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Injunctions and Hold-up under Weak Patent Protection†

By KYOUNGBO SIM*

This paper analyzes how injunctions relate to patent hold-up problems. To this end, we present a simple model of licensing negotiations between a patent holder and a downstream firm in the shadow of litigation. More specifically, we consider the situation in which an injunction is granted as a matter of course if a patent is found valid and infringed upon in litigation, but the patent holder may be under-compensated due to aspects of the patent remedy system other than injunctions. We show that if the downstream user is unaware of the patent before any investment in initially designing its product, the patent hold-up problems created by injunction threats are worrisome when (i) the redesign process is costly, (ii) the degree of patent protection (by aspects of the patent remedy system other than injunctions) is sufficiently strong and (iii) the injunction is requested not to practice the patented technology exclusively but to collect excessive patent royalties. Even if the downstream user is aware of the patent before the initial investment, the patent hold-up problems do not disappear. The findings here imply that a discretionary approach is required towards denying injunctions against patent infringement. If the degree of patent protection is not sufficiently strong, denying injunctions can exacerbate the under-compensation problem. However, once patent protection improves enough (not necessarily perfectly), we may see a surge of patent hold-up problems, and it would be better to apply alternative patent remedies in place of injunctions when necessary. Lastly, we discuss several possible alternatives to injunctions and their pros and cons.

Key Word: Patent Litigation, Injunction, Hold-up,
Patentee Under-compensation, Patent License Negotiation
JEL Code: D82, K11, L24, O34

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I. Introduction

The two fundamental pillars of patent remedies are awarding patent damages and issuing an injunction. In the U.S., it was a general rule that the court awarded patent damages to compensate the patent holder for prior infringement and granted a permanent injunction to prevent continuing infringement if the court found the patent valid and infringed upon. However, since around the early 2000s, there has been vigorous debate regarding the prospect of hold-up problems associated with injunctions in patent cases. Subsequently, the U.S. Supreme Court made a substantial change to the prospective remedy. In *eBay v. MercExchange*, the Supreme Court instructed the district courts to exercise discretion as to whether to grant or deny injunctive relief depending on results of a four-factor test.[1]

Concerns over patent hold-up associated with injunctions grew rapidly after the well-known patent dispute between NTP and Research in Motion (RIM). After RIM had successfully launched Blackberry, a device offering wireless email service, NTP asserted that RIM infringed on NTP's patents. In the patent lawsuit, the jury found that NTP's patents were valid and RIM had infringed upon those patents. Subsequently, NTP sought an injunction, which would have been resulted in the closure of the Blackberry service if the injunction had been enforced. Because RIM was desperate to avoid the effects of the injunction, RIM settled the dispute by agreeing to pay $612.5 million to NTP, much more than the damages established by the jury.[2]

As illustrated by the NTP case, concerns about injunctions are more common in the information technology sector, including, for example, telecommunication parts and devices, computer software and hardware, and semiconductors. (Shapiro, 2010) There could be many reasons for this, but to name a few,[3] first, firms in this sector are more easily exposed to the risk of infringing on a patent inadvertently, not only because many patents are of dubious quality and have vague and broad claims but also because products tend to be complex and include many features. Second, a redesign process in response to an allegation of patent infringement can be quite costly and time-consuming.

In many countries, including Korea, however, an injunction is still issued as a matter of course by law if a patent is held valid and infringed upon during patent litigation.[4] Considering that firms in other countries, at least in the information technology sector, may also face a similar situation, a natural question comes to mind, i.e., whether or not Korea should also follow such patent reforms as in US? It is not straightforward to answer this question. Because there has also been criticism

[1] *eBay Inc. v. MercExchange, LLC*., 547 U.S. 388 (2006), "According to well-established principles of equity, a plaintiff seeking a permanent injunction must satisfy a four-factor test before a court may grant such relief. A plaintiff must demonstrate: (1) that it has suffered an irreparable injury; (2) that remedies available by law, such as monetary damages, are inadequate to compensate for that injury; (3) that, considering the balance of hardships between the plaintiff and defendant, a remedy in equity is warranted; and (4) that the public interest would not be disserved by a permanent injunction."

[2] For more details of the dispute between NTP and RIM, see, for example, *CNN Money*, *IEEE Spectrum* (2006. 3. 1), or the *Wall Street Journal* (2006. 3. 4).

[3] For the complete list, see Shapiro (2010), p.283.

[4] For a comparison across countries on issuing an injunction in patent cases, for example, see Cotter and Golden (2019).

that patent remedies in Korea do not provide strong protection for patent holders in terms of the level of patent damage and win rates,[5] any such reforms may worsen the under-compensation problem for the patent holders in Korea.

This paper analyzes how injunctions relate to a patent holder's payoff when the patent remedy system may not provide enough protection for the patent holder due to aspects other than injunctions. By comparing that payoff to a benchmark level, we identify conditions under which the patent holder is over-compensated by obtaining or threatening to seek an injunction, that is, patent hold-up associated with an injunction arises. Next, according to the analysis, we attempt to draw policy implications for the patent remedy system in Korea. We also briefly discuss several alternatives to injunctions as remedies.

To this end, we present a simple model of licensing negotiations between a patent holder and a downstream firm in the shadow of litigation. More specifically, we consider a model in which the two parties have two different opportunities to negotiate a patent license: one before a patent lawsuit and the other after.

We assume the following litigation process. First, as is often assumed in the recent literature, patents are probabilistic property rights, meaning that patents are held and infringed upon only with some probability of patent lawsuits.[6] We call this type of probability patent "strength" following the literature. Second, both patent strength and patent damage may be discounted to some degree.

To reflect the reality and to take into account key elements which may cause patent hold-up in patent infringement lawsuits, we also assume that the redesigning process is costly once the product of the downstream firm is designed to incorporate the patented feature, as in such cases, the initial investments are specific to the patented technology and thus sunk. In a similar vein, we consider the scenario associated with the "inadvertent infringement" model, in which the downstream firm is unaware of the patent when initially designing its product. We also analyze the "early negotiation" model in which the downstream firm can contemplate whether to incorporate the patented feature into its product while remaining aware of the patent and then compare the results from the two models.

In the inadvertent infringement model, we show that patent hold-up problems are worrisome when (i) the redesign process is costly, (ii) patent strength discounting and patent damage discounting are not too large, and (iii) the patent holder obtains or threatens to seek an injunction not to exclude the downstream firm from practicing the patent but to collect excessive patent royalties. If the injunction is granted but the patent holder still wants to license the patent to the downstream firm, the patent holder captures part of the redesign cost regardless of the value of the patented technology, which potentially causes the patent holder's payoff to exceed the benchmark level. However, if patent strength discounting and patent damage discounting are too large, capturing part of redesign cost would not be sufficient to compensate for the loss caused by the weak patent protection. Our results also indicate that a perfect degree of patent protection is not a prerequisite for a patent reform such as the recent one in the US.

The patent hold-up problem can arise even in the early negotiation model. Two

[5]For example, see Kim (2015).
[6]For example, see Gallini (2002) and Lemley and Shapiro (2005), among others.

different patent hold-up types can emerge. In case the downstream firm decides to use the patented feature after the initial negotiations break down, we see the same type of hold-up problems directly associated with the threat of an injunction. In contrast, if the downstream firm decides not to incorporate the patented feature into its product, we see a different type of hold-up problem. In these cases, the patent holder is over-compensated mainly because the downstream firm withdraws a chance to fight for the invalidation of the patent or defend the infringement allegation. This type of hold-up is especially serious for weak patents.

This paper contributes to the literature on the patent hold-up issue. Many studies have shed light on hold-up problems in a standard setting context. Among others, Farrell *et al.* (2007) offers an excellent overview of related issues. The key issue here is that the bargaining power of a patent holder during license negotiations increases dramatically once a technical standard, including technology protected by a patent holder's patent, is established as an industry standard. The patent holder can then collect much higher royalties than would have been determined before the standard was adopted or before the downstream firm decided to incorporate the standard into its product. Papers in this strand of the literature mainly focus on finding a good way to discipline opportunistic behavior by patent holders through the use of antitrust or patent laws or on studying whether FRAND commitments[7] made by patent holders can effectively mitigate hold-up problems. For example, Ganglmair *et al.* (2012) develops a model in which a patent holder, who abides by a FRAND commitment, and a downstream firm engage in royalty negotiations. They show that FRAND can indeed mitigate a hold-up problem but that it also retards innovation by reducing the patent holder's payoff. They also suggest that an option-to-license contract under which the patent holder and the downstream firm negotiate before any standard-specific investment by the downstream firm is made can outperform the FRAND commitment. In comparison to these works, we attempt to examine hold-up problems associated with injunctions in more general patent license negotiations.

