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A Note on Patent Litigation and Cross Licensing[1]

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1 Introduction

In this note, we investigate the interaction between the leader and the follower in developing new technologies in the presence of litigation against patent infringement and cross licensing as its alternative. After the leader has acquired a patent and manufactures a product based on it, the follower can carry out the follow-on research to manufacture an advanced product, which can partially substitute the leader's product. Upon the losses of revenue, the leader can accuse the follower of infringement to recover monopoly profit. The perpetrator of the alleged infringement, however, is not always found guilty. When making a judgment, the court takes into account how much the advanced technology overlaps with the existing one and how much improvement has been made by the follow-on research, and occasionally the court considers the patent to be invalid, which reveals the nature of "probabilistic patents."[2] For these reasons, the leader can opt for cross licensing over the costly lawsuit. Provided that both parties agree on it, cross licensing allows them to utilize each other's works without fear of infringement. That is, the leader can take advantage of the follower's advanced technology, of which novelty has been made based on his preceding works. The choice between a lawsuit and cross licensing is made by the firms, taking into account the nature of "cumulative innovation" and "probabilistic patents." This is examined in the framework of real options based on Huisman and Kort (2015), in which not only the timing of each investment but also its capacity is endogenously determined. This enables us to incorporate how much the follower will imitate the precursor's work and how much resources will be devoted to yield the improvement.

The present model helps us comprehend the patent war between competitors we can observe in the real world, in which most innovation is sequential and cumulative. First of all, the model shows that the competition in the burgeoning market usually entails a costly lawsuit to resolve the conflict, while the competitors easily agree on cross licensing to take advantage of each other's works in the slow-growing market. This is a natural result because when the market is very lucrative, the leader desires to monopolize the market in spite of the legal expenses and the risk of losing the patent's validity in the court. If it does not seem profitable enough, however, the leader instead chooses to reconcile with the follower via cross licensing, raising extra revenue from the advanced technology developed by the follower because the exercise of exclusive rights paying the costs becomes less attractive. The fact that a more lucrative market is more likely to entail a legal dispute is consistent with the argument from Cooter and Rubinfeld (1989) and

[1]This manuscript is the abbreviated version of Jeon (2015).

[2]A great number of studies have acknowledged probabilistic validity of patents (e.g., Allison and Lemley (1998), Aoki and Hu (1999), Lemley and Shapiro (2005), Llobet (2003), Farrell and Shapiro (2008), Choi (2010)).

Lemley and Shapiro (2005), and this finding is supported by empirical studies such as Lanjouw and Schankerman (2001) and Somaya (2003).

Not only the way they resolve the dispute but also the timing of the initial innovation and the follow-on research has significant implications, especially in terms of differentiated goods. When the market demand is rapidly growing and the follower's challenge is expected shortly after the initial innovation, the leader delays his investment until the market grows enough to compensate the losses of revenue from the competition so that the follow-on research is triggered at the same time, and he files a lawsuit over infringement after it becomes a more severe problem. This implies that there is a distinct difference between the products of the leader and the follower in the fast-growing market unless the follower is found guilty at the court later and driven out of the market. If the demand is expected to grow slowly and the competitors reconcile via cross licensing, the leader delays the initial innovation substantially so that both the follow-on research and the agreement of cross licensing are triggered at the same time. This implies that both parties takes advantage of each other's works from the very beginning, leaving little difference between their products in the market.

The present model also effectively integrates the authorities' patent policy by allowing the probability that the patent is found to be valid to depend on the extent to which the patent scope is applied. The result shows that when the court interprets a patent in a narrow sense, the leader and the follower tend to resolve the conflict via cross licensing. This is a natural result because the leader is less likely to win the case over infringement, and thus opts for cross licensing to raise extra revenue, even with a small market share. This relationship between the credibility of threat of a lawsuit and the way the firms resolve the dispute is in line with Aoki and Hu (1999). Being relieved of the fear of infringement, the follower focuses on making a profit at a lower cost by imitating the existing technology, rather than enhancing the level of technology. As the patent scope becomes wider, the leader holds a more dominant position in the negotiation of cross licensing, and thus takes a larger share in the market of the advanced technology developed by the follower. If it becomes wider enough, the leader chooses to accuse the follower encouraged by the judge's hard line against infringement, and the follower devotes most of his resources to develop his own technology not to be found guilty by the court.

Furthermore, the model clarifies that the policy on patent scope cannot induce the first-best result in terms of the speed of innovation. If the patent scope is interpreted in a narrow sense and the firms decide to resolve the conflict via cross licensing, the introduction of the second-generation technology is so delayed that the agreement of cross licensing is triggered at the same time. This is because the follower is concerned about the expected losses of his revenue from the competition with the leader regarding the novel technology and chooses to wait until the market grows enough to compensate for such losses. If the breadth of patent is wide enough to induce the leader to file a lawsuit over infringement, now it is the initial innovation that is deferred significantly, and the follow-on research is triggered simultaneously. This result comes from the leader's concern about losing monopoly profits by the follower's challenge. Given these results, we can argue that neither policy can induce the first-best outcome in which both technologies are introduced without substantial delay. This argument is in line with Scotchmer (1991) and Green and Scotchmer (1995), which have shown that it is impossible for both the initial innovator and the follow-on innovator to have adequate incentives under a patent system.

Still, we can evaluate the effectiveness of patent policy by carrying out welfare analysis in a more comprehensive way. The total expected surplus of the consumer and that of producer, and thus social welfare, depend not only on the timing of innovations but also on the prices and the quantities of the products in the market, the way the competitors resolve the dispute, and the probability that the patent is found to be valid by the court provided that it ends up with a lawsuit. The welfare analysis taking these aspects into account reveals that social welfare is higher when the conflict is resolved via cross licensing because it does not involve legal expenses and consumers can enjoy more products with the advanced technology at a lower price. This result accords with Shapiro (2001), who noted that any cross license is superior to a world in which the patentee fails to cooperate, and Denicolò (2002), who argued that collusion between patentees via cross licensing can be socially beneficial even if the patents are competing. Given these arguments, one might conclude that the narrower the patent scope is, the more social welfare we can yield. Yet, this is only half the story. Even though the dispute is resolved out of court, the authorities' stance on infringement still comes into play because the leader's bargaining power in the negotation of cross licensing depends on it. Namely, if the patent scope is interpreted in a very narrow sense, the leader has little bargaining power in cross licensing and cannot take advantage of the second-generation technology as much as he wants. Thus, there will be fewer products with the advanced technology even at a higher price, which leads to the decrease of social welfare.

