Patent Licensing for Single-Network Goods

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1 Introduction

The literature on patent licensing has expanded since the early seminal works by Kamien and Tauman (1984, 1986). Economists have investigated richer scenarios, such as insider licensor (Katz and Shapiro, 1985b, 1986), imitation (Katz and Shapiro, 1987; Rockett, 1990), asymmetric information (Gallini and Wright, 1990), and asymmetric costs (Mukhopadhyay et al., 1999), etc. Most of the attention in this field has been devoted to finding the optimal licensing scheme for the licensor in a generalized industry setting, including fixed-fee, royalty, two-part tariffs, profit-sharing, etc. Another related topic is the technology diffusion speed, which has received attention from both economics and management fields (e.g. Fosfuri, 2006; Markman et al., 2005; McCarthy and Ruckman, 2017). In traditional patent licensing models, the diffusion speed is defined as the equilibrium number of firms that accept the licensing contract and adopt the new, cost-reducing technology. This measure is important because it reflects the industry's technological growth progress and the innovator's profitability, thus also affecting innovation incentives. Although earlier studies have shown that the optimal licensing scheme and technology diffusion speed are affected by the licensor's role in the market (i.e., insider vs. outsider) and market structure, other aspects of the industry (especially the industry's network effects) have rarely been considered. This paper examines how the optimal licensing scheme and technology diffusion speed would change in an industry that exhibits network effects. That is, we investigate the role of network effects on licensing schemes and technology diffusion.

Innovation in industries characterized by network effects is frequently associated with technological breakthroughs. There are two types of innovation: product innovation, which refers to the introduction of a new product, and process innovation, which pertains to the development of cost-reducing technology or technology that improves product quality while keeping costs constant. This paper focuses on process innovation. For example, over the past few decades, the telecommunications industry, a well-known network industry, has witnessed technological advancements, such as the transition from 1G networks to 2G (including GSM) and more recently, the still-developing 5G network. These advancements have helped to reduce the cost of providing mobile networks while improving the quality of mobile services. Similar examples can be found in other high-tech industries. In addition, network effects appear to impact the speed of technology diffusion. For instance, since the development of the internet, the personal computer has been adopted at an astonishingly rapid rate, thanks to network effects, in contrast to its slower adoption rate in the 1970s when it was first introduced without any internet connection (Rohlfs, 2001).

The aim of this paper is to provide a theoretical analysis of industries characterized by network externalities. Specifically, we focus on oligopolistic competition among firms that produce perfectly compatible products, resulting in an industry-wide network (sometimes called a single network) structure. This is particularly relevant, not only in light of the prevalence of perfect compatibility in many industries, such as telecom products, but also due to its normative implications. For instance, we investigate how network effects impact the optimal licensing scheme in terms of firms' profits, licensing revenue, and social welfare. Therefore, a comprehensive understanding of the single network case can illuminate the incentives faced by firms and an innovative lab in patent licensing.

To this end, this paper builds upon two prominent areas of literature, namely patent licensing and network externality, in the context of industries with network effects. With respect to patent licensing, we draw upon the seminal works of Kamien and Tauman (1984, 1986), which have inspired a vast body of subsequent research aimed at identifying the optimal licensing scheme under different model specifications. To integrate network effects, we incorporate Kamien and Tauman's (1986) framework into a Cournot oligopoly model. Network effects have been extensively studied in the literature, with seminal contributions by Katz and Shapiro (1985a) and subsequent developments by Amir and Lazzati (2011), which provide an endogenous inverse demand function that reflects rational expectations about the optimal market size for a single industry-wide network with perfect compatibility. While other forms of network structures, such as firm-specific networks, may also be relevant, we focus on the simplest network form to gain initial insights. The solution concept we adopt, following the network externality literature, is the Fulfilled Expectation Cournot Equilibrium (FECE), which ensures that consumers' expected market size for a single network is fulfilled in equilibrium.

The integration of the patent licensing and network externality literature has only recently emerged, with several works by Lin and Kulatilaka (2006); Hong et al. (2015); Zhao et al. (2014); Zhang et al. (2018) adopting a similar framework of Cournot duopoly. These models feature one firm with superior technology that can be licensed out to the other firm. In Zhao et al. (2014), the other firm chooses between buying the license or not, while the other three models assume the other firm either accepts the license contract or invests to acquire technology. Lin and Kulatilaka (2006) considers classic homogeneous Cournot duopoly, Hong et al. (2015) adds horizontal product differentiation, and Zhang et al. (2018) adds supply chain structure. However, these models are limited to the duopoly and insider licensor contexts and assume licensing will transform the network structure from firm-specific to industry-wide. Our research addresses the gap in the literature by considering how an outsider lab can license its technology to an oligopoly of any number of firms without changing the industry's inherent network structure. This scenario is of particular interest when the licensed technology does not necessarily make all products compatible, as in the case of a chip technology that improves the performance of any game console, not making them compatible.

In this study, we explore the licensing strategies of an external innovator, or lab, that possesses a superior technology for cost reduction. To study the market outcomes of such a scenario, we introduce the network externality variable S that represents an industry-wide single network in the linear inverse demand function. Using the Kamien and Tauman (1986) model and Fulfilled Expectation Cournot Equilibrium (FECE) as the solution concept, we compare the market performance under fixed-fee and royalty licensing. Our analysis reveals that social welfare increases after licensing for an industry-wide network structure. In this scenario, licensing leads to each firm producing a weakly greater quantity and all firms obtaining licenses in the equilibrium, resulting in a weakly higher industry output and increased consumer surplus. Notably, firms' profits remain unchanged since the network externality equalizes their opportunity cost to their pre-licensing profits, except for a side case of royalty licensing with drastic innovation.