Studies by Shapiro (2010; 2017) are more closely related to this paper in that those studies focus on licensing negotiations between a single patent holder and a single downstream user. Shapiro (2010) analyzes conditions under which hold-up problems arise, confining his attention to cases in which the patent holder is a non-practicing entity (NPE).[8] Shapiro (2017) investigates conditions under which ongoing royalties outperform injunctions, also confining his attention to cases in which the court already has discretion as to whether to grant an injunction or to order ongoing royalties, and where the patent has already been found valid and infringed upon. Because we must consider the possibility that the patent remedy system may not provide enough protection for the patent holder due to aspects other than injunctions, our model integrates and extends the above two models. More specifically, we analyze how both remedies for past and future infringements affect the patent holder's payoff considering license negotiations before and after litigation and general competitive relationships between patent holders and downstream users.

[7]FRAND is an abbreviation for "Fair, Reasonable, and Non-Discriminatory." Most well-known standard-setting organizations require participants to commit to license their patents on FRAND terms once technology protected by those patents is included in an industry standard later.

[8]Non-practicing entity refer to a patent-owning company that does not practice any of their own patents for themselves but that simply attempt to collect patent royalties by asserting their patents.

Lemley and Shapiro (2007) briefly discuss patent hold-up caused by injunctions but focus more on royalty stacking, which refers to situations in which a single downstream user takes a risk of infringing on many different patents owned by different patent holders. They demonstrate how royalty stacking can amplify hold-up problems in a relationship between a single-downstream user and a multiple-patent holder.

This paper is also related to a number of studies exploring more sophisticated litigation strategies of NPEs. Choi and Gerlach (2018) and Hovenkamp (2013) study how a NPE can more effectively assert their patents while facing multiple potential infringers. Choi and Gerlach (2018) examine the effects of an information externality produced by a prior litigation outcome on subsequent litigations. Assuming asymmetric information between the NPE and downstream users with regard to the type of NPE, Hovenkamp (2013) studies the incentives of NPEs to initiate litigation in the early stage to build a litigious reputation for subsequent litigation. Lemus and Temnyalov (2017) analyze the roles of NPEs when practicing entities can outsource the filing of lawsuits against one another to a NPE and show that the existence of NPEs may increase both the innovation incentives of practicing entities and social welfare.

A number of works in Korea study patent hold-up problems as well. Many of them, such as Cha (2015), Oh (2014) and Song (2014), examine whether the court needs to deny an injunction in a patent infringement case if a plaintiff owns standard essential patents under a FRAND commitment. Several other studies, including those by Cho (2015), Sim (2013) and Son (2011), examine hold-up problems created by injunctions in more general cases of patent licensing. However, while all of the studies discussed above offer insights from a legal perspective, they do not provide a sufficient theoretical background. Moreover, despite the fact that there has been criticism that patent remedies in Korea do not provide strong protection for patent holders, as in Kim (2015), previous works do not seriously take into account such criticism.

The remainder of the paper is organized as follows. Section 2 presents the model. In section 3, we discuss the benchmark royalty rate and payoffs. In sections 4 and 5, we study the inadvertent infringement model and the early negotiation model respectively, in turn. Section 6 discusses policy implications and a few alternative remedies to an injunction. Finally, section 7 concludes the paper.

II. Model

This section introduces the model, which is a modified and integrated version of the two models from Shapiro (2010; 2017). Consider the following three agents in the model: a patent holder P (plaintiff in patent litigation), a downstream firm D (defendant in patent litigation) and the Court C. P owns a single patent, and D produces a good that can potentially employ a technology protected by the patent.

A. *Patented Feature and Competitive Relationship*

Unit time profits for P and D vary depending on whether D includes the patented feature in its product. We denote unit time profits for P and D by π^P

TABLE 1— UNIT TIME PROFITS

	P's unit time profit	*D*'s unit time profit
Patented feature in *D*'s product	π^P	π^D
No patented feature in *D*'s product	$\pi^P + \Delta^P$	$\pi^D - \Delta^D$

and π^D, respectively, when the patented feature is incorporated into D's product. Compared to this situation, if D's product is produced without the patented feature, D's product becomes less attractive or more costly to produce. As a result, D's unit time profit should decrease. We denote this type of loss faced by D as Δ^D. In contrast, P's unit time profit will increase if D's product does not incorporate the patented feature. We denote this gain by P as Δ^P. The unit time profits for each case can then be summarized, as presented in Table 1. All four variables (π^P, π^D, Δ^P and Δ^D) are non-negative, and $\pi^D \geq \Delta^D$.

This profit specification is fairly general in that it can reflect many competitive or licensing relationships between the two firms. For example, we can consider a case in which P is a NPE (by setting $\pi^P = \Delta^P = 0$) as well as a case in which P and D are competitors ($\Delta^P, \Delta^D > 0$).

B. *Patent Litigation Process*

Once P initiates a patent lawsuit, it takes time, $T > 0$, until the litigation ends. We normalize the patent length to 1 such that T denotes the litigation duration as a fraction of the patent length.

When the litigation ends, C decides who wins the litigation. If P's patent is upheld as valid and deemed to have been infringed upon by D, P is the winner of the litigation. In this case, C orders D to pay unit time damages r for the past infringement. In addition, a permanent injunction is granted to prevent future infringements, which requires D to obtain a license from P to continue to sell its product as it is or to redesign the product to stop using the patented feature. In contrast, if P's patent is upheld as invalid or is deemed not to have been infringed upon by D, D is the winner of the litigation. If this is the case, D can continue to sell its product without any further action.

Furthermore, to consider the possibility of under-compensation for patentees, we make the following key assumptions. First, we assume that the "actual" probability λ that P wins the litigation can be less than or equal to the "fair" probability θ that P deserves to win the litigation given the intrinsic characteristics of the patent. As is usual in the literature, θ is referred to as the "patent strength." D wins the litigation with the complementary probability $1-\lambda$. Second, we also assume that unit time patent damages r n be calculated as less than or equal to the benchmark patent damages r^{BM}. We will discuss how this benchmark level is set in the paragraphs below.[9] Patent strength discounting and patent damage discounting

[9]See subsection E for a more detailed discussion of the benchmark royalties.

would reflect reality well, for example, if evidence gathering is difficult due to a lack of legislation and/or policies governing the patent litigation process. Below we state these assumptions more formally.

Assumption 1. $\lambda = \rho\theta$, where $\rho \in [0,1]$ is the degree of patent strength discounting.

Assumption 2. $r = \tau r^{BM}$, where $\tau \in [0,1]$ is the degree of patent strength discounting.

Lastly, each party has to incur costs denoted by L^P and L^D, respectively, for litigation. We only analyze cases in which these costs are not so large that P has sufficient incentive to initiate litigation, at least without any patent strength discounting and/or patent damage discounting. All of the above information about the litigation process is common knowledge.

C. *Product Redesign*

Regardless of whether D incorporates the patented feature into its product or not, we assume that the same fixed costs are required for the initial product design. However, if the patented feature is included initially but must be excluded later, for example in order to comply with a permanent injunction order, D must bear the redesign costs of $F > 0$. The redesign process is completed instantly.[10]

D. *Timeline*

As in Shapiro (2010), we consider the two different but similar models: "inadvertent infringement[11]" and "early negotiations." Game trees for the two models are depicted in Figures 1 and 2, respectively. For simplicity, we do not consider time discounting.

In the first model, D includes the patented feature into its product without being aware of P's patent protecting that feature. Next, ex-ante (before litigation) royalty negotiations take place. If the ex-ante negotiations fail, P decides whether to file a lawsuit.[12] In case there is litigation, court decisions are made after T amount of time passes. If P wins the litigation, the two parties engage in ex-post (after litigation) royalty negotiations once again. If these ex-post negotiations fail, D

[10]Even if we assume that the redesign process is time-consuming, as in Shapiro (2010), qualitative results do not change. In fact, the instant redesign process specification underrates hold problems associated with injunctions compared to the specification from Shapiro (2010).

[11]This corresponds to the "surprise" model in Shapiro (2010).

[12]In principle, the analysis would be more complete if we analyze D's optimal response to the accusation of a patent infringement as well. To reduce the number of cases under consideration, we assume that D proceeds with the trial without redesigning its product right away instead of halting sales of its product or that D proceeds with the trial by redesigning its product immediately. In fact, this assumption underestimates the potential extent of patent hold-up but does not affect our qualitative results.

