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Licensing Contract and Patent Policies in Vertically Separated Market[1]

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1 Introduction

In this paper, we examine the license contract problem in vertically separated market and investigate the effects of patent policies on social welfare based on dynamic investment timing model. Namely, a non-producing patent holder and a manufacturing firm bargain over the terms of license contract, and the government affects the outcome of the bargaining via two channels of patent policies: probabilistic validity of patents and penalty upon infringement. If the manufacturer makes use of the technology without a license contract, the patentee files a lawsuit upon infringement. The alleged infringer is enforced to pay penalties once found guilty, but the patent can rather be invalidated by the court's ruling. The firms decide the timing of investment and the terms of license contract while taking probabilistic patents and damages upon infringement into account.

First of all, our model clarifies the hold-up problem inherent in the license contract. Since the market is vertically separated by the inventor and its practical user, we need both parties to have new technology applied to the products. Yet, their incentives to make the investment are hardly matched, and thus, a hold-up exists in the introduction of new technology due to the misalignment of incentives in most cases. Namely, the investment can be delayed significantly by the patentee even though the licensee wants to make the investment earlier, and vice versa. The hold-up problem in vertically separated markets is in line with Schankerman and Scotchmer (2001) and Shapiro (2010), and we can further clarify this in terms of the timing of investment in virtue of the dynamic model.

The model also shows that strong patent rights can rather harm the patent holder's interests. If the protection of patent rights is excessive, that is, if it is highly probable that the court finds the alleged infringer guilty and levies a heavy punishment on him, the patent holder can raise royalties by exercising more leverage over the bargaining. Given the higher royalties, the manufacturer will be less willing to make products and will delay the timing of the license contract from which the patentee's revenue is raised. In the end, strong patent protection leads to a decrease in the patentee's expected profits, which is in line with Shapiro (2008) who claimed that efficiency is not a monotone function of the rewards provided to patentees. This result

[1]This paper is abbreviated version of Jeon and Nishihara (2016), and was supported by the JSPS KAKENHI (Grant number JP26350424, JP26285071).

implies that what the court does in favor of the patent holder does not always guarantee the improvement of his interests.

Furthermore, we derive the optimal patent policies that maximize social welfare by aligning both parties' incentives to make an investment. The optimal policies make the firms in vertically separated markets invest as if they were vertically integrated, and we can effectively resolve the hold-up problem and eliminate the inherent inefficiency in the market. They are optimal in that not only is the total amount of wealth in society maximized but also the wealth is allocated to the firms in accordance with their contribution to the introduction of new technology, which coincides with the direction of desirable patent reform suggested by Shapiro (2008). It can also be shown that we can always yield the first-best result by means of the optimal policies because the two patent instruments can always complement one another when one of them becomes infeasible.

We also discuss the implications of our model for the direction of patent reform in virtue of a general framework that embraces different types of damages regimes and a full range of probabilistic validity. The model clarifies that an ironclad patent is not optimal as a patent policy in that it might not be able to yield the first-best result in terms of social welfare. From the perspective of the damages regime, it shows that reasonable royalties, the royalties that would have been negotiated initially in the presence of patents with a certain validity, might not be enough to compensate the non-producing patentee in a vertically separated market. In contrast, it can be shown that the application of the entire market value rule to reasonable royalties, which is equivalent to the doctrine of the unjust enrichment rule in the present model, can always achieve the first-best result. This finding supports the direction of patent reform currently under discussion in the U.S. Congress.

2 The model and solutions

2.1 Setup

Suppose there are two risk-neutral firms in the market. One of them is a technology-intensive firm and carries out R&D investment to develop new technology. The investment incurs cost c_P and the firm's novel technology can be protected from possible infringement by patent rights. For simplicity, we suppose the patent is issued instantly after its application. The patent holder, however, cannot commercialize its own technology; namely, it is a non-producing patentee. Thus, the only source of its revenue is a license fee only if the license contract is made after the development of the technology.

Meanwhile, the other firm is rather capital-intensive and is not able to develop its own technology. Yet, it can manufacture products based on newly developed technology only if it has been invented by other firms. From the perspective of real options, the development of new technology and its application to manufacturing can be read as the exercise of a jointly held real option. In the parlance of industrial organization, the market is vertically separated by upstream and downstream firms that can invent technology and utilize it, respectively. The commercialization incurs cost c_L, and the downstream firm also has to pay a license fee to the patentee to make use of the technology. Otherwise, the patentee will file a lawsuit over infringement, which can possibly impose the downstream firm a heavy penalty. For simplicity, we assume there is no litigation cost to ensure the instantaneous lawsuit triggered by the patentee. By manufacturing the products, the downstream firm makes profit flows X_t 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 denote constant coefficients of drift and volatility, respectively, and $(W_t)_{t\geq 0}$ is a standard Brownian motion on a filtered probability space $(\Omega, \mathcal{F}, \mathbb{F} := (\mathcal{F}_t)_{t\geq 0}, \mathbb{P})$ satisfying the usual conditions. A risk-free rate is given as a constant $r > \mu$ to ensure the finiteness of the value functions.

Patent rights, however, are not ironclad. If the downstream firm makes use of the technology without a license contract, the upstream firm will accuse the downstream firm of infringement in expectation of punishment for the infringer. Yet, the patent can rather be found invalid by the court's ruling, after which it is named a "probabilistic patent." Namely, the patent holder wins the trial with probability p and is compensated by a penalty paid by the defendant.[2] The penalty is assumed to be proportional to the market demand x and is denoted by δx where a positive constant δ stands for the stringency of punishment upon infringement. Furthermore, the downstream firm has no choice but to pay royalties from then on in order to utilize the technology with valid patent; that is, the license contract becomes mandatory once the validity of the patent is verified by the court. With probability $1-p$, however, the patent turns out to be invalid and the technology can be used by the downstream firm freely. For simplicity, we assume the ruling is made instantly after the submission of a petition.

In spite of the probabilistic validity of patents, it is the threat to file a lawsuit that makes a (non-binding) license contract feasible and eventually makes the patentee raise revenue from it without patent litigation. In other words, patent litigation plays the role of setting the threat point of bargaining over the license royalties.[3] The licensee's bargaining power over the contract is denoted by $\beta \in [0, 1]$. Given the agreement of both parties, a fraction $\theta \in [0, 1]$ of the licensee's profits is transferred to the patentee as royalties thereafter. For simplicity, we also assume the contract is made instantly if both parties reach an agreement.

2.2 Model & Solution

Suppose the firms make the decision about investment timing first and about the sharing rule later. By backward induction, we analyze the bargaining over license contract first and move on to the investment timing decision later. Suppose the upstream firm has developed new technology and the downstream firm makes products based on it. The expected profits from the market are

[2] Llobet (2003) and Jeon (2016) investigated firms' R&D races and endogenized the probabilistic validity of patents by incorporating the degree of improvement of follow-on research.

