-\beta)^2(3-2\beta)^2}\theta^2 + K$

Region C: $\quad r^* = \frac{1}{2-\beta}\theta - \frac{3-2\beta}{2-\beta}\sqrt{\frac{\theta^2}{(3-\beta)^2} - K}$

Region D: $\quad r^* = \frac{5-4\beta}{2(5-5\beta+\beta^2)}\theta$

Figure 3: Optimal Licenses (Hybrid licenses allowed)

$$\hat{\theta} \equiv (3-\beta)\sqrt{K} \qquad \overline{\theta} \equiv \frac{2(1-\beta)(3-\beta)}{\sqrt{(1+\beta)(2-\beta)(2-5\beta+\beta^2)}}\sqrt{K}$$

Region A': $F^* = \frac{1}{(3-2\beta)^2}\theta^2$

Region B': $F^* = \frac{3\beta(2-\beta)}{(3-\beta)^2(3-2\beta)^2}\theta^2 + K$

Region C': $r^* = \frac{1}{2-\beta}\theta - \frac{3-2\beta}{2-\beta}\sqrt{\frac{\theta^2}{(3-\beta)^2} - K}$

Region D': $F_c^* = \left[\frac{\beta}{2(1-\beta)}\theta\right]^2$, $r_c^* = \frac{1-2\beta}{2(1-\beta)}\theta$

Region E': $F_c^* = \left[\frac{(2-\beta)(1+\beta)(5\beta-2-\beta^2)}{4(1-\beta)^2(3-\beta)^2}\right]\theta^2 + K,\ r_c^* = \frac{1-2\beta}{2(1-\beta)}\theta$

Appendix. Proofs of Proposition 2 and its related corollaries

Sketch of Proof: Since Π_2^{NL} is defined differently for $\theta \le \hat{\theta}$ and $\theta > \hat{\theta}$, we need to solve

Firm 1's constrained maximization problem for $\theta \le \hat{\theta}$ and $\theta > \hat{\theta}$ separately.

For $\theta \le \hat{\theta}$, we first construct the Lagrangian function and derive the first-order conditions

(FOC). We find the interior solutions:

$$r_c^* = \frac{1-2\beta}{2(1-\beta)}\theta \text{ and } F_c^* = \left[\frac{\beta}{2(1-\beta)}\theta\right]^2$$

Obviously, an interior solution requires $0 < \beta < 0.5$.

When $\beta \ge 0.5$, the non-negativity constraint on the royalty rate is binding. Based on

Kuhn-Tucker conditions, we get the optimal pure fixed fee $F^* = \frac{1}{(3-2\beta)^2}\theta^2$. When $\beta = 0$, the

fixed fee is zero and the optimal pure royalty rate is given by $r^* = \frac{1}{2}\theta$.

For $\theta > \hat{\theta}$, again we find the interior solutions by constructing the Lagrangian function

and deriving the FOC:

$$r_c^* = \frac{1-2\beta}{2(1-\beta)}\theta \text{ and } F_c^* = \left[\frac{(2-\beta)(1+\beta)(5\beta-2-\beta^2)}{4(1-\beta)^2(3-\beta)^2}\right]\theta^2 + K$$

When $\beta \ge 0.5$, the non-negativity constraint on the royalty rate is binding and based on

Kuhn-Tucker conditions, we get the optimal pure fixed fee $F^* = \frac{3\beta(2-\beta)}{(3-\beta)^2(3-2\beta)^2}\theta^2 + K$.

We then find that when $\theta < \frac{2(3-\beta)(1-\beta)}{\sqrt{(1+\beta)(2-\beta)(2-5\beta+\beta^2)}}\sqrt{K}$, $F_c^* > 0$. For $\theta \ge \frac{2(3-\beta)(1-\beta)}{\sqrt{(1+\beta)(2-\beta)(2-5\beta+\beta^2)}}\sqrt{K}$,

the non-negativity constraint on the fixed fee component is binding, and by Kuhn-Tucker

conditions, we get the optimal pure royalty rate $r^* = \frac{1}{2-\beta}\theta - \frac{3-2\beta}{2-\beta}\sqrt{\frac{\theta^2}{(3-\beta)^2} - K}$. *Q.E.D.*

Brief Biographies of the Authors

Lihui Lin is an Assistant Professor of Information Systems at the School of Management, Boston University. She received her B.E. in Electrical Engineering from Tsinghua University, China, and her M.S. and Ph.D. in Economics from the University of Texas at Austin. Her research focuses on the impact of network effects, uncertainty, and information asymmetry on firms in the information technology industries. Her research interests include IT investment, technology licensing, standards, knowledge management, and open source. Her work has appeared or is forthcoming in *MIS Quarterly, Management Science,* and *Managerial Finance*.

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