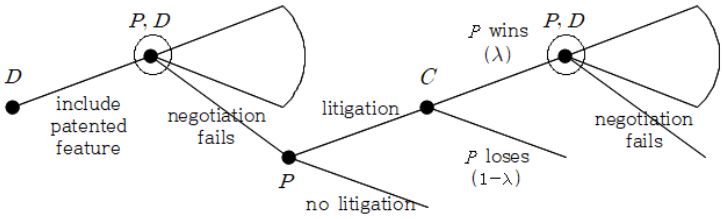

FIGURE 1— INADVERTENT INFRINGEMENT

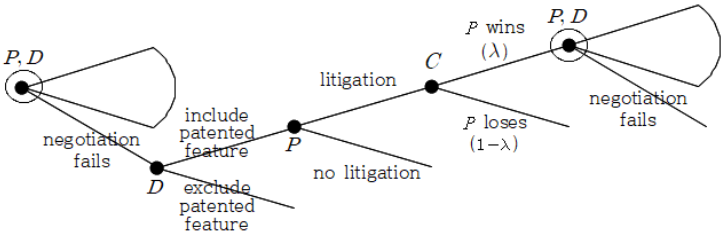

FIGURE 2— EARLY NEGOTIATION

redesigns the product.[13]

In the second model, the game proceeds in the same manner as above except that P and D engage in ex-ante negotiations before D's initial product design.

E. *Royalty Negotiation*

We assume that a Nash bargaining solution determines royalty rates when P and D engage in ex-ante and ex-post negotiations. Parameters $\beta \in [0,1]$ and $1-\beta$ represent the bargaining power of P and D, respectively. Because we analyze a Nash bargaining problem with symmetric information, P receives a share β of the gains from trade in addition to its own disagreement payoff. Similarly, D receives a share $1-\beta$ of the gains from trade in addition to its own disagreement payoff.

III. Benchmark Royalty Rate and Payoff

Before analyzing the two models presented in the previous section, we briefly discuss the benchmark royalty rate and benchmark payoff for the patent holder.

First, we define the benchmark royalty rate r^{BM} as P's unit time payoff net of

[13]As discussed in the previous footnote, in principle the analysis would be more complete if we also analyze D's optimal response subsequent to the failed ex-post royalty negotiations. D could stop selling its product or redesign its product. Again, we abstract from this analysis by assuming that D wants to redesign and keep selling the product for the remaining period, i.e., $(1-T)(\pi - \Delta^D) > F$. In fact, assuming D's optimal response as in footnotes 4 and 5 makes negotiation environments less favorable for P.

π^P that would result via ex-post royalty negotiations if the redesign costs are zero such that there is no concern over a hold-up. In this case, gains from trade exist if and only if

$$(1) \qquad (1-T)(\pi^P + \pi^D) \geq (1-T)\left[(\pi^P + \Delta^P) + (\pi^D - \Delta^D)\right] \Leftrightarrow \Delta^D \geq \Delta^P.$$

Disagreement payoffs to P and D are expressed as $(1-T)(\pi^P + \Delta^P)$ and $(1-T)(\pi^D - \Delta^D)$, respectively. Therefore, the benchmark royalty rate is $r^{BM} = \Delta^P + \beta(\Delta^D - \Delta^P)$ if inequality (1) holds, and $r^{BM} = \Delta^P$ otherwise. In summary,

$$(2) \qquad r^{BM} = \Delta^P + \beta \max\{\Delta^D - \Delta^P, 0\},$$

which can be considered as a form of either "lost profits" or "reasonable royalties." We can observe that the benchmark royalty rate is P's marginal benefit of using the patented feature without licensing plus the gains from licensing discounted by its bargaining power.

Similarly, we also set the benchmark payoff for the patent holder as the sum of the profit level it earns when the patented feature is used by both P and D and the benchmark royalties discounted by the patent strength:

$$(3) \qquad \Pi^{P|BM} = \pi^P + \theta r^{BM}$$

The benchmark payoff would be equal to the patent holder's equilibrium payoff under the following assumptions. First, litigation costs are zero such that these costs do not affect either party's payoff.[14] Second, C sets damages equal to r^{BM} when necessary. Third, there is no patent strength discounting or patent damage discounting during the litigation process.

In what follows, we will compare P's expected payoffs to this benchmark payoff in each model. If the former is larger (smaller) than the latter, we consider the difference between the two to be the portion of P's payoff attributable to the hold-up (hold-out).

IV. Inadvertent Infringement

In this section, we study the inadvertent infringement model, in which D initially designs its product with the patented feature without being aware of P's patent covering that feature. In order to look for a subgame prefect Nash equilibrium,

[14]Actually, assuming litigation costs are neutral is sufficient. We will show under which conditions litigation costs are neutral later.

we solve the model by means of backward induction. We shall mainly focus on determining how much the patent holder's equilibrium payoff is and comparing that to the benchmark level to understand the magnitude of the hold-up (or hold-out). All proofs omitted here are in the appendix.

First, we consider the last stage, in which P and D negotiate over patent royalties after P wins the litigation. Given the assumption that D does not stop producing but redesigns its product when licensing negotiations fail, disagreement payoffs to P and D are expressed as $(1-T)(\pi^P+\Delta^P)$ and $(1-T)(\pi^D-\Delta^D)-F$, respectively. If the two parties sign a licensing agreement, prospective payoffs to P and D are expressed as $(1-T)\pi^P$ and $(1-T)\pi^D$, respectively. Therefore, there are gains from trade if and only if

$$(4)\ (1-T)(\pi^P+\pi^D)\geq(1-T)\Big[(\pi^P+\Delta^P)+(\pi^D-\Delta^D)\Big]-F \Leftrightarrow \Delta^D+\frac{F}{1-T}\geq\Delta^P.$$

The equilibrium outcome of ex-post negotiations is as follows. If there are no gains from trade, negotiations break down, and each party simply receives its own disagreement payoff. In contrast, if there are gains from trade, they reach a licensing agreement in which they split the gains from trade according to each party's bargaining power on top of receiving their own disagreement payoffs; i.e., P and D's payoffs are respectively given by

$$(5)\qquad (1-T)(\pi^P+\Delta^P)+\beta\Big[(1-T)(\Delta^D-\Delta^P)+F\Big]$$

$$(6)\qquad (1-T)(\pi^D-\Delta^D)-F+(1-\beta)\Big[(1-T)(\Delta^D-\Delta^P)+F\Big].$$

The next lemma summarizes the results of the ex-post negotiations.

Lemma 1.
In ex-post negotiations, the patent holder and the downstream firm sign a licensing agreement if there are gains from trade; i.e., equation (4) holds. Otherwise, negotiations break down. The payoffs for the patent holder and the downstream firm are given by

$$(7)\qquad \Pi^{P|ex-post}=(1-T)(\pi^P+\Delta^P)+\beta\max\{(1-T)(\Delta^D-\Delta^P)+F,0\},$$

$$(8)\quad \Pi^{D|ex-post}=(1-T)(\pi^D-\Delta^D)-F+(1-\beta)\max\{(1-T)(\Delta^D-\Delta^P)+F,0\},$$

Two aspects related to these equations are important to note here. First, the condition for successful licensing negotiations is relaxed when redesigning is costly. (To see this, compare the inequalities (4) and (1)). Given that redesigning D's product is costly at this point, the two firms can retain those costs as well by signing

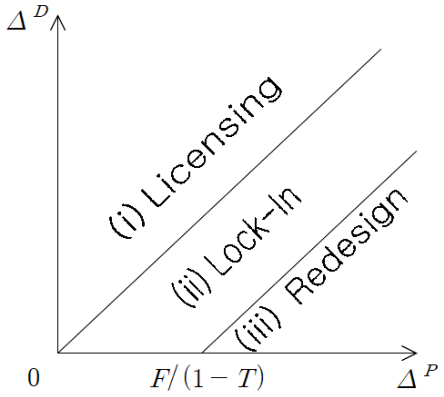

FIGURE 3— LICENSING OUTCOMES BY UNDERLYING NATURE

a licensing agreement. Hence, P's gains from prohibiting D from using the patented feature (Δ^P) now must be smaller than not only D's loss (Δ^D) but also the redesign costs spread over the remaining period the ($\frac{F}{1-T}$).

To simplify the discussion below, we categorize the underlying nature of ex-post licensing negotiations into the following three states depending on whether inequality (1) or (4) holds. "Licensing" states refer to cases in which a licensing agreement is reached regardless of whether the redesign costs are zero or F; i.e., $\Delta^D \geq \Delta^P$. "Lock-in" states refer to cases in which a licensing agreement is reached due to the positive redesign costs, i.e., $\Delta^D + \frac{F}{1-T} \geq \Delta^P \geq \Delta^D$. "Redesign" states refer to cases in which a licensing agreement cannot be reached regardless of whether the redesign costs are zero or F; i.e., $\Delta^P \geq \Delta^D + \frac{F}{1-T}$ (See Figure 3).