2 The model and solutions

2.1 Setup

Suppose that there are two risk-neutral firms in the market, the leader and the follower.[3] The leader has an option to develop technology which can be patented and to manufacture a product based on it. The demand shock is given by a one-dimensional geometric Brownian motion as follows:

$$dX(t) = \mu X(t)dt + \sigma X(t)dW(t) \tag{2.1}$$

where μ and σ are constant coefficients and $(W(t))_{t\geq 0}$ is a standard Brownian motion on a filtered probability space $(\Omega, \mathcal{F}, \mathbb{F} := (\mathcal{F}_t)_{t\geq 0}, \mathbb{P})$. A risk-free rate is assumed to be a constant $r > \mu$ for the sake of finiteness of value function. Given the demand shock, the price of the product with the first-generation technology at time t is determined as follows:

$$P_1(t) = X(t)(1 - \eta_1 Q_1(t)) \tag{2.2}$$

where $Q_1(t)$ and a constant $\eta_1 > 0$ denote total market output of the product with the first-generation technology at time t and its price elasticity, respectively. If the demand shock exceeds

[3]For simplicity, we assume that their roles are predetermined. The role can be endogenized to investigate preemption incentive. See Chapter 9 of Dixit and Pindyck (1994) for detailed illustration regarding this issue.

a threshold, the leader invests in R&D and manufactures a product with capacity Q_1^L, which incurs investment costs of $c_1 Q_1^L$ including the R&D costs, and he makes a profit at the rate of $P_1(t)Q_1^L$. Note that the investment in R&D and the capacity is integrated in one stage for simplicity and that the patent is assumed to be acquired immediately with no expiry date.

The basic technology developed by the leader lays the foundation for the follow-on research. Namely, the follower has an option to develop advanced technology building on the existing one and to manufacture a product with it. Further improvement is expected to be made, but it can partially overlap the predecessor's works. For instance, after a leading firm in the IT industry has invented a smartphone, a rival firm can manufacture a smartphone with fingerprint identification or a curved display. The latter is embedded with newer technologies and can replace the former to a certain extent. The degree of overlapping and the improvement can be represented by the scale of the follower's investment in R&D and the capacities regarding the first-/second-generation technologies, denoted by Q_1^F and Q_2^F, respectively. Note that the size of the capacities is assumed to be proportional to the scale of R&D investment because it is reasonable to suppose that the higher the quality of R&D investment is, the larger capacities the firm would like to have. In the example of a smartphone industry, the follower invests not only in the facilities to produce the components of an existing smartphone but also in those to develop and manufacture a fingerprint reader or a curved display, which correspond to Q_1^F and Q_2^F, respectively. The former can be invested at a lower cost, γc_1 per unit with a constant $\gamma \in [0, 1]$, because the patent has been granted to the leader in exchange for detailed public disclosure of the invention, which enables the follower to imitate easily. Yet, the improvement in technology can only be made at relatively higher costs, and we suppose that a unit of Q_2^F costs c_2.

Given the investments in the technologies with different level of novelty, the follower's revenue consists of two channels; $P_1(t)Q_1^F + P_2(t)Q_2^F$ with

$$P_2(t) = X(t)(1 - \eta_2 Q_2(t)) \tag{2.3}$$

where $Q_2(t)$ and a constant $\eta_2 > 0$ are defined in the same manner as (2.2). The investment regarding the existing technology makes duopoly profit $P_1(t)Q_1^F$ since he competes with the leader in terms of the total output (i.e., $Q_1(t) = Q_1^L + Q_1^F$). Yet, the investment regarding the second-generation technology of which novelty can only be found in the follower's product yields monopoly revenue $P_2(t)Q_2^F$.

Having his product partially substituted by that of the follower, the leader can accuse the follower of infringement, which costs both parties c_L, to recover monopoly profit. Yet, the patentee does not always win the trial. The patent occasionally turns out to be invalid at the court, even though it has been granted by the authorities after appropriate examination. Innovation is inherently cumulative, and thus the court takes into account how much the follower's technology overlaps with the leader's and how much improvement has been made in the subsequent innovation when judging whether the follower has infringed on the precursor's patent rights.[4]

[4]Chang (1995) addressed that courts sometimes refuse to find infringement if the allegedly infringing device features major improvements. Green and Scotchmer (1995) and Llobet (2003) supposed that the amount of

Yet, there is a room for discretion by the court in the sense that there can be a huge difference regarding the interpretation of patent breadth depending on patent policy. With this in mind, we suppose that the patent is found to be valid at the court with probability p given by

$$p(Q_1^F, Q_2^F, d) = \exp\Big(-\frac{Q_2^F}{Q_1^F}d\Big) \tag{2.4}$$

where a constant $d \in (0, \infty)$ denotes the extent to which the "Doctrine of Equivalents" is applied.[5] If the court rules that the follower has infringed on the leader's patent, which occurs with probability p, the follower is forced to cease production thenceforth, while the leader recovers monopoly profits. With probability $1-p$, however, the patent turns out to be invalid, the follow-on research is acknowledged as legitimate innovation, and the follower maintains his position in the market. Note that $\partial p(Q_1^F, Q_2^F, d)/\partial Q_1^F > 0$ and $\partial p(Q_1^F, Q_2^F, d)/\partial Q_2^F < 0$ hold; the former implies that the more the follower's investment overlaps the leader's one, the more it is likely to be found as infringement, while the latter suggests that the more improvement the follow-on research has made, the more it is likely to be admitted as legitimate innovation. Regarding the court's discretion, $\partial p(Q_1^F, Q_2^F, d)/\partial d < 0$ holds, which clarifies the interpretation of d; the lower d is, the wider the patent breadth is. Yet, $\lim_{Q_2^F \to 0} p(Q_1^F, Q_2^F, d) = 1$ and $\lim_{Q_1^F \to 0} p(Q_1^F, Q_2^F, d) = 0$ ensure that the discretion is excluded in the extreme cases.