[3] Schankerman and Scotchmer (2001) also assumed that infringement never occurs in equilibrium and the only role of damages and injunctions is to set threat points for negotiating licenses.

as follows:

$$\Pi(x) := \mathbb{E}\Big[\int_t^{\infty} e^{-r(s-t)} X_s ds \Big| X_t = x\Big] = \frac{x}{r-\mu} \tag{2.2}$$

If the bargaining over a (non-binding) license contract fails, the upstream firm will accuse the downstream firm of infringement. The patentee wins the trial with probability p, and not only is it compensated by the penalty δx but also it can raise revenue from a mandatory license contract thereafter. It is straightforward to show that the per-unit royalties from the mandatory one is β. The patent, however, turns out to be invalid by the court's ruling with probability $1-p$ and the downstream firm can utilize the technology freely. Thus, Nash bargaining over the license contract given the demand shock x can be written as follows:

$$\max_{\theta} \Big[(1-\theta)\Pi(x) - \Big[p\big\{-\delta x + \beta\Pi(x)\big\} + (1-p)\Pi(x)\Big]\Big]^{\beta} \Big[\theta\Pi(x) - p\Big\{\delta x + (1-\beta)\Pi(x)\Big\}\Big]^{1-\beta} \tag{2.3}$$

By solving this problem, we can obtain the portion of profits that will be transferred from the licensee to the patentee upon the license contract as follows:

$$\theta^* = p\big\{\delta(r-\mu) + (1-\beta)\big\} \tag{2.4}$$

The authorities have to choose a mix of the two patent instruments (i.e., p and δ) such that $\theta^*(p,\delta) \in [0,1]$ holds (a detailed discussion will be provided in the following section). Note that (2.4) does not depend on the market demand x. In other words, the sharing rule of profits is chosen as (2.4) regardless of the timing of the license contract, and the following inequalities hold with regard to it:

$$\frac{\partial\theta^*}{\partial p} = \delta(r-\mu) + (1-\beta) > 0 \tag{2.5}$$

$$\frac{\partial\theta^*}{\partial\delta} = p(r-\mu) > 0 \tag{2.6}$$

$$\frac{\partial\theta^*}{\partial\beta} = -p < 0 \tag{2.7}$$

$$\frac{\partial\theta^*}{\partial\mu} = -p\delta < 0 \tag{2.8}$$

Namely, the more the patent is likely to be found valid at the court and the higher the penalty upon infringement is, the more the licensee has to pay as royalties. It is also natural that the more bargaining power the licensee has, the less it has to pay. If the market demand is expected to grow fast, the per-unit royalties decrease since enough will be given to the patentee even when the per-unit royalties are relatively low.

Given the royalties from the license contract, we shall now discuss the licensee's investment decision. Suppose the new technology has been developed by the patentee and the licensee has the option to take advantage of it in order to make products paying the royalties at the rate of θ^* given by (2.4). It is well-known from real options theory that the firm's option value, $v(x)$, satisfies the following ordinary differential equation:

$$rv = \mu x\frac{\mathrm{d}v}{\mathrm{d}x} + \frac{1}{2}\sigma^2 x^2 \frac{\mathrm{d}^2 v}{\mathrm{d}x^2} \tag{2.9}$$

of which the solution takes the form as follows:

$$v(x) = Ax^{\alpha} + Bx^{\gamma} \tag{2.10}$$

where

$$\alpha = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} > 1, \qquad \gamma = \frac{1}{2} - \frac{\mu}{\sigma^2} - \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} < 0 \tag{2.11}$$

Note that $v(0) = 0$ holds in the present setup. Thus, we can derive the licensee's value function by value matching and smooth pasting conditions as follows:

$$\begin{aligned} V_L(x) &= \Big[(1-\theta^*)\Pi(x_L) - c_L\Big]\left(\frac{x}{x_L}\right)^{\alpha} \\ &= \Big[\Big(1 - p\{\delta(r-\mu) + (1-\beta)\}\Big)\Pi(x_L) - c_L\Big]\left(\frac{x}{x_L}\right)^{\alpha} \end{aligned} \tag{2.12}$$

where

$$x_L = \frac{\alpha(r-\mu)c_L}{(\alpha-1)[1 - p\{\delta(r-\mu) + (1-\beta)\}]} \tag{2.13}$$

is the licensee's investment trigger. Namely, the licensee commercializes the new technology as soon as the demand shock $X(t)$ hits the trigger x_L from below. Note that the following inequalities hold with regard to the investment trigger x_L:

$$\frac{\partial x_L}{\partial p} = \frac{\alpha(r-\mu)c_L\{\delta(r-\mu) + (1-\beta)\}}{(\alpha-1)[1 - p\{\delta(r-\mu) + (1-\beta)\}]^2} > 0 \tag{2.14}$$

$$\frac{\partial x_L}{\partial \delta} = \frac{\alpha(r-\mu)c_L p(r-\mu)}{(\alpha-1)[1 - p\{\delta(r-\mu) + (1-\beta)\}]^2} > 0 \tag{2.15}$$

$$\frac{\partial x_L}{\partial \beta} = -\frac{\alpha(r-\mu)c_L p}{(\alpha-1)[1 - p\{\delta(r-\mu) + (1-\beta)\}]^2} < 0 \tag{2.16}$$

$$\frac{\partial x_L}{\partial c_L} = \frac{\alpha(r-\mu)}{(\alpha-1)[1 - p\{\delta(r-\mu) + (1-\beta)\}]} > 0 \tag{2.17}$$

Namely, the more the court is in favor of the patent holder's rights, the less the licensee is willing to commercialize the patented technology. It is also obvious that the more bargaining power the licensee has, the more it is willing to make the license contract. It is needless to say that higher commercialization costs deter the timing of investment.