We also investigate the impact of network externality on the licensing decision of firms and the lab that possesses a cost-reducing superior technology. Specifically, we compare the licensing outcomes under two network structures: traditional industry with no network and industry-wide network. We find that, in the presence of network externality, the external lab prefers fixed-fee licensing to royalty licensing, as licensed firms' profits increase due to the positive network effects, enabling the innovator to extract more surplus. Our analysis further reveals that network effects affect the licensee's opportunity cost, which in turn affects their post-licensing profits. Generally, in the absence of licensing, firms that do not adopt the new technology would experience a decline in market share and lower profits relative to their rivals who have adopted the new technology. However, our analysis shows that in an industry-wide network, all firms earn the same profit after fixed-fee licensing, and even high-cost firms can earn the same profits as before without adopting the new technology. This is due to an industry-wide network effect, which completely offsets the disadvantage faced by high-cost firms.

We also examine the speed of technology diffusion, as measured by the equilibrium number of licenses k^*, under different licensing schemes in the presence of the network externality. Our findings indicate that royalty licensing always results in the fastest technology diffusion, regardless of network effects, as all firms have the incentive to obtain a license. In contrast, fixed-fee licensing typically leads to less than all firms being licensed in equilibrium, particularly when the technology is significantly superior (Kamien and Tauman, 1984). However, our study shows that an industry-wide network accelerates technology diffusion in such a way that all firms become licensed under fixed-fee licensing even when the innovation is drastic.

The paper is structured as follows. In Section 2, we present the model and pre-licensing outcomes as a reference point. In Section 3, we examine the licensing game and determine the optimal licensing strategies for the lab under two licensing schemes with an industry-wide single network. In Section 4, we investigate the influence of the network externality in the licensing game. Finally, Section 5 summarizes the findings and concludes the paper.

2 The model and the pre-licensing case

In this section, we consider the pre-licensing game in a market characterized by positive (direct) network effects when the products of the firms are perfectly compatible so that the relevant network is industry-wide. Several important industries fit the perfect compatibility framework, in particular, those in the telecommunications sector, such as fax, telephone, and the Internet, but also diverse other industries such as compact discs, fashion, and entertainment (Amir and Lazzati, 2011).

In this section, we lay out the basic (pre-licensing) oligopoly model and solve for the FECE before licensing as a useful benchmark for the rest of the paper.

Consider an industry consisting of $n \geq 2$ firms facing a linear inverse demand function

$$P(Q) = a + S - Q,$$

where $a > 0$, Q denotes the industry output and S the expected network size. Before licensing, all firms produce at a constant marginal cost c, $a > c > 0$, and there is no fixed production cost. The firms' products are assumed to be perfect substitutes as well as fully compatible with one another, thus giving rise to a single industry-wide network of buyers/users (Katz and Shapiro, 1985a).

We adopt the widely used equilibrium concept for markets with network effects developed in the pioneering work of Katz and Shapiro (1985a), the so-called Fulfilled Expectation Cournot Equilibrium (FECE). This concept assumes that (i) firms take the network size S as given in their perceived inability to affect consumers' expectations of the market size, and (ii) both consumers and firms correctly predict the ultimate network size, which will coincide with the equilibrium industry output if one assumes in addition that each consumer purchases exactly one unit or none.[1] An alternative justification for FECE as a plausible equilibrium concept, provided by Amir and Lazzati (2011), is that the FECE could be the outcome of a simple myopic learning dynamics even if firms or consumers cannot correctly predict the equilibrium market size at the outset.

The firm's profit function is

$$\pi\left(x, y, S\right) = x[a + S - x - y] - cx$$

where x is the firm's level of output, y the total output of the other $(n-1)$ firms in the market (so $Q = x + y$).

As a useful benchmark case, we first solve for the FECE before licensing. To this end, we first determine the Cournot equilibrium for any given network size $S > 0$ (treated as a

[1] An unusual aspect of this concept is that it combines Cournot equilibrium with one plausible way of determining the right demand function from a collection indexed by the network size S, and thus the ultimately correct market size.

parameter). Following Amir and Lazzati (2011), in an industry of n symmetric "network-size taking" firms with marginal cost c, it is well known that the Cournot equilibrium per firm and industry outputs are, respectively,

$$q(S) = \frac{a+S-c}{n+1} \quad \text{and} \quad Q(S) = \frac{n(a+S-c)}{n+1}.$$

FECE requires that both consumers and firms correctly predict the market outcome so that their beliefs of the industry network size S are confirmed in equilibrium. Thus, by equating the industry output and the expected network size, i.e., letting $Q(S) = \frac{n(a-c+S)}{n+1} = S$, we can solve both variables at the unique FECE to be

$$S^* = Q^* = n(a-c).$$

From $P^* = a - Q^* + S^*$ and $\pi^* = (P^* - c)Q^*$, it follows that the FECE market price, per-firm output, and profit are

$$P^* = a, \; q^* = \frac{Q^*}{n} = (a-c) \text{ and } \pi^* = (a-c)^2.$$

This solution is clearly distinct from the classic Cournot oligopoly outcome for each of these variables. A key qualitative divergence is that per-firm output and profit decrease in the number of operating firms n in regular Cournot, while they become invariant in n in the present model. This outcome is due to two conflicting effects. The first is the usual market competition effect where the presence of more firms drives output and profit down. The second effect is more subtle and initially counter-intuitive as it moves per-firm output and profit up: It reflects the fact that in an industry-wide network, firms act as partners in building up a common network. The underlying mechanism is that, with more firms, total output increases, thereby yielding a higher shift in inverse demand for all firms. For further discussion of the second effect, see Amir and Lazzati (2011).