The litigation process is costly for the patentee in many ways; not only is the legal cost c_L a burden but also he gains nothing with probability $1 - p$ in spite of the litigation expenses. Thus, the leader can consider cross licensing as an alternative of a lawsuit. Namely, the leader, still behind in technology, can make an offer that allows both parties to utilize each other's work without fear of infringement. If agreed upon, the leader invests with his first-best capacity Q_2^L to embrace the new technology in manufacturing his product, which incurs cost of γc_2 per unit, and this yields additional duopoly revenue of $P_2(t)Q_2^L$. The offer, however, can be rejected by the follower if it is better for him to be sued from the perspective of the expected profits. This is because not only does his revenue decrease due to the competition regarding the second-generation technology (i.e., $Q_2(t) = Q_2^L + Q_2^F$) but also there is a chance that he is found not guilty at the court, which makes him continue to compete with the leader regarding the first-generation technology while raising monopoly revenue from the second-generation technology. If this is the case, the leader can make an offer with the second-best capacity Q_2^L which makes the follower indifferent between cross licensing and litigation, as long as the leader is better off than involved in a lawsuit in terms of expected profits.

2.2 The benchmark model

In this subsection, we suppose that litigation is the only way for the leader to recover his profits so as to facilitate the understanding of the framework. As usual, value functions of both parties

improvement determines the patent's validity, and Koo and Wright (2010) assumed that an invention based on infringing research can be patented.

[5] Aoki and Hu (1999) noted that exactly what constitutes "equivalent" is left to the jury to decide, and presumed that the probability that the patent is found to be valid by the court is solely determined by the extent of the Doctrine of Equivalents. A more sophisticated assumption can be found in Llobet (2003), which further takes into account how much improvement is made from the subsequent innovation.

will be determined backwards. For now, we assume that each event occurs sequentially, leaving the case in which some of them take place simulaneously to be illustrated later.

First, suppose that the follower has carried out the follow-on research based on the existing technology to manufacture an advanced product that partially substitutes the leader's product. As the market demand grows, the leader's losses of revenue from the competition with the follower become severe, and we can easily guess that there is an upper threshold, denoted by x_L, which triggers the leader's litigation against infringement with legal costs of c_L for both parties. If x_L is hit, the court judges with probability p that the follow-on research has infringed upon the predecessor's work and forces the follower to cease production. Yet, the patent is found to be invalid with probability $1-p$, and the follower keeps his position in the market. Thus, the leader's expected profit at time t, provided that x_L is hit, can be expressed as follows:

$$\mathbb{E}\Big[\int_t^\infty e^{-r(s-t)}\Big\{p\Big(Q_1^L X(s)(1-\eta_1 Q_1^L)\Big)+(1-p)\Big(Q_1^L X(s)\{1-\eta_1(Q_1^L+Q_1^F)\}\Big)\Big\}ds\Big|X(t)=x\Big]$$
$$=p\frac{Q_1^L x(1-\eta_1 Q_1^L)}{r-\mu}+(1-p)\frac{Q_1^L x\{1-\eta_1(Q_1^L+Q_1^F)\}}{r-\mu}. \tag{2.5}$$

Meanwhile, by the standard argument, the option value of the firm, $v(x)$, satisfies the following ordinary differential equation:

$$rv=\mu x\frac{\partial v}{\partial x}+\frac{1}{2}\sigma^2 x^2\frac{\partial^2 v}{\partial x^2} \tag{2.6}$$

of which the solution takes the form as follows:

$$v(x)=Ax^\alpha+Bx^\beta \tag{2.7}$$

where

$$\alpha=\frac{1}{2}-\frac{\mu}{\sigma^2}+\sqrt{\Big(\frac{1}{2}-\frac{\mu}{\sigma^2}\Big)^2+\frac{2r}{\sigma^2}}>1,\qquad \beta=\frac{1}{2}-\frac{\mu}{\sigma^2}-\sqrt{\Big(\frac{1}{2}-\frac{\mu}{\sigma^2}\Big)^2+\frac{2r}{\sigma^2}}<0. \tag{2.8}$$

With these in mind, we can delineate value function of the leader, having an option to litigate over infringement. Given the demand shock x and both parties' investment capacities Q_1^L and Q_1^F, it can be written as follows:

$$V_L^L(x,Q_1^L,Q_1^F)=\begin{cases}\frac{Q_1^L x\{1-\eta_1(Q_1^L+Q_1^F)\}}{r-\mu}+A_L^L x^\alpha, & x<x_L,\\ p\frac{Q_1^L x(1-\eta_1 Q_1^L)}{r-\mu}+(1-p)\frac{Q_1^L x\{1-\eta_1(Q_1^L+Q_1^F)\}}{r-\mu}-c_L, & x\geq x_L.\end{cases} \tag{2.9}$$

The litigation trigger x_L and the coefficient of option value A_L^L are determined by value-matching and smooth-pasting conditions as follows:

$$x_L(Q_1^L,Q_1^F)=\frac{\alpha(r-\mu)c_L}{(\alpha-1)p\eta_1 Q_1^L Q_1^F},\quad A_L^L(Q_1^L,Q_1^F)=\Big(\frac{p\eta_1 Q_1^L Q_1^F x_L}{r-\mu}-c_L\Big)x_L{}^{-\alpha}. \tag{2.10}$$

Note that $\partial x_L(Q_1^L,Q_1^F)/\partial Q_1^F<0$ and $\partial x_L(Q_1^L,Q_1^F)/\partial Q_1^L<0$ hold. The former shows that the more the follow-on research overlaps the patented technology, the more it is likely to provoke a lawsuit, while the latter implies that the more the leader has devoted his resources to the innovation, the more he is likely to accuse the follower of infringement.