Now we shall proceed to the patentee's R&D investment decision. Suppose the market is so mature that the downstream firm is about to commercialize the new technology as soon as the upstream firm invents it. Following the same argument, the patentee's value function can be evaluated as follows:

$$\begin{aligned} V_P(x) &= \Big[\theta^*\Pi(x_P) - c_P\Big]\left(\frac{x}{x_P}\right)^{\alpha} \\ &= \Big[p\{\delta(r-\mu) + (1-\beta)\}\Pi(x_P) - c_P\Big]\left(\frac{x}{x_P}\right)^{\alpha} \end{aligned} \tag{2.18}$$

where

$$x_P = \frac{\alpha(r-\mu)c_P}{(\alpha-1)p\{\delta(r-\mu) + (1-\beta)\}} \tag{2.19}$$

is the patentee's investment trigger. Namely, the upstream firm carries out R&D investment as soon as $X(t)$ hits x_P from below. Note that the following inequalities hold with regard to the investment trigger x_P:

$$\frac{\partial x_P}{\partial p} = -\frac{\alpha(r-\mu)c_P}{(\alpha-1)p^2\{\delta(r-\mu)+(1-\beta)\}} < 0 \tag{2.20}$$

$$\frac{\partial x_P}{\partial \delta} = -\frac{\alpha(r-\mu)^2 c_P}{(\alpha-1)p\{\delta(r-\mu)+(1-\beta)\}^2} < 0 \tag{2.21}$$

$$\frac{\partial x_P}{\partial \beta} = \frac{\alpha(r-\mu)c_P}{(\alpha-1)p\{\delta(r-\mu)+(1-\beta)\}^2} > 0 \tag{2.22}$$

$$\frac{\partial x_P}{\partial c_P} = \frac{\alpha(r-\mu)}{(\alpha-1)p\{\delta(r-\mu)+(1-\beta)\}} > 0 \tag{2.23}$$

The similar arguments hold for (2.20) through (2.23) as those from (2.14) through (2.17) and we omit the illustration to avoid repetition of the same words.

Meanwhile, the value function in (2.18) drew on the assumption of $x_L < x_P$. That is, we have implicitly assumed that the downstream firm's incentive to commercialize the technology is stronger than the upstream firm's willingness to develop it. In this case, both the R&D investment and its commercialization are triggered simultaneously when the demand shock hits x_P. Even though the licensee wants to make products at x_L, it can only do so after the demand shock exceeds x_P because it is the upstream firm that invents the technology and the downstream firm cannot force him to invest earlier than that.

Yet, this might not be the case. That is, $x_P \leq x_L$ can also hold; the upstream firm wants to invent new technology and get royalties from the licensee contract earlier but the downstream firm wants to manufacture later. If this is the case, even though the upstream firm carries out R&D investment and acquires the patent when the demand shock hits x_P, it can only raise revenue after it exceeds x_L because it cannot force the downstream firm to commercialize it earlier than that. Thus, the patentee's value function is given by

$$\sup_{\bar{x_P} \leq x_L} \left[\theta^* \Pi(x_L)\left(\frac{\bar{x_P}}{x_L}\right)^\alpha - c_P\right]\left(\frac{x}{\bar{x_P}}\right)^\alpha \tag{2.24}$$

which can be rearranged as follows:

$$\sup_{\bar{x_P} \leq x_L} \theta^* \Pi(x_L)\left(\frac{x}{x_L}\right)^\alpha - c_P\left(\frac{x}{\bar{x_P}}\right)^\alpha \tag{2.25}$$

Since the objective function in (2.25) monotonically increases in $\bar{x_P}$, the trigger of R&D investment is chosen as $\bar{x_P} = x_L$ with x_L given by (2.13). Intuitively speaking, the upstream firm will delay its investment until the downstream firm is willing to make the license contract because it earns nothing even if it acquires the patent earlier than that.

The same argument holds with regard to the licensee's value function in (2.12). Thus, the value functions of both parties can be summarized as follows:

$$V_L(x) = \left[(1-\theta^*)\Pi(x^*) - c_L\right]\left(\frac{x}{x^*}\right)^\alpha \tag{2.26}$$

$$V_P(x) = \left[\theta^* \Pi(x^*) - c_P\right]\left(\frac{x}{x^*}\right)^\alpha \tag{2.27}$$

where $x^* := \max\{x_L, x_P\}$ with x_L and x_P given by (2.13) and (2.19), respectively. Given these results, we can evaluated the level of social welfare as the sum of them:

$$V_S(x) = \Big[\Pi(x^*) - c_L - c_P\Big]\Big(\frac{x}{x^*}\Big)^\alpha \tag{2.28}$$

Following the standard argument from real options, one can easily show that social welfare is maximized when the investment is triggered at x_S given by

$$x_S = \frac{\alpha(r-\mu)(c_L + c_P)}{\alpha - 1} \tag{2.29}$$

One can see that social welfare is maximized when the jointly held real option is exercised as if it were held by a single firm. Namely, social welfare improves when the firms in a vertically separated market are integrated. We can also see that (2.29) depends on neither p nor δ. This is because the patent policies come into play via bargaining over the license contract, which is irrelevant to the investment decision of the integrated firm. In other words, it is neither the provisions of the license contract nor the penalty upon infringement but the timing of the actual investment that matters to social welfare.

3 Comparative statics and discussion

3.1 Parameters

In this section, we carry out comparative statics with benchmark parameters given as follows:

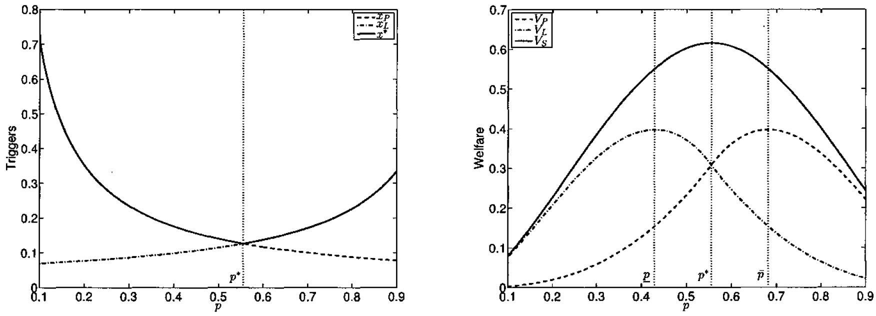
$$\begin{aligned} &r = 0.05; \quad \mu = 0.01; \quad \sigma = 0.1; \quad \beta = 0.5; \\ &c_P = 1; \quad c_L = 1; \quad p = 0.5; \quad \delta = 10; \quad x = 0.1 \end{aligned}$$

Namely, we suppose that the firms are symmetric in terms of the structure of investment costs and their bargaining power. The patent is assumed to have 50% chances of being found valid by the court's ruling taking empirical evidence into account.[4] The stringency of punishment over infringement is chosen at our discretion. The market is expected to grow slowly, in which cases the protection of patent rights needs meticulous care. The initial demand shock is chosen as low enough not to trigger the investment instantly in the range of our analysis.

3.2 The effects of patent policy on investment decision

The probabilistic feature of patent rights plays a pivotal role in our model, and thus it is natural to start off with the analysis of the probability denoted by p.

[4]Allison and Lemley (1998) and Moore (2000) carried out empirical analysis of patent litigation and found that a roughly half of litigated patents are invalidated by the court's ruling.