Second, P captures a part of the redesign costs (βF) unrelated to the value of the patented innovation in the licensing and lock-in states. As will become clear later, this is a key factor determining the degree to which P can hold-up D.

Next, we determine the expected payoffs for P and D depending on P's decision whether to bring a lawsuit. If P does not file a lawsuit, P ultimately receives $\Pi^{P|no-suit} = \pi^P$. Similarly, D receives $\Pi^{D|no-suit} = \pi^D$ in the end.

Even if P sues D at the cost of L^P, P earns π^P per unit time until the litigation outcomes are known or if it loses the litigation. However, if P wins the litigation, it earns $\Pi^{P|ex-post}$ for the remaining period plus damages $T\tau r^{BM}$ awarded by the court for the past infringement. After some tedious algebra, one can ascertain each party's expected payoffs from the litigation, as in the following lemma.

Lemma 2.
If the patent holder files a lawsuit, the expected payoffs for the patent holder and the downstream firm are given respectively by

$$(9)\quad \Pi^{P|suit} = \pi^P + \rho\theta[T\tau r^{BM} + (1-T)\Delta^P + \beta\max\{(1-T)(\Delta^D - \Delta^P) + F, 0\}] - L^P,$$

$$(10)\quad \Pi^{D|suit} = \pi^D + \rho\theta[-T\tau r^{BM} - (1-T)\Delta^D - F + (1-\beta)\max\{(1-T)(\Delta^D - \Delta^P) + F, 0\}] - L^D.$$

In equation (9), one can see how the size of extra (expected) benefits for P from the litigation is determined. It is simply the product of the probability that P wins the litigation ($\rho\theta$) and the amount of extra payoffs that P can capture if it wins (the term in the squared bracket). These extra payoffs can again be decomposed into two parts: the term associated with patent damage ($T\tau r^{BM}$) and the terms associated with an injunction order (all of the other terms in the squared bracket). The greater the patent strength discounting or patent damage discounting, the smaller the size of the extra benefits for P.

P will optimally choose to litigate if and only if the extra benefits from litigation exceed the litigation costs; i.e.,

$$(11)\quad \rho\theta[T\tau r^{BM} + (1-T)\Delta^P + \beta\max\{(1-T)(\Delta^D - \Delta^P) + F, 0\}] \geq L^P.$$

As stated earlier in section II, we consider only cases in which P's litigation threat is credible, at least without any patent strength discounting and patent damage discounting. More specifically, we assume that the benchmark royalties discounted by the patent strength exceed the corresponding litigation costs, which ensures that P's litigation threat is credible without patent strength discounting or patent damage discounting.[15]

Assumption 3. $\theta[\Delta^P + \beta\max\{\Delta^D - \Delta^P, 0\}] \geq L^P$.

What remains in this section is to study the equilibrium payoffs of the entire game and to compare those to the benchmark payoffs. Depending on whether or not the two firms reach a licensing agreement during ex-post negotiations, the results are qualitatively different. Therefore, we consider the licensing and lock-in states first and then the redesign states later.

A. *Licensing and Lock-In States*

We consider the licensing and lock-in states at this point. In the appendix, we prove the following statement.

[15]This corresponds to inequality (11) when $\rho = \tau = 1$ and $F = 0$.

Lemma 3.
In the licensing and lock-in states, ex-ante negotiations are always successful. The patent holder has an incentive to file a lawsuit if

$$\rho\theta[T\tau r^{BM} + (1-\beta)(1-T)\Delta^P + \beta(1-T)\Delta^D + \beta F] \geq L^P. \tag{12}$$

The equilibrium payoffs for the patent holder and the downstream firm determined during ex-ante negotiations are expressed respectively as

$$\Pi^P = \begin{cases} \pi^P + \rho\theta[T\tau r^{BM} + (1-\beta)(1-T)\Delta^P + \beta(1-T)\Delta^D + \beta F] + \beta L^D - (1-\beta)L^P & \text{if (12)}, \\ \pi^P & \text{if } \sim \text{(12)}, \end{cases} \tag{13}$$

$$\Pi^D = \begin{cases} \pi^D + \rho\theta[T\tau r^{BM} + (1-\beta)(1-T)\Delta^P + \beta(1-T)\Delta^D + \beta F] + (1-\beta)L^P - \beta L^D & \text{if (12)}, \\ \pi^D & \text{if } \sim \text{(12)} \end{cases} \tag{14}$$

where r^{BM} *is defined as in (2).*

Lemma 3 tells us that ex-ante negotiations always result in a licensing agreement in licensing and lock-in states. This does not necessarily mean that the patent holder is always able to collect some positive patent royalties. When P's litigation threat is not credible (i.e., when inequality (12) does not holds), they reach a licensing agreement at a patent royalty rate of zero simply because nothing changes as a result of the ex-ante negotiations.

However, if P's litigation threat is credible, the two firms anticipate that they will have to engage in costly litigation. Because the two firms always reach a licensing agreement during ex-post negotiations in the licensing and lock-in states, they can do better by signing a licensing agreement given these circumstances and avoiding the litigation costs. To see this, it is helpful to compare Π^P with $\Pi^{P|suit}$. The two payoff functions are identical except for the last terms associated with litigation costs (i.e., $\beta L^D - (1-\beta)L^P$ and $-L^P$). The net bargaining surplus discussed above is captured by the last term in Π^P, $\beta L^D - (1-\beta)L^P$. This term can be positive or negative depending on the relative amount of the litigation cost and on the bargaining power capabilities of the two firms in principle. For the remainder of this analysis, we assume that the litigation costs are neutral, which means that $\beta L^D - (1-\beta)L^P$ is zero.[16]

Proposition 1.
In the licensing and lock-in states, the patent holder is over-compensated, i.e.,

[16]This assumption is true if, for example, $\beta = 1/2$ and $L^P = L^D$.

$\Pi^P > \Pi^{P|BM}$, *if patent strength discounting and patent damage discounting are low, and otherwise the patent holder is under-compensated (i.e.,* $\Pi^P < \Pi^{P|BM}$*). In order to state the above result more formally, we define a set* E *that contains all pairs* (τ, ρ) *for which the patent holder's payoff is equal to the benchmark level; i.e.,*

$$E = \{(\tau, \rho) \in [0,1]^2 \mid \Pi^P = \Pi^{P|BM}\}.$$

E *is a convex curve in the* $\tau\rho$*-plane depicted by thick solid lines as in panel (a) or (b) in Figure 4. In the region to the upper right of the curve, the patent holder is over-compensated, and in the region to the lower left, the patent holder is under-compensated.*

In the licensing and lock-in states, the hold-up problem arises as long as the extent of patent strength discounting or patent damage discounting is not excessive. In other words, the patent holder can obtain excessive patent royalties even when the full degree of patent protection ($\tau = \rho = 1$) is not being offered. Of course, the patent holder is under-compensated if the degree of patent protection becomes too weak

To gain a deeper understanding of the above finding, we express the difference between the patent holder's payoff and the benchmark. For expositional convenience, we consider licensing states, but the same logic applies to lock-in states as well.

$$\Pi^P(\tau, \rho) - \Pi^{P|BM} = \rho\theta\beta F - \{1 - \rho\tau T - \rho(1-T)\}\theta r^{BM} \quad (15)$$

The first term on the right side is the value of the expected redesign costs capturable by the patent holder with an injunction threat. This term is the component that causes the patent holder's payoff potentially to exceed the benchmark level. The second term on the right side shows how much less the expected patent royalties are relative to the benchmark level. These discounts can be further decomposed into two parts: one associated with patent damage ($\rho\tau T$) and the other associated with the

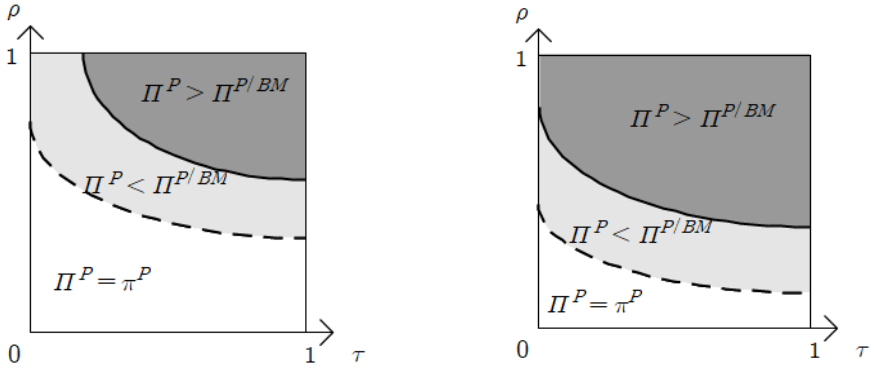

FIGURE 4— COMPARISON BETWEEN THE PATENT HOLDER'S PAYOFF AND THE BENCHMARK LEVEL

injunction threat ($\rho(1-T)$). As the degree of patent protection increases, the first term increases while the second one decreases. All other things being equal, the degree of the hold-up, i.e., the term in equation (15), increases with a decrease of T or with an increase of β or F .