Having the litigation trigger determined by the leader, we can describe value function of the follower confronted with an upcoming legal dispute. Given the demand shock x and investment capacities Q_1^L, Q_1^F and Q_2^F, it can be obtained in the same manner as follows:

$$V_F^L(x, Q_1^L, Q_1^F, Q_2^F) = \begin{cases} \frac{Q_1^F x\{1-\eta_1(Q_1^L+Q_1^F)\}+Q_2^F x(1-\eta_2 Q_2^F)}{r-\mu} + A_F^L x^\alpha, & x < x_L, \\ (1-p)\frac{Q_1^F x\{1-\eta_1(Q_1^L+Q_1^F)\}+Q_2^F x(1-\eta_2 Q_2^F)}{r-\mu} - c_L, & x \geq x_L. \end{cases} \tag{2.11}$$

The coefficient of option value A_F^L is determined by value matching condition as follows:

$$A_F^L(Q_1^L, Q_1^F, Q_2^F) = \Big[-p\frac{Q_1^F x_L\{1-\eta_1(Q_1^L+Q_1^F)\}+Q_2^F x_L(1-\eta_2 Q_2^F)}{r-\mu} - c_L \Big] x_L^{-\alpha}. \tag{2.12}$$

Now, we proceed to the follower's decision to carry out the follow-on research and to manufacture advanced products based on it. We can easily guess that there is an upper threshold, denoted by x_I, which triggers the follow-on research (or "alleged infringement"), provided that the basic technology has been developed by the predecessor. Innovation is inherently cumulative, and thus the outcome of the follower's research and development can partially substitute the leader's product. The investment capacity regarding the first-generation technology, denoted by Q_1^F, costs γc_1 per unit, and it yields duopoly revenue. Yet, the second-generation technology can only be found in the follower's product, and thus he can raise monopoly profit from the investment in Q_2^F which incurs c_2 per unit. Note that the follower takes into account the forthcoming lègal dispute that depends on the ratio of the capacities of his investment. Thus, the follower's value function at the moment of investment given the demand shock x is as follows:

$$\frac{Q_1^F x\{1-\eta_1(Q_1^L+Q_1^F)\}+Q_2^F x(1-\eta_2 Q_2^F)}{r-\mu} + A_F^L x^\alpha - \gamma c_1 Q_1^F - c_2 Q_2^F \tag{2.13}$$

where A_F^L is given by (2.12). Maximizing (2.13) with respect to Q_1^F and Q_2^F yields the optimal capacities $Q_1^{F*}(x, Q_1^L, Q_2^F)$ and $Q_2^{F*}(x, Q_1^L, Q_1^F)$, respectively. Following the similar argument, value function of the follower given the demand shock x and the leader's investment capacity Q_1^L can be described as follows:

$$V_F^I(x, Q_1^L) = \begin{cases} A_F^I x^\alpha, & x < x_I, \\ V_F^L(x, Q_1^L, Q_1^{F*}, Q_2^{F*}) - \gamma c_1 Q_1^{F*} - c_2 Q_2^{F*}, & x \geq x_I. \end{cases} \tag{2.14}$$

The trigger of "alleged infringement" x_I and the coefficient of option value A_F^I are determined by value-matching and smooth-pasting conditions at the trigger as follows:

$$x_I(Q_1^L) = \frac{\alpha(r-\mu)(\gamma c_1 Q_1^{F*} + c_2 Q_2^{F*})}{(\alpha-1)[Q_1^{F*}\{1-\eta_1(Q_1^L+Q_1^{F*})\}+Q_2^{F*}(1-\eta_2 Q_2^{F*})]}, \tag{2.15}$$

$$A_F^I(Q_1^L) = \Big[\frac{Q_1^{F*} x_I\{1-\eta_1(Q_1^L+Q_1^{F*})\}+Q_2^{F*} x_I(1-\eta_2 Q_2^{F*})}{r-\mu} + A_F^L(Q_1^L, Q_1^{F*}) x_I^\alpha - \gamma c_1 Q_1^{F*} - c_2 Q_2^{F*}\Big] x_I^{-\alpha}. \tag{2.16}$$

Having the trigger determined by the follower, now we can calculate value function of the leader of which product can be partially substituted in the same manner as follows:

$$V_L^I(x, Q_1^L) = \begin{cases} \frac{Q_1^L x(1-\eta_1 Q_1^L)}{r-\mu} + A_L^I x^\alpha, & x < x_I, \\ V_L^L(x, Q_1^L, Q_1^{F*}), & x \geq x_I. \end{cases} \tag{2.17}$$

The coefficient of option value A_L^I is determined by value-matching condition at the trigger as follows:

$$A_L^I(Q_1^L) = A_L^L(Q_1^L, Q_1^{F*}) - \frac{\eta_1 Q_1^L Q_1^{F*} x_I^{1-\alpha}}{r-\mu}. \tag{2.18}$$

Lastly, we proceed to the leader's value function at the initial stage. We can also easily guess that there is an upper threshold, denoted by x_P, which triggers the leader's innovation and patent acquisition. The investment capacity Q_1^L cost c_1 per unit, and the leader makes monopoly profit from it until the follower challenges it by making a product that can partially substitute his product. The leader takes into account the upcoming challenge by the follower, and thus his value function at the moment of investment given the demand shock x is as follows:

$$\frac{Q_1^L x(1-\eta_1 Q_1^L)}{r-\mu} + A_L^I x^\alpha - c_1 Q_1^L \tag{2.19}$$

where A_L^I is given by (2.18). The optimal investment capacity $Q_1^{L*}(x)$ can be obtained by maximizing (2.19) with respect to Q_1^L. Following the same argument, we can describe the leader's value function at the initial stage as follows:

$$V_L^P(x) = \begin{cases} A_P x^\alpha, & x < x_P, \\ V_L^I(x, Q_1^{L*}) - c_1 Q_1^{L*}, & x \geq x_P. \end{cases} \tag{2.20}$$