(a) The level of triggers w.r.t. p (b) Welfare analysis w.r.t. p

Figure 1: Comparative statics with respect to the stochasticity of patent's validity

Panel (a) of Figure 1 shows the level of investment triggers for both parties. As explained earlier, x_L and x_P are the triggers provided that the other party is willing to carry out its own investment, and the actual investment of both R&D and its commercialization is triggered at the same time when the demand shock hits $x^* = \max(x_L, x_P)$.

We can clearly see the discrepancy between x_L and x_P from Panel (a) except for a single point p^* at which $x_L = x_P$ holds. That is, as shown by (2.14) and (2.20), x_L and x_P monotonically increases and decreases in p, respectively, and intersects at p^*. This result clarifies the misalignment of incentives of the firms in vertically separated markets. For $p < p^*$, the downstream firm wants to manufacture products when the demand shock hits x_L but the upstream firm is not willing to carry out R&D investment at that time. This is because it is less likely to win the trial, which will lead to lower royalties for the license contract as shown by (2.5). Thus, the actual investment of both parties is delayed until the demand shock reaches x_P.

For $p > p^*$, however, now it is the downstream firm that deters the development of new technology. The patentee is protected by strong patent rights and is willing to invent new technology when the demand shock hits x_P. Yet, it eventually chooses to delay the investment until it reaches x_L because it would have earned nothing until then even if it invested earlier than that. This result reveals the hold-up problem inherent in the license contract problem, which has been pointed out in previous studies such as Schankerman and Scotchmer (2001) and Shapiro (2010). In other words, when the market is vertically separated by the developer of technology and its practical user, there exists the underinvestment problem in the market unless p^* is chosen so that x_P coincides with x_L.

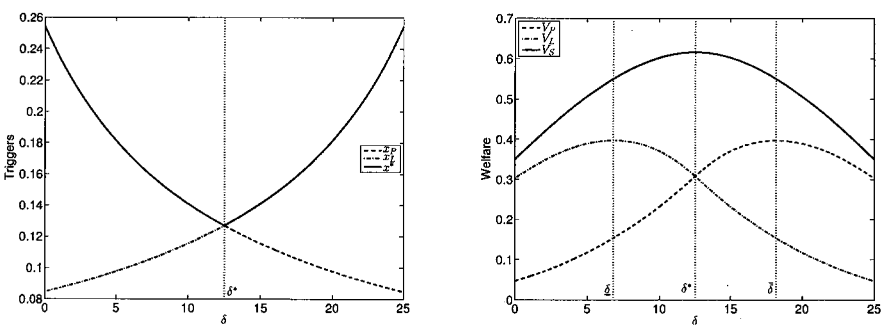
Panel (b) of Figure 1 presents the welfare analysis with respect to p. First of all, we can see that the level of p at which the patentee's surplus is maximized, denoted by $\bar{p}$, differs from that at which the licensee's surplus takes the highest value, denoted by $\underline{p}$; $\bar{p}$ is much higher than $\underline{p}$. This is obvious because the policy on patent rights affects the firms with different roles in a different way and the patentee is the beneficiary of a strong patent policy.

Furthermore, we can see that the patentee's surplus does not monotonically increase in p. This result is of special interest in that it implies that strengthening patent rights can rather harm the patent holder's interests. The timing of R&D investment from which the patentee's revenue is raised depends not only on the patentee's willingness to invest but also on that of the licensee (i.e., the actual investment is triggered at $x^* = \max(x_L, x_P)$). Even though the royalties the patentee will receive from the license contract increase in p, the timing of the closure of the deal from which it starts to raise the revenue is delayed after p exceeds p^*, which leads to a decrease in the patentee's surplus in the end. This result can be read in the context of Schankerman and Scotchmer (2001) who claimed that a failure to deter infringement might benefit the patent holder since both parties' profits will come from selling a proprietary product that the new technology will facilitate. It is also consistent with Shapiro (2008) who asserted that efficiency is not a monotone function of the rewards provided to patent holders and that excessive rewards can rather reduce efficiency and stifle innovation.

The similar arguments hold with regard to the impact of p on the licensee's surplus. When p is sufficiently low, its increase raises the licensee's expected profits by putting the timing of the actual investment forward, which has been delayed by the patentee. After it exceeds a certain level, however, the losses from higher royalties dominate the benefits from earlier investment and eventually lead to a decrease in the firm's surplus, even though it makes the investment at its best in terms of its timing (i.e., $x^* = x_L$) after p exceeds p^*.

From the perspective of social welfare, one can see that the total wealth in society is highest when p is chosen as p^* so that x^* takes the lowest value (recall that $x^* = \max\{x_L, x_P\}$ is minimized when x_L coincides with x_P because of (2.14) and (2.20)). This result can also be construed from the view point of consumer welfare in that social welfare is maximized when the new technology is introduced at the earliest time.

The penalty for infringement is another main axis of patent policies. The defendant is supposed to pay the penalty in proportion to the market demand (i.e., δx) when found guilty. Even though the penalty is not levied upon the downstream firm in practice, it comes into play as the patentee's leverage upon the license bargaining. Thus, we need to investigate the impact of δ, the stringency of punishment for infringement.



(a) The level of triggers w.r.t. δ

(b) Welfare analysis w.r.t. δ

Figure 2: Comparative statics with respect to the stringency of punishment upon infringement

First of all, we can verify the hold-up problem in vertically separated markets by examining the discrepancy between x_L and x_P in Panel (a) of Figure 2. As shown by (2.15) and (2.21), x_L and x_P monotonically increases and decreases in δ, respectively, and they intersect at a single point δ^* defined by δ at which $x_L = x_P$ holds. It is evident that the licensee wants to delay his investment as the penalty for infringement, which is directly linked to the royalties as shown by (2.6), increases. In contrast, the patent holder is willing to develop new technology earlier as the penalty rises since it is the beneficiary of it.

Yet, we need to recall that x_L and x_P are the investment triggers provided that the other party is willing to carry out its own investment and that the timing of the actual investment depends on both parties' willingness to invest. As we can see from Panel (b) of Figure 2, each firm's expected profits are not monotone with respect to δ. In particular, the patent holder's surplus starts to decrease after δ exceeds a certain level, which implies that what the court does in favor of the patentee can rather aggravate his surplus. This result is consistent with what we have discussed regarding the effect of p on the patentee's surplus.

When δ is sufficiently low, the licensee's welfare at first increases in δ because the increase in δ puts the investment timing forward, which has been delayed by the patentee. After it exceeds a certain level, however, the burden from the increase of royalties becomes significant, and now it is the licensee who yields the hold-up problem. Even though the licensee carries out the investment at its best in terms of its timing after δ exceeds δ^* (i.e., $x^* = x_L$), its surplus starts to decrease in δ because of the increase in the license fee.