Proposition 1 implies that a discretionary approach is required with regard to denying injunctions against patent infringement. If the degree of patent protection is not sufficiently strong, banning injunctive reliefs can exacerbate the under-compensation problem. Thus, it may be at least temporarily desirable to allow the patent holder to request an injunction as leverage for collecting excessive patent royalties. Nonetheless, it must be considered that such an approach has clear limitations in the sense that it is an attempt to increase the patent holder's payoff not based on the intrinsic value of the patent but based on the hold-up component.

A more fundamental solution would be to strengthen the degree of patent protection in other dimensions. However, once the under-provision of patent protection improves to a certain (not necessarily perfect) degree, the patent hold-up problems can come to the fore. In such a case, it may be desirable to limit the patent holder's right to seek injunctive relief in licensing or lock-in states. We will discuss how to deal with hold-up problems in section VI.

B. *Redesign State*

At this point, we consider redesign states in which ex-post negotiations break down because the patent holder wants to stop the downstream firm from utilizing the patented feature. We follow a similar procedure to construct the patent holder's payoff and then compare that to the benchmark level. The next lemma characterizes the equilibrium outcomes and the patent holder's payoff in redesign states.

Lemma 4.
In redesign states, the patent holder has an incentive to file a lawsuit if

$$\rho\theta\{1-(1-\tau)T\}\Delta^P \geq L^P. \tag{16}$$

The condition under which there are gains from trade in ex-ante negotiations is given by

$$\rho\theta\{(1-T)(\Delta^P-\Delta^D)-F\} \leq L^P+L^D. \tag{17}$$

If (16) holds but (17) does not, ex-ante negotiations break down. Otherwise, ex-ante negotiations are successful. The equilibrium payoffs to the patent holder and the downstream firm are expressed respectively by

$$\Pi^P = \begin{cases} \pi^P + \rho\theta[1-(1-\tau)T]\Delta^P - L^P & \text{if (16)} \wedge (\sim (17)), \\ \pi^P + \rho\theta[\{1-(1-\tau)T\}\Delta^P - \beta\{(1-T)(\Delta^P - \Delta^D) - F\}] & \text{if (16)} \wedge (17), \\ \pi^P & \text{if} \sim (16), \end{cases} \tag{18}$$

$$\Pi^D = \begin{cases} \pi^D - \rho\theta[T\tau\Delta^P + (1-T)\Delta^D + F] - L^D & \text{if (16)} \wedge (\sim (17)), \\ \pi^D - \rho\theta[T\tau\Delta^P + (1-T)\Delta^D + F + (1-\beta)\{(1-T)(\Delta^P - \Delta^D) - F\}] & \text{if (16)} \wedge (17), \\ \pi^D & \text{if} \sim (16), \end{cases} \tag{19}$$

In redesign states, the joint surplus of the two firms is maximized when the patent holder excludes the downstream firm from using the patented feature. With this consideration, we consider the following three distinct cases in turn. Case (i): if equation (16) holds but (17) does not, the patent holder captures the full extra surplus that it would expect to obtain from the litigation. Case (ii): if both equation (16) and (17) hold, ex-ante negotiations are successful due to the relatively high litigation costs. The patent holder and the downstream firm agree on avoiding the litigation costs in this case. However, the patent holder loses the opportunity to obtain a permanent injunction, as represented by the second line in the square bracket in equation (18). Case (iii): if equation (16) does not hold, the patent holder cannot expect any extra surplus from litigation.

The patent holder's payoff would be highest without patent strength discounting and patent damage discounting. However, even in such a case, the patent holder's payoff is only equal to or less than the benchmark payoff.

Proposition 2.

In redesign states, the patent holder earns the benchmark payoff, i.e., $\Pi^P = \Pi^{P|BM}$ *if there is no patent strength discounting and patent damage discounting, and if either the patent holder's litigation costs are zero or the underlying nature of licensing negotiations is on the boundary of the lock-in and redesign states. Otherwise, the patent holder is under-compensated; i.e.,* $\Pi^P < \Pi^{P|BM}$.

In sharp contrast to the findings in licensing and lock-in states, there is no concern over patent hold-up in redesign states. These results can be understood as follows. Here, patent strength or patent damage can still be discounted as before. However, the patent holder seeks the injunction not to demand higher royalties but to practice the patented feature exclusively so that some of the redesign cost is no longer captured by the patent holder. Consequently, there is no chance for the patent holder to be over-compensated in redesign states.

Considering the results from Proposition 1 and 2 together, our model shows that patent hold-up problems are worrisome when (i) the redesign process is costly, (ii) patent strength discounting and patent damage discounting are not excessive, and

(iii) an injunction is requested not to exclude the downstream firm from utilizing the patent but to collect excessive patent royalties (i.e., in licensing and lock-in states).[17]

V. Early Negotiation

In this section, we examine the early negotiation model in which P and D engage in ex-ante negotiations before D initially designs its product. As in the previous section, we mainly focus on comparing the patent holder's equilibrium payoff with the benchmark payoff to understand the magnitude of the hold-up (or hold-out).

Because the game proceeds identically to the inadvertent infringement model does beginning the moment P initiates litigation (see Figures 1 and 2), we can refer to the results for such subgames in the previous section. Then, it remains to analyze D's optimal decision regarding the initial product design and the bargaining outcomes during ex-ante negotiations.

If P's litigation threat is not credible, it is always optimal for D to include the patented feature in its product ("do not design around"). In contrast, if P's litigation threat is credible, D has to compare the benefits and costs of not designing around the patented feature. If D does not design around the feature, D will face litigation and ultimately receive $\Pi^{D|suit}$, as defined in Lemma 2. If D excludes the feature ("design around"), D ultimately receives $\pi^D - \Delta^D$. Therefore, D's optimal decision regarding the initial product design is described below.

Lemma 5.
If the patent holder's litigation threat is not credible (equation (11) does not hold), the downstream firm never designs arounds the feature. Otherwise, the patent holder does not design around if $\pi^D - \Delta^D < \Pi^{D|suit}$ *and does design around it otherwise* ($\pi^D - \Delta^D \geq \Pi^{D|suit}$).

During ex-ante negotiations, the disagreement payoffs depend on D's decision regarding the initial product design. If D still wants to include the patented feature even after the failure of the negotiations, the equilibrium outcomes coincide with those either in Proposition 1 or Proposition 2. Otherwise, the disagreement payoffs of P and D are respectively expressed as $\pi^P + \Delta^P$ and $\pi^D - \Delta^D$. Then, it becomes immediately necessary to characterize the equilibrium of the early negotiation model as follows. We correspondingly denote the equilibrium payoffs to P and D in the early negotiation model as $\tilde{\Pi}^P$ and $\tilde{\Pi}^D$.

[17]Even if Propositions 1 and 2 have important implications with regard to enforcement intensity, as represented by unobservable variables in our model, one can think of a testable hypothesis regarding these propositions when there is a policy change that strengthens patent protection. For example, assuming that the downstream firm's investment level is positively correlated with its expected payoff, one can test whether the investment levels of downstream firms change differently depending on other variables related to the magnitude of the hold-up problems (for example, the levels of the redesigning costs) with such a policy change. However, conducting such an empirical analysis may not be an easy task for the following reason. In many circumstances, it is challenging to classify firms exclusively into two categories, i.e., upstream or downstream firms, making it difficult to find a proxy variable that can feasibly measure the degree of the patent hold-up.

Proposition 3.
If the downstream firm does not design around after the ex-ante negotiations break down, the equilibrium is then characterized as in Proposition 1 in licensing and lock-in states or as in Proposition 2 in redesign states. If the downstream firm designs around, (i) ex-ante negotiations are successful when $\Delta^D \geq \Delta^P$*, during which the equilibrium payoffs to the two firms are respectively* $\tilde{\Pi}^P = \pi^P + \Delta^P + \beta(\Delta^D - \Delta^P)$ *and* $\tilde{\Pi}^D = \pi^D - \Delta^D + (1-\beta)(\Delta^D - \Delta^P)$ *and (ii) break down when* $\Delta^P > \Delta^D$*, at which point the equilibrium payoffs to the two firms are respectively* $\tilde{\Pi}^P = \pi^P + \Delta^P$ and $\tilde{\Pi}^D = \pi^D - \Delta^D$.