The latter study also demonstrates via examples that either of the two effects may actually dominate for both per-firm output and profit, which thus may move in either direction as more firms compete. Therefore, the fact that the two effects *exactly offset* each other in the present model is an artifact of our specification and not a robust outcome. The advantage of this simple outcome is that it allows for a tractable solution to our game, a benefit that would disappear with a specification for which per-firm output and profit depend directly on n.

3 The two licensing outcomes

The previous section provides a standard analysis for finding the FECE of a Cournot game in an industry with network effects. In this section, we consider the licensing game in such an industry. Following Kamien and Tauman (1984, 1986), we consider a research lab (thus not by itself a producer) that has developed a superior technology for the production of a good that exhibits network effects. The technology is a process innovation that helps to reduce the (marginal) production cost. In addition, technology does not change the basic property of the good, so that the products remain fully compatible regardless of which technology, the old or the superior, is used in production. In other words, the technology does not change the nature of the network as an industry-wide one. This sets our model apart from Lin and Kulatilaka (2006); Hong et al. (2015); Zhao et al. (2014); Zhang et al. (2018), where it is assumed that the licensing of new technology makes two originally incompatible products compatible. Our assumption is pertinent for many innovations that do not change the product's compatibility with older generations. For example, the use of cellphones has an industry-wide network externality, and then a technological innovation in the processor and the chip of cellphones in terms of performance and speed brings a cost-reducing advantage [2] to cellphone producers who adopt the new technology, without changing the industry-wide network.

Consider the following two-period licensing game. At Stage 1, the lab offers licensing contracts to all firms, requiring the firm either to pay a one-time upfront fixed fee or to pay constant royalty for each unit produced in order to use the superior technology. The lab maximizes its licensing revenue. At Stage 2, firms first decide whether or not to accept the licensing contract and update their production technology, upon which all firms compete a la Cournot where the equilibrium concept adopted is again FECE.

In the next subsections, we will solve the FECE under fixed-fee licensing, and then under

[2] In modern manufacturing especially within the technology sector, it is no longer common to see pure cost-reducing innovation that works only as a way to boost the factory's production efficiency. Innovation more often comes with quality or performance improvement of the product, either at a higher cost initially which is gradually brought down over time, or at a cost not higher than the old technology in the first place. Therefore, the cost-reducing technology considered in this paper can mean two ways: either a technology that purely reduces manufacturing cost without changing the product's quality, or one that increases the product's quality without bringing up the production cost.

royalty licensing, separately to draw some comparisons between the two licensing schemes.

3.1 Fixed-fee licensing

The lab has developed a superior technology that reduces a firm's marginal production cost from c to $(c-x)$, $0<c<x$. The lab can sell one license to one firm via a lump-sum fixed fee β, which is paid upfront and allows the firm to use the technology freely thereafter. If a firm does not buy the license, it can continue to produce at a marginal cost c.

Next, let us solve for the FECE of the licensing game by backward induction. At Stage 2, assume there are k licensed firms (who will produce at $c-x$) and $(n-k)$ unlicensed firms (who will produce at c). If all firms take the network size S as given and keep operating in the equilibrium (i.e., no one quits), we can solve for the firms' optimal production quantity to be: $q_l = \frac{a+S-c+(n-k+1)x}{n+1}$ for licensed firms and $q_{nl} = \frac{a+S-c-kx}{n+1}$ for unlicensed firms, with the condition $a+S-c-kx>0$. This result is a standard one for asymmetric Cournot oligopoly, or one can derive the same expression by replacing a in Kamien and Tauman (1986) by $(a+S)$ to reflect the network effects.

Then by the definition of FECE, the expected industry size is fulfilled by the actual industry output in equilibrium, thus $Q = nq_l + (n-k)q_{nl} = S$, which yields $Q = S = k(a-c+x)+(n-k)(a-c)$ for the Cournot game at Stage 2. Since there are k licensed firms and $(n-k)$ unlicensed firms, it is obvious that the output for licensed and unlicensed firms are $q_l = a-c+x$ and $q_{nl} = a-c$, respectively. So the market price is $P = a+S-Q = a$. With such output and price, the profit of a licensed firm (gross of any license fee) is $\pi_l = (P-c+x)q_l = (a-c+x)^2$, and the profit of an unlicensed firm is $\pi_{nl} = (a-c)^2$. Notice that the condition $a+S-c-kx>0$ for all firms to stay in the market is automatically satisfied in the unique FECE.

Consider the other case, that firms with old technology are forced out of the market in the equilibrium, i.e., assuming $a+S-c-kx \leq 0$. When k firms compete with marginal cost $c-x$, treating S as given, the standard Cournot result gives rise to $q_l = \frac{a+S-c+x}{k+1}$ as the output for such licensed firms. Then, proceed with the definition of FECE to solve for S, $Q = kq_l = S$, which yields $S = k(a-c+x)$ and $q_l = a-c+x$. This is the FECE output for licensed firms when unlicensed firms stop production. However, it is easily seen that such S violates the condition $a+S-c-kx \leq 0$, since $a+S-c-kx = (k+1)(a-c) > 0$. So such a FECE does not exist, and all firms shall be able to stay in the market no matter how many of them have adopted the new technology. This stands in contrast to the classic licensing model proposed by Kamien and Tauman (1986), i.e., one without network effects, and the key argument is that the industry-wide network externality lessens the competition among firms.