The same result holds with regard to social welfare; the level of δ at which social welfare is maximized coincides with the one that makes x_L equal to x_P. Namely, social welfare improves the most when the punishment is chosen so that both parties' incentive to invest coincides and the novel technology is introduced as soon as possible.

3.3 Optimal patent policy

In the preceding subsection, we clarified the misalignment between the firms' incentive to carry out their own investment. In particular, the level of the patent policies (i.e., p and δ) at which the firms' expected profits are maximized differs from one another. Thus, it is obvious that they also differ from patent policies that maximize social welfare, the sum of both parties' surplus, which can be seen from Panel (b) of Figures 1 and 2.

As mentioned earlier, social welfare is maximized when the firms in vertically separated markets make the investment as if they were integrated. In other words, there is no inefficiency in the market when both parties' optimal investment timing coincides. In terms of the level of investment triggers, this corresponds to the case of $x_L = x_P$. Thus, we can yield the first-best result if we adopt p^* or δ^* as patent policies. By equating x_L and x_P in (2.13) and (2.19), we can derive the analytic solutions as follows:

$$p^*(\delta) = \frac{c_P}{\{\delta(r-\mu) + (1-\beta)\}(c_L + c_P)} \tag{3.1}$$

$$\delta^*(p) = \frac{1}{r-\mu}\left[\frac{c_P}{p(c_L + c_P)} - (1-\beta)\right] \tag{3.2}$$

Namely, if we choose p^* for a given δ or choose δ^* for a given p, we can effectively eliminate the inefficiency in the market without requiring the firms to be integrated in practice, which is of special interest from the perspective of industrial organization. As a matter of fact, one can easily show that $x^* = \max\{x_L, x_P\}$ in the presence of p^* or δ^* coincides with x_S in (2.29) at which social welfare is maximized. Therefore, we can call them optimal patent policies in that they yield the first-best result in terms of social welfare. The outcome of license bargaining in the presence of optimal patent policies is as follows:

$$\theta^*\big(p^*(\delta), \delta\big) = \theta^*\big(p, \delta^*(p)\big) = \frac{c_P}{c_L + c_P} \in (0, 1) \tag{3.3}$$

Namely, the per-unit royalties are the ratio of development costs to the total investment costs, which is irrevelant to their bargaining power.

To scrutinize the effects of the optimal patent policies, we first need to carry out sensitivity analysis regarding each policy. Suppose the authorities adjust the probabilistic validity of patents in accordance with the target penalty for infringement. Then, we have the following results regarding the optimal patent policy p^*:

$$\frac{\partial p^*}{\partial \delta} = -\frac{c_P(r-\mu)}{\{\delta(r-\mu) + (1-\beta)\}^2(c_L + c_P)} < 0 \tag{3.4}$$

$$\frac{\partial p^*}{\partial c_P} = \frac{c_L}{\{\delta(r-\mu) + (1-\beta)\}(c_L + c_P)^2} > 0 \tag{3.5}$$

$$\frac{\partial p^*}{\partial c_L} = -\frac{c_P}{\{\delta(r-\mu) + (1-\beta)\}(c_L + c_P)^2} < 0 \tag{3.6}$$

$$\frac{\partial p^*}{\partial \beta} = \frac{c_P}{\{\delta(r-\mu) + (1-\beta)\}^2(c_L + c_P)} > 0 \tag{3.7}$$

$$\frac{\partial p^*}{\partial \mu} = \frac{\delta c_P}{\{\delta(r-\mu) + (1-\beta)\}^2(c_L + c_P)} > 0 \tag{3.8}$$

The implications of the above results are straightforward. If the authorities want to levy higher penalties on the infringement, they have to invalidate the patents more often to compensate the licensee's willingness to invest. If it costs too much to develop new technology, more incentives need to be granted to the inventor by the court's favorable ruling so that the investment is not delayed. If its commercialization incurs a significant amount of costs, however, the court needs to apply stricter standards for verifying the validity of patents so that the investment is not delayed by the downstream firm. If the licensee holds a dominant position in the bargaining, the court needs to keep the balance between the firms by standing on the patentee's side. Lastly, the court needs to pay more attention to the protection of more profitable technology since it is easy to be infringed.

Now let us suppose that the authorities adjust the amount of penalty in accordance with the target stochasticity of patent validity. Then, we have the following results regarding the optimal patent policy δ^*:

$$\frac{\partial \delta^*}{\partial p} = -\frac{c_P}{(r-\mu)p^2(c_L + c_P)} < 0 \tag{3.9}$$

$$\frac{\partial \delta^*}{\partial c_P} = \frac{c_L}{(r-\mu)p(c_L + c_P)^2} > 0 \tag{3.10}$$

$$\frac{\partial \delta^*}{\partial c_L} = -\frac{c_P}{(r-\mu)p(c_L+c_P)^2} < 0 \tag{3.11}$$

$$\frac{\partial \delta^*}{\partial \beta} = \frac{1}{r-\mu} > 0 \tag{3.12}$$

$$\frac{\partial \delta^*}{\partial \mu} = \frac{1}{(r-\mu)^2}\left[\frac{c_P}{p(c_L+c_P)} - (1-\beta)\right] > 0 \tag{3.13}$$

The results given by (3.9) through (3.13) follow the same arguments from (3.4) through (3.8), and we omit the illustration here for brevity. Note that the sign of (3.13) is positive because δ^* given by (3.2) needs to be positive according to its definition.

Having derived the optimal patent policies p^* and δ^*, we shall now proceed to the effects of the policies on the allocation of wealth to the firms in vertically separated markets. The value fuctions of both parties in the presence of optimal patent policies can be evaluated as follows:

$$V_L^*(x) := V_L(x;p^*) = V_L(x;\delta^*) = \frac{c_L}{\alpha-1}\left[\frac{(\alpha-1)x}{\alpha(r-\mu)(c_L+c_P)}\right]^\alpha \tag{3.14}$$

$$V_P^*(x) := V_P(x;p^*) = V_P(x;\delta^*) = \frac{c_P}{\alpha-1}\left[\frac{(\alpha-1)x}{\alpha(r-\mu)(c_L+c_P)}\right]^\alpha \tag{3.15}$$

First of all, we can see that the surplus of both parties is consistent no matter what type of patent policy is adopted by the government. Namely, they are independent of p and δ once the optimal policy is enforced. Also, one can see that the sum of them coincides with (2.28) where x^* is chosen as x_S given by (2.29). This is a natural result considering how p^* and δ^* are determined. It is of special interest that the allocation of wealth is in proportion to their investment costs. In other words, both parties are compensated in accordance with their contribution to society, not according to their bargaining powers, which sheds light on the optimality of the policies in terms of the allocation of wealth. This result is in line with Shapiro (2008) who suggested the direction of desirable patent reform; economic efficiency is promoted if rewards to patent holders are aligned with and do not exceed their social contributions.[5]