The patent hold-up problem can arise even in the early negotiation model. If the two firms expect that D will utilize the patent after the failure of current negotiations, the patent holder can be over-compensated by the threat of an injunction, as demonstrated in the previous model.

However, in the opposite case, the two firms expect that a breakdown in ex-ante negotiations does not lead to D's infringement on P's patent. Therefore, the payoffs to the two firms are irrelevant with regard to the redesign costs, and there is no scope for the patent hold-up problem associated with an injunction. Nonetheless, the patent holder's payoff can still be excessive unless the patent strength is equal to one. To observe this, note that

$$\tilde{\Pi}^P - \Pi^{P|BM} = (1-\theta)[\Delta^P + \beta \max\{\Delta^D - \Delta^P, 0\}] \geq 0. \tag{20}$$

These excessive payoffs result not from the threat of an injunction but from the probabilistic nature of patents. Here, the downstream firm does not want to incur the risk of going to court and thus relinquishes the chance to fight for the invalidation of the patent or to defend against the infringement allegation. The weaker the patent strength is, the greater the hold-up component of the patent holder's payoff becomes.[18]

The exact condition under which D designs around is given in the appendix, but we illustrate how this condition changes depending on the patent strength and the underlying nature of licensing in Figure 5. In each panel, there is a graph which delivers information similar to that in Figure 4. In the region to the upper right of the thick solid curves, the patent holder is over-compensated. Similarly, in the region to the upper right of the short dashed curves, the patent holder's litigation threat is credible. The newly added long dashed (blue) curve represents the points at which D is unvarying with regard to redesigning or not redesigning. In the region to the upper right of those curves, designing around is optimal for D. As shown in Figure 5, a weaker patent strength means less room for designing around. Going through a similar exercise, we can also find that weaker bargaining power by the patent holder

[18]Shapiro (2010) also describes the same finding. There can potentially be other social costs associated with probabilistic patents. Many other studies have explored these issues from various angles. For example, Farrell and Shapiro (2008) study the welfare implications of licensing of probabilistic patents to multiple firms when the redesign process is neither time-consuming nor costly.

or a longer duration of litigation will lead to less room for designing around.

We can also check when patent hold-out (or reverse patent hold-up) tends to occur in Figure 5. Patent hold-out refers to a situation in which downstream firms intentionally ignore patents or refuse royalty negotiations to use those patents at lower royalty rates or for free. In our model, the hold-out problem arises when the patent holder's payoff is less than the benchmark level. In Figure 5, this corresponds to the region to the lower left of both of the following two curves: those represented by thick solid lines and those indicated by long dashed lines. This finding implies that patent hold-out problem can prevail when the degree of patent protection is not sufficiently strong.

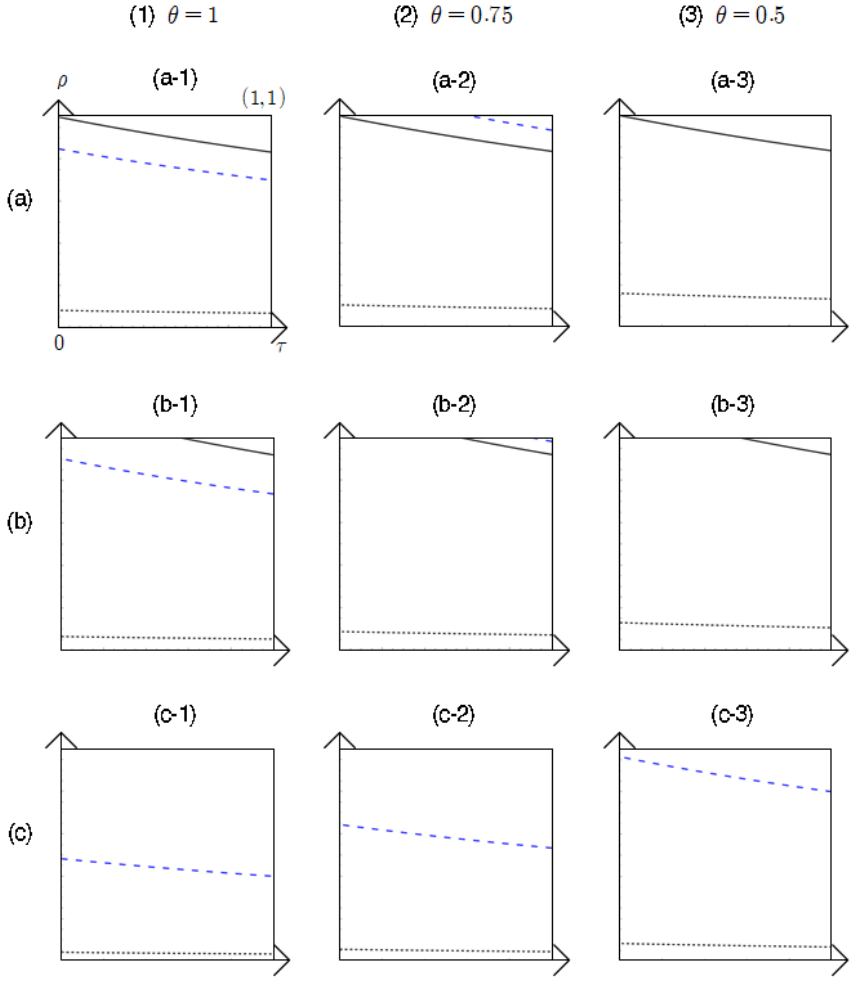

FIGURE 5— EXAMPLE EQUILIBRIUM OUTCOMES IN THE EARLY NEGOTIATION MODEL

Note: In each panel, the horizontal axis represents the degree of patent damage discounting and the vertical axis represents the degree of patent strength discounting. In this example, parameter values were set such that rows (a), (b) and (c) correspond to the licensing, lock-in and redesign states, respectively. More specifically, $\Delta^D = 30$, $F = 10$, $T = 0.2$ and $\Delta^P = 20$ in rows (a), 35 in (b) and 60 in (c). The patent strength is set to 1 in column (1), to 0.75 in (2) and to 0.5 in (3). All other parameter values are set as follows: $\beta = 0.5$, $L^P = L^D = 2$.

We can also compare the results in the previous model (inadvertent infringement model) and those in the current one (early negotiation model) to observe how the patent holder's payoff is affected when D has the opportunity to decide whether or not to design around before the initial negotiation between the two firms. Depending on the parameter values, the results can differ. When the patent strength equals one, the patent holder's payoff is equal to the benchmark level given that designing around is optimal for D. Therefore, there is a possibility that the problem of under-compensation or over-compensation for the patent holder in the previous model can be corrected in the current model (the region to the upper right of the long dashed curve in panels (a-1), (b-1) and (c-1)). However, when the patent strength is less than one, the level of over-compensation can be switched to another level (the region to the upper right of the long dashed curve in panels (a-2) and (b-2)), or the under-compensation problem can be overturned to the over-compensation problem (the region to the upper right of the long dashed curve in panels (c-2) and (c-3)). As stated earlier, patent hold-up associated with D's designing around strategy is not directly related to the threat of an injunction

VI. Policy Implications

Thus far, we have mainly examined how and under which conditions the threat of an injunction results in the patent hold-up problem. From the results in the previous section, we can infer that if policymakers endeavor to improve the degree of patent protection, patent hold-ups may be prevalent in the near future, though this is not the case thus far. Accordingly, it may be beneficial to contemplate in advance applicable alternative patent remedies in place of an injunction when necessary.

In this section, we briefly discuss such alternative remedies. To this end, here we consider only cases in which the degree of patent protection is strong enough such that patent the hold-up issue may be worrisome. In other words, we consider only cases in which τ and ρ are close to 1 in our model.

The most basic alternative remedy conceivable here is the awarding of "ongoing royalties." This remedy allows the downstream firm to continue to infringe on the asserted patent as long as the downstream firm pays ongoing royalties set by the court onwards. In fact, the ongoing royalties remedy is in force in patent litigation in the U.S., specifically after the *eBay v. MercExchange* case.

To observe how the ongoing royalties remedy can address the hold-up problem associated with an injunction, we reconsider our model and suppose this time that $\tau = \rho = 1$, with the court setting the ongoing royalty rate to r^{BM}. The following proposition shows how the outcomes of ex-post negotiations turn out.

Proposition 4.