To conclude, if k firms are licensed at Stage 2, the unique FECE gives rise to the following expressions for the output and profit of licensed and unlicensed firms:

$$q_l = a - c + x, \quad \pi_l = (a - c + x)^2, \quad \text{and} \quad q_{nl} = a - c, \quad \pi_{nl} = (a - c)^2.$$

These results hold as long as $a > c > x > 0$. Essentially, patent licensing introduces asymmetric production costs across firms. However, notice that the profits of both licensed firms and unlicensed firms are not affected by k, the number of licensed firms. This property of the profits is a major divergence from a classic Cournot model without network effects. That is, the network externality completely offsets the competition effect in the industry, such that the equilibrium profits for both types of firms are independent of n or k.

Lemma 1. *In an industry with an industry-wide network, if k firms are licensed in the form of fixed-fee licensing, then in the unique FECE, the profits, and outputs of licensed and unlicensed firms are, $q_l = a - c + x$, $q_{nl} = a - c$, $\pi_l = (a - c + x)^2$, and $\pi_{nl} = (a - c)^2$*

Back to Stage 1, the lab maximizes its licensing revenue, $k\beta$. Notice that licensed firms always earn higher profits than unlicensed firms (i.e., $\pi_l > \pi_{nl}$), so it is easy to induce all firms to buy the license, as long as $\beta \leq \pi_l - \pi_{nl}$. If otherwise, $\beta > \pi_l - \pi_{nl}$, no firm buys the license. Therefore, the optimal strategy for the lab is to license all firms at a fee that extracts all their surplus, i.e.,

$$k_f^* = n \quad \text{and} \quad \beta_{s,f}^* = (a - c + x)^2 - (a - c)^2 = x^2 + 2(a - c)x$$

where the subscript f stands for fixed-fee licensing. Then, each firm is indifferent between buying and not buying the license, and the lab's revenue totals $R_f^* = n\beta_f^*$. The following Proposition summarizes the results.

Proposition 1. *In an industry with an industry-wide network, the optimal fixed-fee licensing is to have all firms licensed, i.e., $k_f^* = n$, at a lump-sum upfront fee, $\beta_f^* = x^2 + 2(a - c)x$. Then each firm's net profit is $(a - c)^2$, the industry output is $Q_f^* = n(a - c + x)$, and the lab's licensing revenue is $R_f^* = n\Big(x^2 + 2(a - c)x\Big)$.*

3.2 Royalty licensing

In this Subsection, we consider the case of royalty licensing. As a preview, recall that Kamien and Tauman (1986) concluded that fixed-fee licensing is a better licensing scheme than royalty licensing in terms of revenue generation for the lab. The underlying mechanism is that by imposing a royalty rate on each unit produced by the firm, such licensing hurts the firms' incentives to produce, and firms will respond by producing less in the equilibrium, which in turn hurts the amount of royalties collected by the lab. This same intuition will be shown to carry over to markets with network effects.

Starting with Stage 2 by backward induction, assume k firms are licensed via a royalty contract, which specifies that the firm needs to pay α to the lab for each unit of output it produces, $0 < \alpha \leq x$. Then, the effective marginal cost for these k firms will be $c - x + \alpha$, and for the other $(n-k)$ unlicensed firms is still c. Treating S as given for now, the standard asymmetric-cost Cournot competition gives rise to the output of licensed and unlicensed firms, $q_l = \frac{a+S-c+(n+1-k)(x-\alpha)}{n+1}$ and $q_{nl} = \frac{a+S-c-k(x-\alpha)}{n+1}$.. Next, solve the FECE of the game by letting $Q = kq_l + (n-k)q_{nl} = S$, which yields $S = k(a-c+x-\alpha) + (n-k)(a-c)$, and consequently,

$$q_l = a - c + x - \alpha \quad \text{and} \quad q_{nl} = a - c$$

Again, the possibility that unlicensed firms stop producing in the FECE can be ruled out by similar reasoning as that for fixed-fee licensing.

Lemma 2. *In an industry with an industry-wide network, if k firms are licensed in the form of royalty licensing at rate α, then in the unique FECE, the profits, and outputs of licensed and unlicensed firms are: $q_l = a-c+x-\alpha$, $q_{nl} = a-c$, $\pi_l = (a-c+x-\alpha)^2$ and $\pi_{nl} = (a-c)^2$.*

In the proof, we have shown that the first-order condition of a firm's profit maximization implies that the firm's profit is always the square of its output, i.e., $\pi_i = (q_i)^2$. Since $\alpha \leq x$, we have $\pi_l \geq \pi_{nl}$. So all firms weakly prefer to buy the license regardless of n and k. Therefore, at Stage 1, the lab should optimally license all firms, $k_r^* = n$, with the subscript r representing royalty licensing, and then choose the royalty rate α to maximize its licensing revenue $n\alpha(a-c+x-\alpha)$, under the constraint $\alpha \leq x$. The solution to this maximization problem of the lab is $\alpha_r^* = \min(\frac{a-c+x}{2}, x)$. Specifically, if the innovation is non-drastic, i.e.,$\frac{a-c}{x} \geq 1$, then $\alpha_r^* = x$, and the lab's revenue is $R_r^* = nx(a-c)$. If the innovation is drastic, i.e., $\frac{a-c}{x} < 1$, then $\alpha_r^* = \frac{a-c+x}{2}$, and the lab's revenue is $R_r^* = \frac{n(a-c+x)^2}{4}$.