The trigger of patent acquisition x_P and the coefficient of option value A_P are determined by value-matching and smooth-pasting conditions at the trigger as follows:

$$x_P = \frac{\alpha(r-\mu)c_1 Q_1^{L*}}{(\alpha-1)Q_1^{L*}(1-\eta_1 Q_1^{L*})}, \quad A_P = \left[\frac{Q_1^{L*} x_P(1-\eta_1 Q_1^{L*})}{r-\mu} + A_L^I(Q_1^{L*}) x_P^\alpha - c_1 Q_1^{L*}\right] x_P^{-\alpha}. \tag{2.21}$$

So far, we have implicity assumed that the following inequality holds regarding the triggers:

$$x_P < x_I < x_L. \tag{2.22}$$

This has enabled us to focus on the case in which the events occur sequentially. However, the follower can delay his investment so that

$$x_P, x_L < x_I. \tag{2.23}$$

holds. Furthermore, the leader can also delay the initial investment so that

$$x_I < x_P < x_L. \tag{2.24}$$

or

$$x_I, x_L < x_P. \tag{2.25}$$

holds. The explanation on these cases is omitted here, and can be found in Jeon (2015).

2.3 The main model

Having outlined the framework, now we proceed to the main model in which the leader can make an offer of cross licensing. If agreed upon, the leader makes an investment with capacity Q_2^L to take advantage of the second-generation technology developed by the follower, and it incurs a cost of γc_2 per unit. The offer, however, can be rejected by the follower, and furthermore it might not even be offered from the very beginning for the sake of the leader's interests. Namely, the leader might choose a lawsuit over an agreement of cross licensing if he is better off in terms of expected profits, even though the follower is willing to accept the offer. For now, we suppose that the leader makes an offer and it is accepted by the follower and that the events occur sequentially, leaving the whole picture to be described later.

First, suppose that the subsequent innovation has been made by the follower and the leader's product has been partially substituted by that of the follower. Then, the leader can make an offer of cross licensing in order to raise extra revenue from the second-generation technology developed by the follower. We can guess that there is an upper threshold, denoted by x_C, which triggers cross licensing, and having x_C hit, the leader's value function at the moment of investment given the demand shock x is as follows:

$$\frac{Q_1^L x\{1-\eta_1(Q_1^L+Q_1^F)\}+Q_2^L x\{1-\eta_2(Q_2^L+Q_2^F)\}}{r-\mu}-\gamma c_2 Q_2^L. \tag{2.26}$$

Maximizing (2.26) with respect to Q_2^L yields the leader's optimal capacity regarding the second-generation technology $Q_2^{L*}(x,Q_2^F)$, and the leader's value function at this stage can be written as follows:

$$V_L^C(x,Q_1^L,Q_1^F,Q_2^F)=\begin{cases}\frac{Q_1^L x\{1-\eta_1(Q_1^L+Q_1^F)\}}{r-\mu}+A_L^C x^\alpha, & x<x_C,\\ \frac{Q_1^L x\{1-\eta_1(Q_1^L+Q_1^F)\}+Q_2^{L*}x\{1-\eta_2(Q_2^{L*}+Q_2^F)\}}{r-\mu}-\gamma c_2 Q_2^{L*}, & x\geq x_C,\end{cases} \tag{2.27}$$

where smooth-fit condition at the trigger determines the following:

$$x_C(Q_2^F)=\frac{\alpha(r-\mu)\gamma c_2}{(\alpha-1)\{1-\eta_2(Q_2^{L*}+Q_2^F)\}},\quad A_L^C(Q_2^F)=\Big[\frac{Q_2^{L*}x_C\{1-\eta_2(Q_2^{L*}+Q_2^F)\}}{r-\mu}-\gamma c_2 Q_2^{L*}\Big]x_C^{-\alpha}. \tag{2.28}$$

Having the trigger of cross licensing determined by the leader, we can delineate value function of the follower of which novel technology can be utilized by his competitor. If agreed upon, he competes with the leader with regard to not only the first-generation technology but also the second-generation technology from which he has raised monopoly profits, and thus the follower's value function can be written as follows:

$$V_F^C(x,Q_1^L,Q_1^F,Q_2^F)=\begin{cases}\frac{Q_1^F x\{1-\eta_1(Q_1^L+Q_1^F)\}+Q_2^F x(1-\eta_2 Q_2^F)}{r-\mu}+A_F^C x^\alpha, & x<x_C,\\ \frac{Q_1^F x\{1-\eta_1(Q_1^L+Q_1^F)\}+Q_2^F x\{1-\eta_2(Q_2^{L*}+Q_2^F)\}}{r-\mu}, & x\geq x_C,\end{cases} \tag{2.29}$$

where value-matching condition at the trigger yields the following:

$$A_F^C(Q_2^F)=-\frac{\eta_2 Q_2^{L*}Q_2^F x_C^{1-\alpha}}{r-\mu}. \tag{2.30}$$

The rest of the steps follow the same argument as the benchmark model: deriving value functions of the two firms backwards for the follow-on and the initial investments. We omit them here for brevity and they can be found in the original paper of Jeon (2015).

2.4 The whole picture

In the previous subsections, we illustrated a few possible scenarios from the present model separately. In Section 2.2, we focused on the benchmark model in which litigation over infringement is the only way for the leader to recover his profits, and in Section 2.3, we integrated the agreement of cross licensing, which allows the stakeholders to utilize each other's technology without fear of infringement. In particular, the latter has been discussed under the condition that the follower accepts the offer, although the investment capacity of the leader might be either the first-best or the second-best, and this implicitly presumes that the leader makes an offer to the follower.

In reality, however, this might not be the case. Namely, the leader might not offer the contract of cross licensing and rather chooses to accuse the follower of infringement in spite of the legal costs and the risks of losing the validity of his patent. To be more precise, the leader compares his option value of litigation and that of cross licensing with the first-best capacity, if possible, or with the second-best capacity, and chooses the one that maximizes his expected profits. Furthermore, not only the way the firms resolve the dispute but also the sequential/simultaneous occurrence of each event is determined for the sake of the stakeholders' interests, provided that they hold for given parameters.