Suppose that the degree of patent protection is perfect, i.e., $\tau = \rho = 1$*, and that the court orders the downstream user to pay ongoing royalties at the royalty rate of* r^{BM} *instead of granting an injunction when the patent holder wins the litigation. In this case, the downstream firm chooses to pay ongoing royalties if*

$$\Delta^P \leq \Delta^D + \frac{F}{1-T}. \tag{21}$$

and to redesign its product otherwise. The payoff to the patent holder during ex-ante negotiations is

$$\Pi^{P|ex-post} = (1-T)[\pi^P + \Delta^P + \beta \max\{\Delta^D - \Delta^P, 0\}]. \tag{22}$$

If we compare this case with one in which the court grants an injunction as a matter of course, we find that the conditions under which the downstream firm does not have to redesign its product (see equations (21) and (4)) remain the same. However, when comparing the patent holder's payoffs, we find a distinct difference. Under the ongoing royalty regime, the patent holder no longer captures a part of the redesign costs (see equations (22) and (7)). Therefore, the patent hold-up problem caused by the threat of an injunction disappears when we switch to the ongoing royalty regime.

One caveat to the above finding is that it was derived assuming that the degree of patent protection is perfect. If the degree of patent protection is strong enough but still not perfect, the patent holder is under-compensated under the ongoing royalty regime.

Practically, the court has to bear slightly more of a burden by setting a fair ongoing royalty rate. Of course, because the court has to award patent damages for the prior infringement even under the (as-a-matter-of-course) injunction regime, one simple approach is to match the ongoing royalty rate to the reasonable royalty rate calculated for awarding patent damages. This approach would work well if underlying market conditions are stable over time, as in our model. If market conditions are expected to change significantly, however, the ongoing royalty rate must be adjusted accordingly.

Nevertheless, it is almost certain that the ongoing royalty remedy should be the backbone of alternative remedies because it is not only relatively easy to implement but also considering that the other remedies discussed below are basically a mixture of the ongoing royalty remedy and some other means. It will be valuable to learn lessons from the US experience[19] and accumulate more research[20] on how properly to set patent royalty rates from a practical perspective.

We also introduce two hybrid types of remedies suggested and briefly discussed by Shapiro (2017) in turn. The first is to grant an "injunction with a ban on licensing." Under this remedy regime, the court allows the patent holder to choose between two remedies: ongoing royalties or an injunction order with an additional court order precluding the patent holder from engaging in licensing negotiations with the downstream firm.

Under the same assumption that the degree of patent protection is perfect, let us see how the ex-post (litigation) payoff to the patent holder is determined under this remedy regime in our model. If the patent holder chooses to obtain the modified injunction, the ex-post payoff to the patent holder is simply $(1-T)(\pi^P + \Delta^P)$. On

[19]For example, see Lemley (2011) and Sidak (2016).
[20]Some existing studies in Korea on this topic include that by Chang (2017).

the other hand, if the patent holder opts for paying ongoing royalties, the ex-post payoff is expressed as equation (22). The patent holder prefers the ongoing royalty remedy in the licensing states and is indifferent between the two remedies in the lock-in and redesign states. Therefore, the patent holder's payoff remains the same, as before (equation (22)), which implies that this modified injunction remedy can handle patent hold-up problems.

In fact, this remedy is likely to perform better than the ongoing royalty remedy in some circumstances. Even if the degree of patent protection is strong enough but still not perfect, the patent holder can be fairly compensated at least when $\Delta^P > \Delta^D$ such that the patent holder prefers to obtain a modified injunction over ongoing royalties. Furthermore, this remedy causes the patent holder to self-select the more preferred prospective remedy of the two, which can be a substantial merit when the court does not have enough information about the underlying nature of licensing negotiations or market conditions.

Despite the above advantages, there are a few factors that we also need to deliberate on from a practical viewpoint prior to the implement of this remedy. For this remedy to work as intended, the court should be able to ensure that the two firms do not engage in licensing negotiations after the injunction order. If this is not possible, the introduction of certain punishment measures for such negotiations should be considered.

The second hybrid type of remedy is "ongoing royalties followed by an injunction." Under this remedy regime, the court postpones the time at which the injunction goes into effect and allows the downstream firm to pay ongoing royalties until that time.

We determine how the patent ex-post payoff turns out under this remedy regime as well. In addition to the same assumptions used in the two previous cases, we also assume that the injunction order goes into effect at $T + t$ and the redesign costs are reduced to $f < F$ at that time. Because only the timing of the negotiations is delayed slightly, the patent holder's ex-post payoff can be expressed as

$$\Pi^{P|ex-post} = (1-T)\pi^P + t\tau r^{BM} + (1-T-t)\Delta^P \beta \max\{(1-T-t)(\Delta^D - \Delta^P) + f, 0\}. \tag{23}$$

This remedy will fairly compensate the patent holder well when the degree of patent damage discounting is nil, and the redesign costs can be reduced in a short time interval. Another merit of this remedy, though scarcely considered in our model, is that the remedy will allow the downstream firm to escape a considerable loss from not being able to sell its product even if the redesign process is lengthy. However, for this remedy to perform as intended, the court should be able to make a proper decision regarding how long to delay the implementation of the injunction order. At the same time, setting a fair ongoing royalty rate is also a prerequisite for this remedy to perform well.

VII. Concluding Remarks

This paper analyzes how injunctions relate to a patent holder's payoff when the patent remedy system may not provide enough protection for the patent holder due to aspects other than injunctions. By comparing that payoff to the benchmark payoff, we identify conditions under which patent hold-up problems associated with an injunction arise.

We show that if the downstream user is unaware of the patent before any investment when initially designing its product, patent hold-up problems created by injunction threats are worrisome when (i) the redesign process is costly, (ii) patent strength discounting and patent damage discounting are not excessive, and (iii) an injunction is requested not to exclude the downstream firm from utilizing the patent but to collect excessive patent royalties. Even if the downstream user is aware of the patent before the initial investment, patent hold-up problems do not disappear.

Our results imply that a discretionary approach is required with regard to denying injunctions against patent infringement. If the degree of patent protection is not sufficiently strong, denying injunctions can exacerbate the under-compensation problem. Thus, it may be at least temporarily desirable to allow the patent holder to request an injunction as leverage for collecting excessive patent royalties. However, once patent protection improves enough (not necessarily perfectly), we may see a surge of the patent hold-up problems. In such cases, it would be better to apply the alternative patent remedies discussed in section VI when necessary. Because all of the alternative remedies are at least partly based on the ongoing royalty remedy, it is important to accumulate more knowledge on how properly to set the patent royalty rate from a practical perspective in advance.

This paper only considers patent license negotiations between a single patent holder and a single downstream firm. Thus, one avenue for future research is to check whether our results carry over to more complex patent license settings. For example, in a model where one product potentially infringes on many patents owned by multiple patent holders, it would be interesting to investigate if our results change substantially depending on whether the related patents are substitutes or complements or whether license negotiations take place simultaneously or sequentially. Another meaningful future research agenda would be to explore more explicitly how patent hold-ups associated with injunctions change the intensity of innovation activities or the compositions of innovation projects pursued by both patent holders and downstream users.

APPENDIX

Proof of Lemma 2.

Until the final court decision is made, both firms will utilize the patent and earn $T\pi^P$ for that period. If the patent holder loses the litigation, it earns $(1-T)\pi^P$ for the remaining period. If the patent holder wins, it earns $T\tau r^{BM} + \Pi^{P|ex-post}$. Because the probability that P wins the litigation is $\lambda = \rho\theta$, the expected payoff for P from filing a suit is given by

$$\text{(A-1)} \quad \Pi^{P|ex-post} = T\pi^P + \rho\theta(T\tau r^{BM} + \Pi^{P|ex-post}) + (1-\rho\theta)(1-T)\pi^P - L^P.$$

Plugging equation (7) into (A-1) and rearranging the terms yield equation (9). In a similar way, equation (10) can be obtained. *Q.E.D.*

Proof of Lemma 3.

It is obvious that if the patent holder's litigation threat is not credible, P and D's payoffs are π^P and π^D, respectively.

At this point, we consider the case in which the patent holder's litigation threat is credible. In the licensing and lock-in states, equation (11) can be written as equation (12). Because in this case the two firms always sign a licensing agreement during ex-post negotiations, the joint surplus does not change, but the two firms must pay litigation costs. To avoid these costs, they always sign a licensing agreement during ex-ante negotiations. Therefore, the patent holder's payoff in this case equals

$$\text{(A-2)} \quad \Pi^P = \Pi^{P|suit} + \beta(L^P + L^D).$$

By substituting equation (9) in licensing and lock-in states for $\Pi^{P|suit}$, we obtain equation (13). The payoff to the downstream firm can be obtained in a similar manner. *Q.E.D.*

Proof of Proposition 1.