The following inequalities demonstrate the result of sensitivity analysis on value functions in the presence of the optimal patent policies:

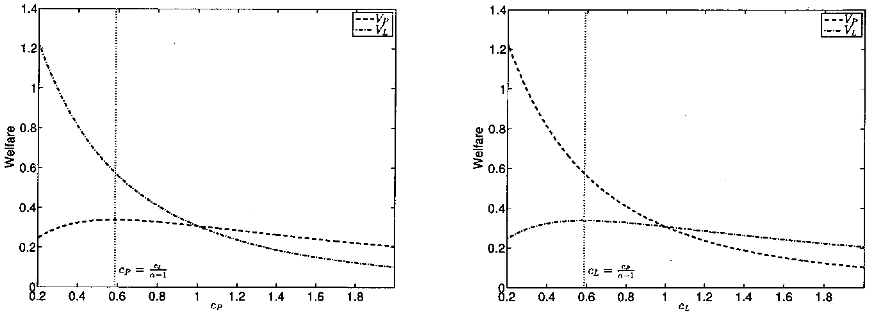
$$\frac{\partial V_L^*(x)}{\partial c_P} = -\frac{\alpha c_L}{(\alpha-1)(c_L+c_P)}\left[\frac{(\alpha-1)x}{\alpha(r-\mu)(c_L+c_P)}\right]^\alpha < 0 \tag{3.16}$$

$$\frac{\partial V_P^*(x)}{\partial c_P} = \frac{1}{\alpha-1}\left[\frac{c_L-(\alpha-1)c_P}{c_L+c_P}\right]\left[\frac{(\alpha-1)x}{\alpha(r-\mu)(c_L+c_P)}\right]^\alpha \tag{3.17}$$

$$\frac{\partial V_P^*(x)}{\partial c_L} = -\frac{\alpha c_P}{(\alpha-1)(c_L+c_P)}\left[\frac{(\alpha-1)x}{\alpha(r-\mu)(c_L+c_P)}\right]^\alpha < 0 \tag{3.18}$$

$$\frac{\partial V_L^*(x)}{\partial c_L} = \frac{1}{\alpha-1}\left[\frac{c_P-(\alpha-1)c_L}{c_L+c_P}\right]\left[\frac{(\alpha-1)x}{\alpha(r-\mu)(c_L+c_P)}\right]^\alpha \tag{3.19}$$

[5]The author defined the appropriability ratio as the ratio of the patent holder's payoff to the social contribution associated with the patent invention, which corresponds to $c_P/(c_L+c_P)$ in the present model.



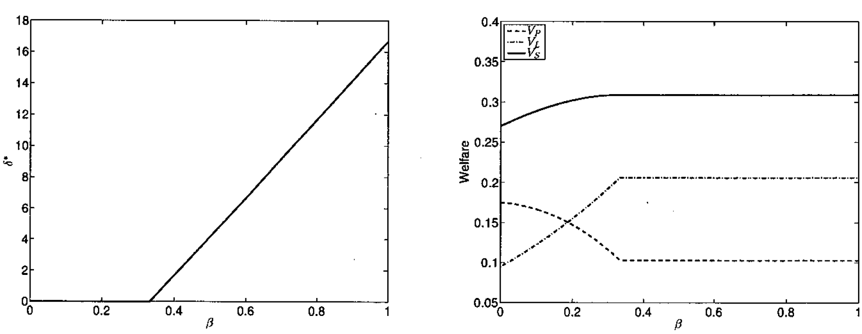
(a) Welfare analysis w.r.t. c_P

(b) Welfare analysis w.r.t. c_L

Figure 3: Comparative statics of the firms' surplus with respect to the investment costs in the presence of the optimal patent policy

It can be seen from (3.16) and (3.18) that both firms' surplus decreases as their counterparties' investment costs increase. This is because the authorities need to allocate more wealth to the one with a higher burden to incentivize it. Since the total amount of wealth also decreases in the costs, the increase of the counterparties' surplus leads to a decrease of their own surplus.

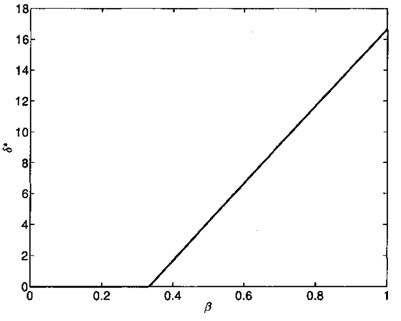
The implication of (3.17) and (3.19), however, is not as clear as that of (3.16) and (3.18). To be more specific, (3.17) is positive if $c_P/c_L < 1/(\alpha - 1)$ and is non-positive otherwise. Likewise, (3.19) is positive if $c_L/c_P < 1/(\alpha - 1)$ and is non-positive otherwise. Namely, each firm is compensated for the increment of its investment cost by the optimal policies as long as the relative cost is smaller than $1/(\alpha - 1)$. If it is larger than that, the authorities cannot afford to compensate him further for the incremental costs since the total amount of wealth also decreases. Note that $\partial\alpha/\partial\mu, \partial\alpha/\partial\sigma < 0$ holds, and thus, both parties are more likely to be compensated for their investment costs when the market is expected to grow fast and is volatile. This is a natural result because there will be more wealth to allocate when the market is more profitable.



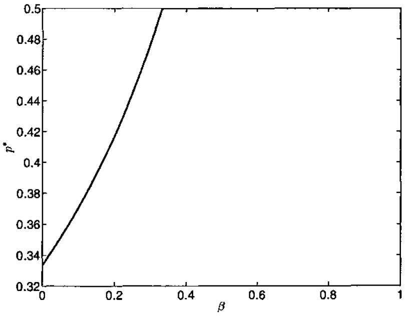
(a) The level of $\delta^*(> 0)$

(b) Welfare analysis

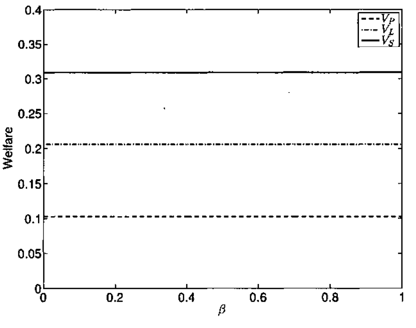
Figure 4: The infeasibility of optimal patent policy δ^* ($c_P = 1$, $c_L = 2$)