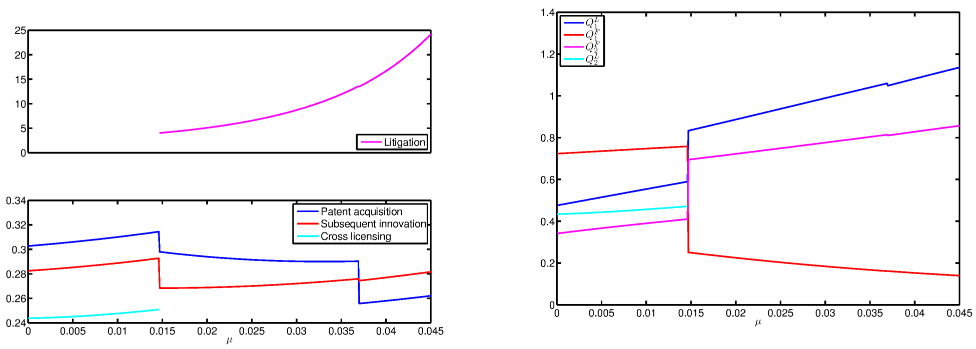
3 Comparative statics and discussion

3.1 Parameters

We adopt the following parameters as the benchmark case:

$$\begin{aligned} &r = 0.05; \quad \mu = 0.02; \quad \sigma = 0.2; \quad \eta_1 = 0.4; \quad \eta_2 = 0.6; \\ &c_1 = 2; \quad c_2 = 2; \quad c_L = 1; \quad \gamma = 0.7 \quad d = 0.5; \quad x = 0.1. \end{aligned} \tag{3.1}$$

3.2 Market demand and investment decisions



(a) The level of triggers for each event

(b) The investment capacities of the leader and the follower

Figure 1: The comparative statics regarding the expected growth rate of market demand

Panel (a) of Figure 1 shows the level of triggers with regard to the expected growth rate, which naturally reveals the sequential/simultaneous occurrence of the events. First of all, we can see that the leader and the follower agree on cross licensing when the expected growth rate of market demand is very low. It is obvious that when the market is not profitable enough, the firms have less incentive to monopolize their technologies bearing the legal costs. Moreover, the introduction of basic technology is so delayed that the follow-on research and cross licensing are triggered simultaneously. That is, both parties start their business when the market is very mature, and there is no difference in the level of technology adopted in their products.

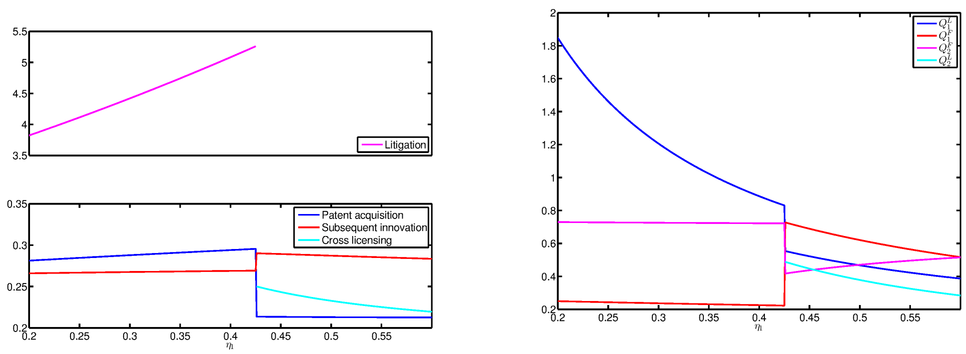
As the expected growth rate increases, however, they fail to reach an agreement on cross licensing and resolve the dispute over infringement at the court. Intuitively, they desire to take a larger share in the fast-growing market, which makes the agreement less likely to be reached. Yet, the advent of basic technology is still deferred so that the follow-on research initiates as soon as the leader carries out the initial innovation, while the lawsuit is brought later on, and this corresponds to (2.24). Panel (b) of Figure 1 represents the optimal investment capacities of both parties, and we can see that as the law steps in the resolution of conflict, the follower curtails his investment capacities in imitating the old technology significantly and augments those devoted to enhancing the technology. This is because the follower knows that unless he does so, he is more likely to lose the case and to be driven out of the market. The implication of this result becomes even clearer as the expected growth rate increases further.

If the expected growth rate of market demand is very high and the investment is lucrative enough to reward the anticipated losses of profits from the competition with the follower, the leader does not delay his investment in innovation and patent acquisition. That is, (2.22) holds when μ is very high. Furthermore, Panel (b) shows that as the expected growth rate increases further, the follower devotes more investment capacity to yield improvement in technology rather than "invent around" the existing one, and there are two reasons for this result. First, for given p, the leader is more willing to accuse the follower of infringement as the market becomes more profitable, and thus the follower focuses on developing his own technology so as not to provoke a lawsuit that can possibly lead to a ban on his production. Recall that p is endogenously determined by (2.4), and that it decreases as more capacity of the subsequent investment is devoted to yield improvement in technology. Second, if the market is lucrative enough, the follower has stronger incentive to develop the technology of which novelty can only be found in his product in order to raise monopoly revenue from it, rather than sharing profits from the old-fashioned technology with precursor.

We can also comprehend these results from the perspective of differentiated goods. If the expected growth rate of market demand is so high that the competition between the firms ends with a legal dispute, there is a distinct difference between the products manufactured by the leader and the follower unless the follower is found guilty at the court and driven out of the market. The product of the leader, who has established the foundation from which progress can be made, is behind the technology, and the follower's product is advanced in terms of the novelty of technology adopted in it unless the subsequent innovation loses its legitimacy by the ruling. Meanwhile, if the market demand is expected to grow very slowly, the advent of the first-generation technology is so delayed that the follow-on research and the reconciliation via cross licensing are triggered at the same time. This implies that the features of the products in the market converge upon each other, leaving little difference between them from the very beginning. This is consistent with what we can observe in the real world. There are a number of differentiated goods in the burgeoning market, while the products become similar with each other when the market loses its momentum in its growth.