Proposition 2. *In an industry with an industry-wide network, the optimal royalty licensing is to have all firms licensed, i.e., $k_r^* = n$, and to set royalty rate α_r^* as follows.*
(i) For non-drastic innovation, or $\frac{a-c}{x} \geq 1$: $\alpha_r^* = x$, and then the industry output is $Q_r^* = n(a-c)$, and the lab's revenue is $R_r^* = nx(a-c)$.
(ii) For drastic innovation, or $\frac{a-c}{x} < 1$: $\alpha_r^* = \frac{a-c+x}{2}$, and then the industry output is $Q_r^* = \frac{n(a-c+x)}{2}$, and the lab's revenue is $R_r^* = \frac{n(a-c+x)^2}{4}$.

Comparing the fixed fee and royalty licensing, one gets the conclusion that both the lab and consumers prefer fixed fee licensing[3], while firms weakly prefer royalty licensing (indifferent when the innovation is non-drastic). Indeed, the industry output under fixed fee, $Q_f^* = n(a-c+x)$, is higher than Q_r^* no matter whether the innovation is drastic or non-drastic. Thus consumers are better off with fixed-fee licensing. The lab's fixed-fee revenue is $R_f^* = n\big((a-c+x)^2 - (a-c)^2\big)$, which is always higher than R_r^* no matter whether the innovation is drastic or non-drastic by a simple calculation. Lastly, the firm's profit is $\pi_f^* = (a-c)^2$ with a fixed fee, the same as what an unlicensed firm's profit would be since all surplus is extracted by the lab. With royalty, a firm's profit is $\pi_r^* = \frac{(a-c+x)^2}{4}$ for drastic innovation and $\pi_r^* = (a-c)^2$ for non-drastic innovation. Simple algebra leads to the fact that firms prefer royalty licensing when the innovation is drastic, and are indifferent between the two when the innovation is non-drastic.

Our last comment is a direct observation of how network externality affects the lab's licensing strategies. Here, the network externality shows up in its strongest form when the industry interconnects as a single network with some industry-wide compatible products, which gives rise to the equilibrium in which a licensed firm always earns higher profits than an unlicensed firm regardless of n and k (the profits are actually constants with linear demand). Therefore, it is in the lab's interest, as well as in accordance with firms' incentives, to get all firms licensed in equilibrium.

The network externality in the form of an industry-wide network completely erases the possibility that the lab might be better off by licensing some, but not all, firms in the industry, the partial licensing scenario predicted by the inner solution in Kamien and Tauman (1986). Indeed, several examples from the real world would fit the results (recall that we treat quality-improving and cost-reducing technologies as the same, differing from production innovation which creates a new product). Intel liberally licensed out its PCI (Peripheral Component

[3]By following Katz and Shapiro (1985a), in any FECE with linear inverse demand, the actual consumer surplus equals the expected consumer surplus, $\frac{1}{2}Q^2$, where $Q$is the industry output. See Section 4 for the details.

Interconnect) Bus technology, which supports the capabilities of CPU, thus a cost-reduction technology to firms producing peripheral products in the network industry, hoping that as many firms as possible would adopt their technology (Moenius and Trindade, 2007). Another example goes back to the early 1970s, Dolby released their noise-reduction patent to firms producing recorded devices as well to the public for the recorded cassettes market (Ziegler et al., 2013), reflecting an incentive to fully cover the market with the new technology.

4 Comparison of results with network structure

In the previous section, we analyze the optimal licensing strategies under fixed-fee and royalty licensing schemes with an industry-wide network structure. We further investigate the impact of licensing with a network structure on industry performance and social welfare in the following two subsections to highlight the role of the network externality in the model.

4.1 Industry Performance Before and After licensing

We begin by comparing the industry performance and social welfare *before*- and *after*- licensing. To measure social welfare, we adopt the definition used in the patent licensing literature (e.g., Fauli-Oller and Sandonis, 2002), which includes consumer surplus, producer surplus (profits), and lab revenue.

4.1.1 Profit and Revenue Comparison

From Proposition 1 and 2, we know that every firm is a licensee, and the lab always optimally licenses all firms in the equilibrium with an industry-wide network setting. Now, let us start by examining the following proposition to compare the market performance with licensing.

Proposition 3. *In an industry with an industry-wide network,*
(a) Industry output is (weakly) higher after licensing.
(b) Firms (weakly) prefer royalty licensing to fixed fee licensing or no licensing.
(c) The lab prefers fixed fee licensing to royalty licensing.

Licensing affects market performance by allowing firms to produce at a lower cost, though firms are not necessarily better off since the lab extracts much of the surplus. Recall that a firm produces $(a-c)$ units of output before licensing, which becomes $(a-c+x)$ for fixed-fee licensing, $(a-c)$ for royalty licensing with non-drastic innovation (i.e., $a-c \geq x$), and

$\frac{a-c+x}{2}$ for royalty licensing with drastic (i.e., $a - c < x$) innovation, respectively. In all cases, licensing results in each firm producing a quantity (weakly) greater than its before-licensing output level. Since all firms are licensed at the equilibrium, industry output is (weakly) higher after licensing. The improvement is strict except for the case of royalty licensing with non-drastic innovation. As in the standard model of Katz and Shapiro (1986), in this case, the optimal royalty rate is exactly the cost reduction amount, so licensed firms produce as if at their original marginal cost c, and the market outcome remains unchanged after licensing.