(a) The level of $\delta^*(> 0)$



(b) The level of $p^*(\in (0,1))$

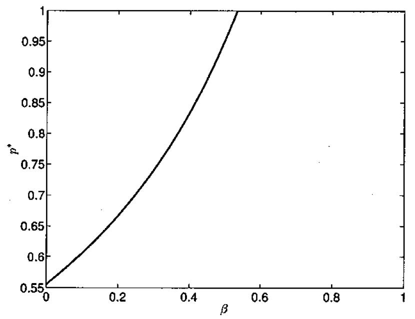


(c) Welfare analysis

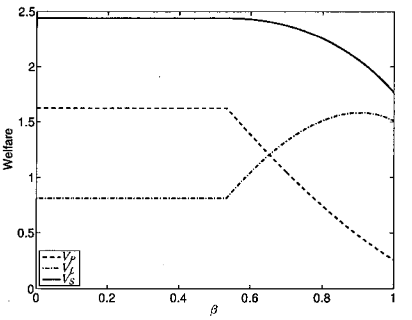
Figure 5: The optimal patent policy δ^* in the presence of a complementary policy p^*

These optimal policies, however, might not be feasible as a stand-alone policy, and this is where the two channels of policies come into play. That is, they are complementary in that both of them need to be enforced to yield the first-best result under certain circumstances. It is clear from the definition that the penalty upon infringement has to be positive, but δ^* in (3.2) can take a non-positive value if c_P is low, c_L is high, β is low, and p is high. Namely, the optimal patent policy in terms of the penalty for infringement might not be feasible when new technology is relatively easy to develop yet hard to commercialize and the patentee holds a dominant position in the license contract. We can see from Figure 4 that the level of social welfare starts to decrease when the stand-alone policy δ^* decreases and is eventually absorbed into the boundary of 0. As shown in Figure 5, however, this problem is resolved when p^* is set to work as a complementary policy. That is, the government can adopt δ^* as a main policy and utilize p^* as a complementary one when δ^* becomes infeasible.

Likewise, $p \in [0,1]$ needs to hold, but p^* in (3.1) can be larger than 1 if μ is high, c_P is high, c_L is low, β is high, and δ is low. That is, the optimal patent policy in terms of the probabilistic validity of patents might not be feasible when novel technology, the demand for which is expected to grow fast, is hard to develop yet easy to utilize and the licensee holds a dominant position over the contract. Figure 6 shows that the stand-alone policy p^* cannot yield the first-best result after it is absorbed into the boundary of 1. Yet, this problem can also be resolved when it is enforced along with the complementary policy δ^* as shown by Figure 7.

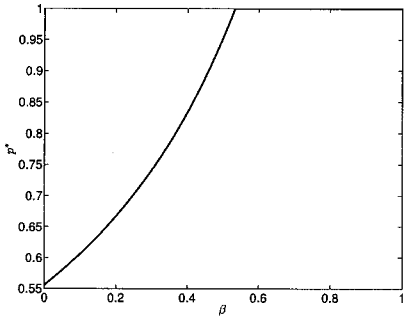


(a) The level of $p^*(\in (0,1))$

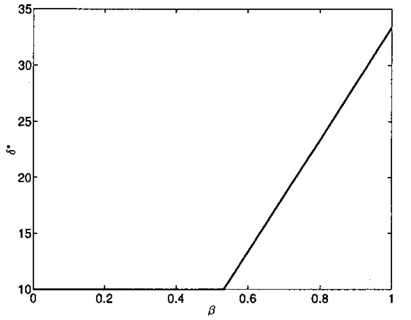


(b) Welfare analysis

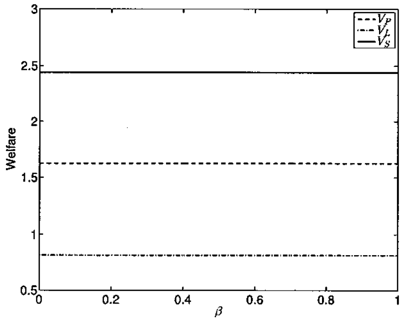
Figure 6: The infeasibility of optimal patent policy p^* ($\mu = 0.03$, $c_P = 2$, $c_L = 1$)



(a) The level of $p^*(\in (0,1))$



(b) The level of $\delta^*(> 0)$



(c) Welfare analysis

Figure 7: The optimal patent policy p^* in the presence of a complementary policy δ^*

It can easily be shown that the first-best result can always be achieved by having both policies complement one another. If δ^* is absorbed into 0 and is not feasible anymore, p^* in (3.1) is not larger than 1 as long as $c_P/(c_L + c_P) \leq 1 - \beta$ holds. This condition, however, is always satisfied since δ^* becomes non-positive when $c_P/\{p(c_L + c_P)\} \leq 1 - \beta$. Meanwhile, if p^* is absorbed into 1 and becomes infeasible, δ^* in (3.2) is positive as long as $c_P/(c_L + c_P) > 1 - \beta$ holds. This condition is always satisfied because p^* is larger than 1 when $c_P/(c_L + c_P) > \delta(r - \mu) + (1 - \beta)$. Thus, the patent policies p^* and δ^* can always complement one another to induce the first-best result regardless of the investment costs, the firms' bargaining power, and the expected growth rate of market demand.

3.4 Implications for patent reform

Many studies have called the efficiency of the patent system into question. For instance, Takalo and Kanniainen (2000), Hunt (2006), and Chu, Cozzi, and Galli (2012) have shown that the patent system can rather stifle innovation, and they have been supported by numerous examples of empirical evidence such as those of Sakakibara and Branstetter (2001), Jaffe and Lerner (2004), Qian (2007), and Lerner (2009). Given these observations, researchers have urged the reform of the patent system in various ways.[6] Having discussed the patent instruments in association with legal disputes, we will address the implications for patent system reform from this perspective.

As discussed, patent rights are inherently probabilistic and they can be invalidated by the court's ruling. Even though the criteria for both direct and indirect infringement are specified in patent law (35 U.S. Code §271), there is still room for the court's discretion on the ruling. For instance, many jurisdictions apply the doctrine of equivalents, which allows the court to hold a party liable for infringement even when the accused does not fall within the literal scope of a patent claim but is equivalent to the claimed invention.[7] From this perspective, Aoki and Hu (1999) presumed that the probability that the patent is found valid is solely determined by the extent to which the doctrine of equivalents is applied. There exist a number of previous studies that have regarded probabilistic validity as a patent strength,[8] and it is denoted by p in our model.

The present model covers a full range of stochasticity of patent validity, and the conventional view on patent rights, ironclad patents, corresponds to the case of $p = 1$. The argument in (3.2) shows that the optimal amount of penalty for ironclad patents is $\delta^* = [c_P/(c_L + c_P) - (1 - \beta)]/(r - \mu)$. Yet, this policy might not be feasible depending on the parameters. Namely, the first-best result might not be achieved in the presence of ironclad patents if the new technology is relatively easy to develop yet hard to commercialize and the patent owner holds a dominant position in the bargaining (i.e., c_P is low, c_L is high, and β is low). This result is consistent with conventional wisdom in that it urges the court to limit the protection of patent rights when the patentee is in a more favorable position than the licensee. It is straightforward to see from (3.2)

[6]For a comprehensive discussion of the direction of patent reform, see Scotchmer (1991), Sakakibara and Branstetter (2001), Gallini (2002), Lemley and Shapiro (2005), and Shapiro (2008).