To facilitate better understanding, let us take an example of the market of smartphones again. A few years ago, the market started growing rapidly, and the giant IT firms such as Apple and Samsung manufactured their smartphones with distinctly different features. Furthermore, they used to accuse each other of infringement, even regarding the design of software, leading to a year-long patent war. As the growth of the market becomes slower, however, they chose to settle the ongoing lawsuits and began taking advantage of the features of each other's products, flooding the market with similar products in terms of size, design, hardward, and even software embedded in them. We can observe the similar tendency in the market of tablet PCs, where demand has grown rapidly in the wake of smartphones. From these observations, we can easily expect that the same sequence of events will occur in the market of smart wearables in which the demand is about to explode in the very near future.

The present model effectively integrates price-elasticity into the timing of investment, its capacity, and the resolution of conflict. Thus, it is worth investigating the comparative statics with regard to the price elasticity.



(a) The level of triggers for each event

(b) The investment capacities of the leader and the follower

Figure 2: The comparative statics regarding the price elasticity of the first-generation technology

Figure 2 presents the comparative statics with regard to η_1, the price elasticity of the first-generation technology developed by the leader. Panel (a) shows that when the demand on the first-generation technology is very inelastic, they fail to reach an agreement of cross licensing. Intuitively, when customers are willing to pay a high price regarding the first-generation technology, the leader has strong bargaining power in the negotiation, and thus claims a large share in the market of the second-generation technology, which makes the agreement of cross licensing less likely to be reached. As it becomes more price-elastic, the follower reduces his resources devoted to imitate the first-generation technology from which less revenue is expected to be made, and this leads to the downward slope of Q_1^F (Panels (b)). Note that the competition with the follower in the market makes the leader defer his investment until the market becomes mature.

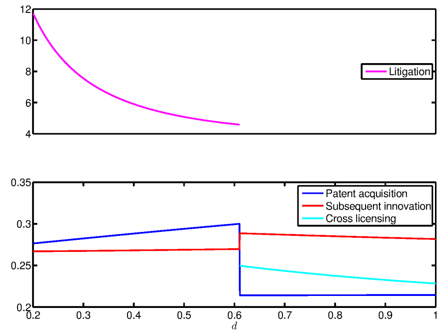
After η_1 exceeds a certain level, however, the firms succeed in resolving the problem without a legal dispute because the leader requires less share in the market of the second-generation technology. The follow-on research is delayed significantly so that the cross licensing is triggered simultaneously, while the initial innovation is made individually. Furthermore, as we can see from Panel (b), the follower curtails his investment devoted to enhancing the technology significantly and rather chooses to invent around the old technology at a lower cost because he is no longer afraid of a lawsuit over infringement.

If the price elasticity regarding the first-generation technology increases further, the follower reduces the capacity of the first-generation technology and raises that of the second-generation technology. This is a natural result because the investment in the first-generation technology becomes less attractive, yielding less profits and raising the possibility of being driven out of the market. In contrast, the leader reduces the investment capacities in both technologies. The decrease of investment in the first-generation technology is obvious, and that in the second-generation technology results from the fact that the leader has less bargaining power in the negotiation of cross licensing as the investment in the basic technology becomes less attractive.

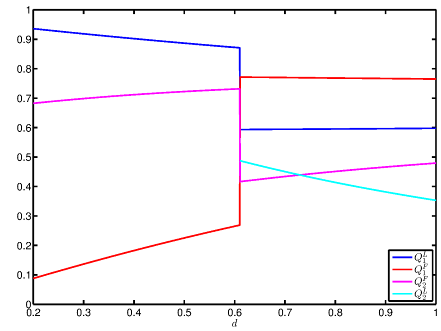
In this subsection, we have examined the impact of market demand on the way the stakeholders resolve the conflict from various perspectives; its expected growth rate and the consumer's willingness to pay a high price. The bottom line was that the more lucrative the market is, the more the competitors are likely to go to court, and this finding is consistent with the argument of a number of previous studies. For instance, Cooter and Rubinfeld (1989) delineated key determinants of legal disputes among the firms and argued that the probability of litigation rises in the size of the stakes. Lemley and Shapiro (2005) also noted that the patents involved in a lawsuit are those that are commercially important enough to endure the costs of litigation. Empirical studies carried out by Lanjouw and Schankerman (2001) showed that more "valuable" patents tend to involve a lawsuit with much higher probability, and Somaya (2003) also provided empirical evidence showing that the lawsuits are less likely to be settled if the stakeholders have large stakes in the litigated patent.

3.3 Patent system and welfare analysis

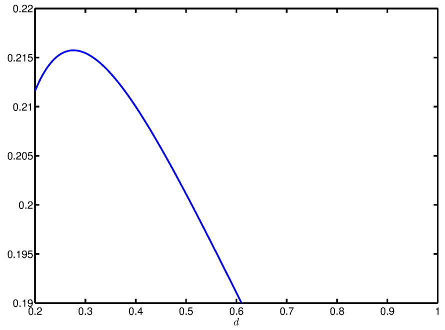
One of the most significant features of the present model is that it endogenously determines how much the subsequent innovation overlaps with the existing technology and how much improvement is made from it. This feature draws on the assumption that the probability of the existing patent found to be valid by the court depends on the degree of overlapping and improvement, and thus the follower takes this into account in deciding how his resources will be allocated in the follow-on research in order to maximize his expected profits. Yet, there is still a room for discretion by the court represented by d, except for the extreme cases in which there is no imitation or no novelty (i.e., $Q_1^F = 0$ or $Q_2^F = 0$), and it can be read as the authorities' patent policy, that is, the extent to which the scope of patent is applied. It is of special interest how



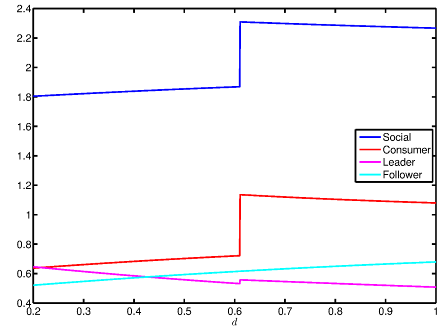
(a) The level of triggers for each event



(b) The investment capacities of the leader and the follower



(c) The probability that the patent is found to be valid at the court



(d) Total expected surplus of each agent and social welfare

Figure 3: The comparative statics regarding the extent to which the patent scope is interpreted for the base case

the policy on patent rights affects the firms' investment timing, their capacities, the way they resolve the conflict, and thus the level of social welfare. Figure 3 represents the comparative statics with regard to d.