For Proposition 3(b) and (c), firms' profits, in general, remain the same after licensing because almost all surplus is taken by the lab. For a fixed fee with drastic or non-drastic innovation, a licensed firm generates gross profit $(a-c+x)^2$, part of which is taken by the lab, and $(a - c)^2$ is left to firms as this would be their profit using the old technology. The same holds for royalty licensing with non-drastic innovation, where the royalty rate equals the cost reduction and firms earn $(a - c)^2$ in the equilibrium. The trick for the fixed-fee cases is that an unlicensed firm always has the profit $(a - c)^2$, whether every rival of theirs is licensed, or all of them remain unlicensed (which is the pre-licensing scenario). This becomes their opportunity cost of being licensed, and the lab simply takes away all the producer surplus generated by licensing. However, if the innovation is drastic and the lab chooses royalty licensing, the optimal royalty rate $\frac{a-c+x}{2}$ is less than the cost reduction amount x, and firms earn higher profits by producing at an overall reduced marginal cost. In fact, if the lab forces x on firms as the royalty rate, firms will respond by producing much less output and the lab's revenue will not be maximized.

4.1.2 Welfare Comparison

Before comparing social surplus from *before-* and *after-* licensing, let us compare consumer surplus. To calculate consumer surplus, we follow Katz and Shapiro (1985a). With an industry-wide network, the consumer surplus that a consumer derives from buying a good depends on the number of other customers who join the network associated with that product, thus consumers will make their purchase decisions on expected network sizes that must be equal to the expected network size in the equilibrium by the characteristics of FECE. With the hedonic price setting from the firms' side, we obtain consumers' expected surplus, $\frac{1}{2}Q^2$, where Q is the industry output. Thus, we have the below proposition.

Proposition 4. *In an industry with an industry-wide network, fixed fee licensing yields the highest consumer surplus, followed by royalty licensing in the case of drastic innovation. In* *the scenario of non-drastic innovation, the consumer surplus remains unchanged relative to the result without licensing.*

Propositions 3 and 4 demonstrate that, compared to the pre-licensing scenario, licensing results in increased profits for the firms, higher revenue for the lab, and greater consumer surplus. Consequently, the following corollary immediately follows.

Corollary 1. *Regardless of the specific licensing scheme, licensing leads to a strict improvement in social welfare compared to the pre-licensing scenario.*

This is easily seen by combining the facts that consumers are weakly better off due to higher industry output, firms are also weakly better off (in most cases remaining the same), and the lab has a positive revenue from licensing. This conclusion is not surprising from an intuitive standpoint, given the social benefit of introducing a process innovation into an industry that reduces production costs.

4.2 Comparison *with* and *without* network effects

In this subsection, we will provide a brief discussion on the impact of network effects in a licensing game by comparing the results obtained from Kamien and Tauman (1986) with those derived in our study to shed light on the significance of network effects in licensing.

4.2.1 Profit, Revenue and Welfare Comparison

Throughout this study, we have introduced an industry-wide network S into the model of Kamien and Tauman (1986) and have examined the resulting differences from classic Cournot oligopoly outcomes, with a particular focus on per-firm output and profit. In contrast to the classic licensing model of Kamien and Tauman (1986), we find that the presence of an industry-wide network builds a common network that completely offsets the competition effect as total output increases with more firms in the market. Consequently, the presence of industry-wide network results in per-firm output and profit becoming invariant in the number of firms n, leading to an overall improvement in market performance. In particular, all firms can remain in the market in equilibrium, regardless of the licensing scheme employed. This is the key contrast to the classic licensing model of Kamien and Tauman (1986).

Proposition 5. *In all scenarios, the presence of network effects leads to strictly higher social welfare.*

From the perspective of the firms, a licensed firm always earns higher profits than an unlicensed firm, and all firms have incentives to obtain a license, as explained in Section 3. Furthermore, from the lab's perspective, the network externality in the form of an industry-wide network eliminates the possibility that the lab might be better off by licensing only some firms in the industry, as can happen in the Kamien and Tauman (1986) model.

In conclusion, the presence of an industry-wide network improves social welfare by increasing per-firm output, profit, and industry output, compared to the classic licensing model.

4.2.2 Diffusion of Technology

This subsection provides an analysis of the impact of network externalities on the technology diffusion speed, particularly in the context of two licensing schemes.

The lab, as the technology provider, determines the speed of technology diffusion, which, in turn, depends on the firm's incentive structure, determined by the outcome of Cournot competition between low-cost and high-cost firms. This incentive structure, in turn, is affected by the network structure. Comparing the diffusion speed measured by k^* in the traditional no-network case and an industry-wide network case discussed in Section 3, we observe that the diffusion speed increases in the presence of network externalities. The lab has a preference for licensing a superior technology in an industry with network externalities because it can induce more firms to purchase the license profitably, and its license revenue per firm is also higher.

Regarding the licensing scheme, the diffusion of technology is generally the fastest for royalty licensing regardless of the network structure. This is straightforward because the licensed firm's effective marginal cost, $(c - x + \alpha)$, is always lower than the unlicensed firm's marginal cost, c, due to the lab's inability to request a royalty rate α higher than the cost reduction amount x. The competition becomes a standard Cournot with firms' respective effective marginal costs, leading to higher profits for licensed firms. Such a profit structure incentivizes all firms to seek licenses and motivates the lab to license all firms to maximize the diffusion speed.

Similarly, for fixed-fee licensing in an industry-wide network, the strong network externality increases equilibrium output, resulting in higher profits $(a - c + x)^2$ for licensed firms compared to unlicensed firms' profits $(a - c)^2$. Consequently, all firms have the incentive to obtain a license, as long as the lab charges no more than $(a - c + x)^2 - (a - c)^2$. However, the diffusion of technology may only be partial in industries with no network effect. Proposition 2 from Kamien and Tauman (1986) shows that the profits of both licensed and unlicensed firms decrease with an increase in the number of licensees, k; so does the subtractable fee, β. In other words, the more firms get licensed, the less the lab can charge each firm. As a result, the lab would license all firms only when the number of firms in the market is moderate, (i.e., $n \leq 2(\frac{\frac{a-c}{x}+1}{3})$), and for larger n, the industry may be partially licensed. The following proposition summarizes the results.