[7]The structure of the doctrine of equivalents is specified in 35 U.S. Code §112.

[8]See Anton and Yao (2006), Farrell and Shapiro (2008), Choi (2009), Henry and Turner (2010), and Shapiro (2010).

that $p = 0$ is infeasible as a patent policy since the corresponding optimal penalty diverges to infinity.

The doctrine of patent damages differs depending on jurisdictions, but in general there are two main damages regimes: the lost profits rule and the unjust enrichment rule. The former focuses on providing appropriate compensation to patent owners and forcing the defendant to make up for the patentee's profits that would have been made in the absence of the infringement. Meanwhile, the latter aims at imposing a just punishment for the infringers, requiring the defendant to disgorge the whole profits from the infringement. In the U.S., the Amendment of Patent Act in 1946 ended the use of the unjust enrichment rule in practice, and the doctrine of lost profits has been adopted for the purpose of damages assessment since then. However, many patent holders have had difficulty proving their entitlement to lost profits, ending up with compensation based on the reasonable royalty rule instead. This refers to the royalty rate that would have been negotiated initially in the presence of patents with certain validity.[9]

In virtue of the general framework, we can embrace a wide range of damages regimes. For instance, $\delta = 0$ corresponds to reasonable royalty rule because when found guilty, the defendant has to pay royalties at the rate of β, which would have been negotiated initially over patents with certain validity. This regime, however, might not be optimal in a vertically separated market with a non-producing patentee, for which the rule is designed.[10] We can see from (3.1) that the optimal probabilistic validity is given by $p^* = c_P/\{(1-\beta)(c_L + c_P)\}$ for $\delta = 0$, which can be larger than 1 when c_P is high, c_L is low, and β is high. This result implies that protection of patent rights needs to be stronger than the reasonable royalty rule if new technology is hard to develop yet easy to be commercialized by the downstream firm with the dominant bargaining power.

Even though the patentee cannot prove the entitlement of lost profits due to the absence of manufacturing capacity,[11] the authorities can still enforce stronger protection of patents by applying "entire market value rule" to reasonable royalty, of which specification in the patent law is currently under discussion in the U.S. Congress. This corresponds to the case of $\delta = \beta/(r-\mu)$ since it enforces the downstream firm to pay the whole profits from the infringement as damages. As a matter of fact, this is equivalent to the doctrine of unjust enrichment in our model in that it forces the infringer to disgorge all of its ill-gotten gains. Under this rule of limited liability, the first-best result can always be achieved because the optimal probabilistic validity for this case is $p^* = c_P/(c_L + c_P) \in (0,1)$, which clarifies the suboptimality of ironclad patents in the presence of the unjust enrichment rule. This result is in line with Schankerman and Scotchmer (2001) who claimed that unjust enrichment rule provides better protection in a

[9] 35 U.S. Code §284 provides its legal basis, stating that upon finding for the claimant, the court shall award the claimant damages adequate to compensate for the infringement but in no event less than a reasonable royalty for the use made of the invention by the infringer.

[10] Lemley (2009) noted that the reasonable royalty rule is designed with a non-practicing patentee in mind, emphasizing that a licensee has to make profits as well.

[11] Schankerman and Scotchmer (2001) studied the effects of different types of damages in a vertically separated market with a non-producing patentee, yet they incorporated the doctrine of lost profits by interpreting lost profits as lost royalties.

vertically separated market with a non-producing patentee. Lemley (2009) cast a doubt on the specification of the entire market value rule, claiming that it overcompensates the patent holder especially when the patentee does not have manufacturing capacity.[12] Yet, his work discussed the effects of the damages regime without considering the probabilistic nature of patents. As a matter of fact, his concern about the overcompensation of the entire market value rule can be understood by recalling the optimal penalty for ironclad patents that we have discussed earlier: $[c_P/(c_L + c_P) - (1 - \beta)]/(r - \mu)$, which is lower than $\beta/(r - \mu)$. Yet, we can ease the concern about overcompensation by incorporating probabilistic validity as a counterbalance to damages.

The court can enforce even stronger protection of patent rights. Namely, the penalty for infringement can be given by $\delta > \beta/(r - \mu)$. This implies that the infringer has to pay more than what he earns from the infringement, which can be read as punitive damages. It can be easily shown that the optimal probabilistic validity that corresponds to this case is always feasible as well. One might argue that this doctrine is against the spirit of the Amendment of the Patent Act in 1946 in that patent damages are designed to make up for patentees' losses, not to punish infringers. Yet, the U.S. patent law specifies that punitive damages can be levied on "willful infringement."[13] Anton and Yao (2006) showed that infringement always occurs in equilibrium under the lost profits measure of damages even if there is an option of non-infringement, which explains the necessity of punitive damages.

4 Conclusion

In this paper, we have examined the license contract in vertically separated markets and discussed how patent policies associated with litigation over infringement affect the timing and provisions of the license contract. First of all, we showed that the hold-up problem is inherent if the firm that invents the new technology does not have its own manufacturing capacity. Namely, the misalignment of the firms' incentive to invest leads to inefficiency in the market. Patent policies are directly linked to the outcome of bargaining over royalties, and thus, the surplus of both the patentee and the licensee. It was demonstrated that an excessive protection of patent rights can rather harm the patent holder's interests. This is because the timing of the license contract from which the patentee's revenue is raised depends not only on his willingness to invest but also on that of the counterparty, the licensee. We regarded the probabilistic validity of patents and the penalty for infringement as two patent instruments and derived the optimal patent policies that yield the first-best result in terms of social welfare. They are the policies that make both firms invest as if they were vertically integrated. The government not only can maximize the total amount of wealth in society but can also allocate the wealth according to the firms' contribution to the introduction of new technology. Even though each instrument can be infeasible as a stand-alone policy, a mix of instruments can always yield the first-best result

[12] The author documented that it is effectively never the case that the patent is responsible for all of the value of a product, and even if there are no other relevant patents, the defendant's know-how, materials, and marketing efforts always contribute some value, and usually the most significant part of the value of an infringing product.

[13] 35 U.S. Code §284 stipulates that the court may increase the damages up to three times the amount found or assessed.

since they can complement one another when one of them becomes infeasible. We also discussed the direction of patent reform in virtue of the general framework that embraces various types of damages regimes. The model provided the theoretical background to justify the application of the entire market value rule to reasonable royalty in that it can always guarantee the first-best result.

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