We can see from Panel (a) that when the scope of patent is interpreted in a very narrow sense so that its validity is acknowledged in a very limited case (i.e., when d is very high), the stakeholders resolve the conflict via cross licensing. This is a natural result because the leader is less likely to win the case over infringement, and thus he rather opts for cross licensing to raise extra revenues, even with a small market share as described in Panel (b). This can be read in the context of Aoki and Hu (1999), which showed that a patentee may decide to license the technology to prevent imitation if the legal costs and probability of winning make the patentee unable to credibly threaten the challenger with a lawsuit. Note that given the leader's willingness to take advantage of the second-generation technology, the follower delays his investment significantly until the market grows enough to reward the losses of revenue from the competition, and thus the follow-on research and the agreement of cross licensing are triggered at the same time.

As the breadth of patent becomes wider (i.e., as d decreases), the leader holds a more dominant position in the negotiation of cross licensing, and this is represented by the increase of Q_2^L and the decrease of Q_2^F in Panel (b). When d decreases further and falls below a certain level, the leader chooses to accuse the follower, encouraged by the judge's hard line against patent infringement. Panel (c) shows that as d decreases, the probability that the patentee wins the case increases for a while, which is a natural result. When d gets much lower, however, p has a tendency to decrease because the follower reduces Q_1^F at a more rapid rate than Q_2^F. That is, when the patent protection is so strong that alledged infringement is found guilty even with little imitation of the patented technology, the follower devotes most of his resources to develop his own technology. This leads to the increase of litigation trigger described in Panel (a).

Furthermore, Panel (a) shows that if the patent scope is wide enough (i.e., d is low enough) to induce the leader to choose a lawsuit over cross licensing, the advent of the basic technology is so delayed that it triggers the subsequent innovation at the same time because of the expected losses of revenue from the follower's challenge, while the legal dispute is triggered separately. This is in sharp constrast with the case in which both parties agree on the cross licensing due to the weak protection of patent rights (i.e., high value of d). Recall that, in that case, it is the follow-on research that is delayed significantly so that both parties begin to take advantage of the advanced technology at the same time, while the initial innovation is carried out without triggering any other events. This can be read in the view of the erosion of monopoly profits and the firms' response to it. In the former case, it is the leader of which monopoly revenue is threatened by the competitor's challenge, and thus the leader delays his investment until the demand grows enough. In the latter case, however, now it is the follower of which monopoly profit from his own technology is expected to be eroded by the competitor, and thus the follower defers the subsequent innovation until the market becomes mature. This result has significant implication from the perspective of public policy and social welfare. It implies that the policy on patent scope cannot yield the first-best result in terms of the pace of technological progress. This is in line with Scotchmer (1991) and Green and Scotchmer (1995), who have shown that, under appropriate assumptions, it is impossible for both the initial innovator and the follow-on innovator to have adequate incentives under a patent system.

The timing of the advent of technologies, however, is not the only determinant in the estimation of social welfare. That is, we need to take into account other aspects of the change in the market as well in order to evaluate social welfare in a more accurate way. After a tedious algebra, we can evaluate consumer surplus, producer surplus, and social welfare. We omit them here, and they can be found in the original paper of Jeon (2015).

Panel (d) of Figure 3 depicts welfare analysis regarding the patent policy represented by d. By comparing with Panel (a), we can easily see that consumer surplus and social welfare are much higher when the dispute is resolved via cross licensing, and this is because it does not involve legal costs and there are many more products with novel technology at much lower prices. This finding is in line with Shapiro (2001), who argued that a royalty-free cross license is the first-best result from the perspective of competition and that any cross license is superior to a world in which the stakeholders fail to cooperate. U.S. Department of Justice and the Federal Trade Commission (1995) also shed light on the procompetitive features of cross licensing, noting that it helps the firms to integrate complementary technologies by clearing blocking positions and to ease the burden of transaction costs and legal expenses. Denicolò (2002) addressed that collusion between successive patentees through cross-licensing agreements might be socially beneficial under circumstances much less limited than in Chang (1995), which provided only limited support for the permission on collusion, even if the patents are competing rather than complementary or blocking.

Given these results, one might conclude that the narrower the patent scope is, the more social welfare we can yield. Yet, we can see from Panel (d) that after d exceeds a certain level at which the firms agree on cross licensing, consumer surplus and social welfare gradually decrease as d increases further, that is, as the scope of patent becomes even narrower. At a glance, this might seem unnatural because they do not go to the court in which d directly matters. However, d still comes into play if the agreement of cross licensing is made based on the leader's second-best capacity, which makes the follower indifferent between litigation and cross licensing. Namely, when d is relatively low yet still in the range that ensures the agreement of cross licensing, the patent is interpreted in a relatively wide sense and the leader has more bargaining power in the negotiation, which enables him to raise investment capacity regarding the second-generation technology. We can observe from Panel (b) that as d increases further, Q_2^L decreases at a more rapid rate than the increase of Q_2^F, and this is because the follower has an incentive to manufacture fewer products to keep the price as high as possible. If d is very high and the patent can maintain its validity only in a very limited case, however, the follower, who is aware of this, requires more rewards to accept the offer of cross licensing, which leads to less products with the advanced technology at a higher price. Thus, we can claim that the authorities' stance against infringement still matters even if the dispute is resolved out of court and that the narrow interpretation of patent rights to induce the agreement of cross licensing does not always guarantee the improvement of social welfare.

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