Proposition 6. *The presence of an industry-wide network enhances the rate of technology diffusion, as indicated by the number of licensed firms, denoted as* k^**, in the equilibrium. More precisely:*
(i) Irrespective of the presence of network externalities, the technology diffusion rate is highest under royalty licensing, that is, all firms are optimally licensed in the equilibrium with and without network structure.
(ii) Fixed fee licensing leads to a faster technology diffusion rate when an industry-wide network is present, as compared to the scenario when there are no network effects.

In conclusion, the presence of network externalities results in an accelerated technology diffusion rate, as the profit differential between licensed and unlicensed firms is amplified. Moreover, the lab is able to extract a greater surplus from licensed firms in industries with network effects, as compared to those without such externalities. Consequently, there is a greater likelihood of the lab licensing more firms with an industry-wide network.

5 Conclusion

This paper contributes to two distinct streams of literature: patent licensing (pioneered by Kamien and Tauman, 1984, 1986), and network effects (formalized in Katz and Shapiro, 1985a). We analyze a scenario in which an outsider lab licenses a process innovation to an industry characterized by network effects, with a focus on an industry-wide single network structure as explored in Amir and Lazzati (2011). We compare two conventional licensing forms, fixed-fee and royalty licensing, in terms of their optimal licensing strategies, industry performance, and technology diffusion speed under different network structures or licensing forms. Our findings suggest that, in general, consumers benefit from increased industry outputs. However, firms fare differently depending on the licensing form: they are worse off with fixed-fee licensing as the lab captures all generated surplus, but they are better off with royalty licensing because they can adjust production quantities in response to royalty rates. Nonetheless, since fixed-fee is paid upfront for a single period, the firms' future profitability increases by adopting the technology, thus providing an incentive for license adoption. Although such investment trade-offs fall outside the scope of our static model, the introduction of cost-reduction technology increases the total surplus. Finally, we observe that the lab strictly prefers to license in industries with network externalities, such as the industry-wide single network analyzed in this paper, as the network effect enhances the surplus available for extraction.

The present paper focuses on an industry-wide single network structure, as explored in Amir and Lazzati (2011), as a tractable means of capturing the effects of network externalities. This approach, while limiting, serves to provide a clear comparison of two conventional licensing forms—fixed-fee and royalty licensing—in terms of industry performance and technology diffusion speed. A natural extension of the model would be to consider firm-specific networks and explore how the market performance of an industry and the lab's optimal strategy change as the strength of network effects vary. Furthermore, extending the framework to include insider licensors, i.e., firms, could prove fruitful as their incentives for licensing differ from those of independent labs. As network externalities continue to spread and dominate modern industries, it is our view that traditional innovation and patent licensing literature should be expanded to incorporate these new changes. Such efforts may pave the way for more comprehensive and insightful analyses of innovation and licensing strategies in networked industries.

Appendix

Proof of Lemma 1

Denote by $P(Q) = a-Q+S$ the market demand where S is the network externality with single network. Then, the Cournot equilibrium output for each firm can be derived by the first order derivative of firms' profit function. The firm i's profit function is $\pi_i = P(Q)q_i - cq_i = (a - Q + S)q_i - cq_i$ and from its first order condition $\frac{\partial \pi_i}{\partial q_i} = a - Q - c_i + S - q_i = 0$, we get $q_i^* = \frac{a-c+S}{n+1}$, which is the pre-invention Cournot equilibrium output for each firm, and since there are n homogeneous firms, the pre-invention Cournot equilibrium industry output is

$Q^* = \frac{n(a-c+S)}{n+1}$.

By following the concept FECE in Katz and Shapiro (1986), which requires both firms' strategic behavior in the market and the coordination of expectations as to the right market size. (Amir and Lazzati (2011)). Thus, the industry produces precisely the expected network size. That is, from $S = \frac{n(a+S-c)}{n+1}$, we get $S^* = n(a-c)$. By plugging S^* into q_i^*, each firm produces $q_i^* = (a-c)$ and the market price is $P^* = a + n(a-c) - n(a-c) = a$. Per-firm profit $\pi_i^* = (a+S-Q-c)q_i = (q_i^*)^2$ since $(a+S^*-Q^*-c-q^*) = 0$ from the first order condition.

Next, to solve the FECE for the licensing game by backward induction, let us assume there are k licensed firms and $(n-k)$ unlicensed firms at $Stage2$. Note that the market equilibrium price is always a regardless of firms' competition behavior, thus we do not need to distinguish drastic and non-drastic inventions in linear demand and single network setting. By following *Lemma 3* in Kamien and Tauman (1984) and if all firms produce positive quantities in equilibrium $(a+S-c-kx>0)$, we replace a by $(a+S)$ in the equilibrium output since firms are network-size takers.

$$q_l = \frac{a+S-c+(n-k+1)x}{n+1} \tag{1}$$

$$q_{nl} = \frac{a+S-c-kx}{n+1} \tag{2}$$

By equating the industry output and the network size $nq_l + (n-k)q_{nl} = S$, we can solve for S^* as the FECE. $S^* = k(a-c+x) + (n-k)(a-c)$. Plugging S^* into (1) and (2), we get $q_l^* = a-c+x$ and $q_{nl}^* = a-c$. The firm's profit is $\pi_i = (q_i)^2$ since $Q = S$ as before, thus we have $\pi_l^* = (a-c+x)^2$ and $\pi_{nl}^* = (a-c)^2$.

Next, check whether the equilibrium is supported when $a+s-c-kx \leq 0$ so that non-licensed firms produce zero quantity in the equilibrium. Then k licensees' output and $(n-k)$ non-licensees' output are $q_l = \frac{a+S-c+x}{1+k}$, $q_{nl} = 0$, respectively. FECE requires $kq_l = k(\frac{a+S-c+x}{1+k}) = S$, Thus we get $S^* = k(a-c+x)$, which is a contradiction to the condition $a+s-c-kx \leq 0$ since $a+S-c-kx = (k+1)(a-c) > 0$. Therefore, all firms produce positive quantities at the equilibrium in a single network licensing game. The firm's profit in the equilibrium is not affected by the total number of licensed firms as the competition effect is offset by the network effects. Therefore, firms would buy the license since $\pi_l^* > \pi_{nl}^*$.

Proof of Proposition 1

From Lemma 1, a licensed firm will not deviate from his strategy to buy the license for a given β as long as $\beta \leq \pi_l^* - \pi_{nl}^* = (a-c+x)^2 - (a-c)^2$. In addition, when the lab chooses $\beta_{s,f}^* = (a-c+x)^2 - (a-c)^2$, a non-licensed firm would be indifferent whether they purchase the license or not for given β^*. If the non-licensed firm would purchase the license, the profit will change to $(a-c+x)^2 - \beta_{s,f}^*$ from $(a-c)^2$. The increment to its profit is $(a-c+x)^2 - (a-c)^2 - \beta_{s,f}^* = 0$. Thus, by choosing $\beta_{s,f}^* = (a-c+x)^2 - (a-c)^2$ at *Stage*1, the lab would license every firms ($k_{s,f}^* = n$) and extract all firms' surplus. As a result, the industry output is $Q_{s,f}^* = n(a-c+x)$ and the lab's total revenue $R_{s,f}^*$ from licensing is $R_{s,f}^* = n\beta_{s,f}^* = n[(a-c+x)^2 - (a-c)^2]$.

Proof of Lemma 2

When the license is granted by royalty α per-unit output, then the model is basically equivalent to the Cournot with asymmetric costs: k licensed firms' marginal cost is $(c-x+\alpha)$, and $(n-k)$ non-licensed firms' marginal cost is c. The general result of a firm's Cournot ouput with asymmetric costs is $q_i = \frac{a+S-(n+1)c_i+\sum_{j=1}^n c_j}{n+1}$. Then, we get the licensee's and non-licensee's output by treating the network size S as a constant parameter as below.

$$q_l = \frac{a+S-(n+1)(c-x+\alpha)+k(c-x+\alpha)+(n-k)c}{n+1} = \frac{a+S-c+(n+1-k)(x-\alpha)}{n+1}$$

$$q_{nl} = \frac{a+S-(n+1)c+k(c-x+\alpha)+(n-k)c}{n+1} = \frac{a+S-c-(x-\alpha)k}{n+1}$$

Next, in order to solve S^* in FECE, we equate the single network size S and the industry output. From $kq_l + (n-k)q_{nl} = S$, we get $S^* = k(a-c+x-\alpha) + (n-k)(a-c)$. By plugging S^* into the above $q_l = \frac{a+S-c+(n+1-k)(x-\alpha)}{n+1}$ and $q_{nl} = \frac{a+S-c-k(x-\alpha)}{n+1}$, the licensee's and non-licensee's output and profits in single network with royalty licensing game at *Stage 2* are $q_l^* = a-c+x-\alpha$, $q_{nl}^* = a-c$, $\pi_l^* = (a-c+x-\alpha)^2$, and $\pi_{nl}^* = (a-c)^2$, respectively. Because the royalty rate α cannot exceed the cost reduction from the invention, $a \leq x$, the licensee's profit is weakly greater than the non-licensee's profit, $\pi_l^* \geq \pi_{nl}^*$.

Proof of Proposition 2

From the Lemma 2, we know $\pi_l^* \geq \pi_{nl}^*$, which means a firm would want to be licensed regardless of n and k. Thus, the lab would optimally license all firms, $k_{s,r}^* = n$ and maximizes his licensing revenue $n\alpha(a-c+x-\alpha)$, which is the product of the number of licensed firms k and the royalty rate α, by choosing the royalty rate α, given $\alpha \leq x$.

$$\max_{\alpha \leq x} n\alpha(a-c+x-\alpha)$$

The solution to this maximization problem is $\alpha_{s,r}^* = min(\frac{a-c+x}{2}, x)$. Therefore, there are two cases. If the invention is non-drastic, $\frac{a-c}{x} \geq 1$, then the lab chooses the optimal royalty rate $\alpha_{s,r}^* = x$, and since all n firms would be licensed given α^*, the industry output is $Q_{s,r}^* = n(a-c+x-\alpha^*) = n(a-c+x-x) = n(a-c)$. Thus, the lab's licensing revenue is $R_{s,r}^* = n\alpha^*(a-c+x-\alpha^*) = nx(a-c)$. On the other hand, if the invention is drastic, $\frac{a-c}{x} < 1$, then the lab chooses the optimal royalty rate $\alpha_{s,r}^* = \frac{a-c+x}{2}$, and since all n firms would be licensed given α^*, the industry output is $Q_{s,r}^* = n(a-c+x-\alpha^*) = n\left[a-c+x-\frac{(a-c+x)}{2}\right] = \frac{n(a-c+x)}{2}$. Thus, the lab's licensing revenue is $R_{s,r}^* = n\alpha^*(a-c+x-\alpha^*) = \frac{n(a-c+x)^2}{4}$.

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