Here, we only offer the proof in lock-in states, but the proof in licensing states is similar. Note that $\Delta^D + \frac{F}{1-T} \geq \Delta^P \geq \Delta^D$ in lock-in states. Therefore, the patent holder's payoff and the benchmark payoff are given by

$$\text{(A-3)} \quad \Pi^P(\tau,\rho) = \pi^P + \rho\theta[T\tau\Delta^P + (1-T)\{\Delta^P + \beta(\Delta^D - \Delta^P) + \beta F\}]$$

$$\text{(A-4)} \quad \Pi^{BM} = \pi^P + \theta[\Delta^P + \beta(\Delta^D - \Delta^P)]$$

Because the following equations are true,

$$\frac{\partial \Pi^P}{\partial \tau} = \rho\theta T\Delta^P > 0 \tag{A-5}$$

$$\frac{\partial \Pi^P}{\partial \rho} = \theta[T\tau\Delta^P + (1-T)\{\Delta^P + \beta(\Delta^D - \Delta^P)\} + \beta F] > 0 \tag{A-6}$$

$$\frac{\partial^2 \Pi^P}{\partial \tau^2} = 0,\ \frac{\partial^2 \Pi^P}{\partial \rho^2} = 0 \tag{A-7}$$

$$\frac{\partial^2 \Pi^P}{\partial \tau \partial \rho} = \theta T\Delta^P > 0 \tag{A-8}$$

the payoff function to the patent holder is increasing and concave in its arguments.

Using the properties of $\Pi^P(\tau,\rho)$, we now investigate the properties of E. E is a level set on the $\tau\rho$-plane such that $\Pi^P(\tau,\rho) = \Pi^{BM}$. Given that

$$\frac{d\rho}{d\tau} = -\frac{\dfrac{\partial \Pi^P}{\partial \tau}}{\dfrac{\partial \Pi^P}{\partial \rho}} < 0 \tag{A-9}$$

and Π^P is concave, E must have the form of a decreasing convex curve on the $\tau\rho$-plane. Next, we check that E lies within $[0,1]^2$, as shown in Figure 4. To this end, we define a new function $\phi(\tau,\rho) \equiv \Pi^P - \Pi^{BM}$ and then check the signs of ϕ on the four vertexes of the square of $[0,1]^2$.

$$\begin{aligned}
&\phi(0,0) = -\theta\{\Delta^P + \beta(\Delta^D - \Delta^P)\} < 0 \\
&\phi(1,0) = -\theta\{\Delta^P + \beta(\Delta^D - \Delta^P)\} < 0 \\
&\phi(0,1) = \theta\beta F - \theta T\{\Delta^P + \beta(\Delta^D - \Delta^P)\} \\
&\phi(1,1) = \theta\beta F + \theta\beta T(\Delta^P - \Delta^D) > 0
\end{aligned} \tag{A-10}$$

Because $\phi(1,0)$ is negative, $\phi(1,1)$ is positive and ϕ is continuous in ρ, there exists a unique $\rho^* \in (0,1)$ such that $\Pi^P(1,\rho^*) = \Pi^{BM}$. Meanwhile, as the sign of $\phi(0,1)$ is not deterministic, E can take two different forms, as shown in Figure 4. If

$$\phi(0,1) > 0 \Leftrightarrow F > T\{\Delta^P / \beta + (\Delta^D - \Delta^P)\}, \tag{A-11}$$

there exists a unique $\rho^{**} \in (0,1)$ such that $\Pi^P(1,\rho^{**}) = \Pi^{BM}$, which corresponds to panel (b). In contrast, if

$$\text{(A-12)} \qquad \phi(0,1) < 0 \Leftrightarrow F < T\{\Delta^P / \beta + (\Delta^D - \Delta^P)\},$$

there exists a unique $\tau^* \in (0,1)$ such that $\Pi^P(\tau^*,1) = \Pi^{BM}$, which corresponds to panel (a). It is clear that the patent holder is over-compensated in the region to the upper right of curve E because Π^P is increasing in τ and ρ.

Lastly, we show that the region in which P's litigation threat is not credible is a subset of the region in which P is under-compensated. The litigation threat is credible if $\Pi^P - \pi^P \geq L^P \Leftrightarrow \Pi^P \geq \pi^P + L^P$. Then, it follows that the above statement is true because $\Pi^{BM} \geq \pi^P + L^P$ according to Assumption 3. *Q.E.D.*

Proof of Lemma 4.

In redesign states, i.e., $\Delta^D + \frac{F}{1-T} < \Delta^P$, $r^{BM} = \Delta^P$, which implies that equation (11) is the same as equation (16). If equation (16) does not hold, it is easy to see that $\Pi^P = \pi^P$, and it thus remains to investigate the opposite case.

If equation (16) holds, the disagreement payoffs to the patent holder and the downstream firm are

$$\text{(A-13)} \qquad \begin{aligned} \Pi^{P|suit} &= \pi^P + \rho\theta[1-(1-\tau)T]\Delta^P - L^P, \\ \Pi^{D|suit} &= \pi^D - \rho\theta[T\tau\Delta^P + (1-T)\Delta^D + F] - L^D, \end{aligned}$$

respectively. There are gains from trade if and only if $\pi^P + \pi^D \geq \Pi^{P|suit} + \Pi^{D|suit}$. Using (A-13) and rearranging the terms, equation (17) can be obtained. Therefore, if equation (17) holds, ex-ante negotiations are successful and

$$\text{(A-14)} \qquad \begin{aligned} \Pi^P &= \Pi^{P|suit} + \beta(\pi^P + \pi^D - \Pi^{P|suit} - \Pi^{D|suit}) \\ &= \pi^P + [\{1-(1-\tau)T\}\Delta^P - \beta\{(1-T)(\Delta^P - \Delta^D) - F\}] + \beta L^D - (1-\beta)L^P. \end{aligned}$$

Because we assume that the redesign costs are neutral, equation (A-14) coincides with the second line in equation (18). If equation (17) does not hold, the patent holder earns its disagreement payoff such that $\Pi^P = \Pi^{P|suit}$, which is the first line in equation (18).

The method used to determine the equilibrium payoff of the downstream firm is similar. *Q.E.D.*

Proof of Proposition 2.

We show that $\Pi^P \leq \Pi^{BM}$ in all three possible cases; (i) if equation (16) holds but (17) does not hold,

$$\text{(A-15)} \qquad \Pi^P - \Pi^{P|BM} = -\theta[1-\rho\{1-(1-\tau)T\}]\Delta^P - L^P.$$

Thus, $\Pi^P = \Pi^{P|BM}$ only when $\tau = \rho = 1$ and $L^P = 0$, and $\Pi^P < \Pi^{P|BM}$ otherwise. (ii) If both equation (16) and (17) hold,

$$\text{(A-16)} \quad \Pi^P - \Pi^{P|BM} = -\theta[\{1-\rho(1-(1-\tau)T)\}\Delta^P + \rho\beta\{(1-T)(\Delta^P - \Delta^D) - F\}].$$

Thus, $\Pi^P = \Pi^{P|BM}$ only when $\tau = \rho = 1$ and $(1-T)(\Delta^P - \Delta^D) - F = 0$, and $\Pi^P < \Pi^{P|BM}$ otherwise. (iii) If equation (16) does not hold, clearly $\Pi^P = \pi^P < \Pi^{P|BM}$. *Q.E.D.*

Proof of Lemma 5 and Proposition 3.

From the results derived in section III and the discussion in section IV, it is straightforward to derive the results in Lemma 5 and Proposition 3. That being so, we only present the conditions under which the downstream firm chooses to design around the feature. Designing around is optimal (i) if equation (12) and

$$\text{(A-17)} \qquad \rho\theta[\{1-(1-\tau)T\}\Delta^P + \beta F] + L^D > [1-\rho\theta\beta\{1-(1-\tau)T\}]\Delta^D$$

hold in licensing states, (ii) if equation (12) and

$$\text{(A-18)} \qquad \rho\theta[\{1-\beta-(1-\beta-\tau)T\}\Delta^P + \beta F] + L^D > [1-\rho\theta\beta(1-\tau)]\Delta^D$$

hold in lock-in states, and (iii) if equation (16) and

$$\text{(A-19)} \qquad \rho\theta[T\tau\Delta^P + F] + L^D > [1-\rho\theta(1-T)]\Delta^D$$

hold in redesign states. *Q.E.D.*

Proof of Proposition 4.

The court sets the ongoing royalty rate to $r^{BM} = \Delta^P + \beta\max\{\Delta^D - \Delta^P, 0\}$. Therefore, the downstream firm's marginal loss from paying the ongoing royalties is equal to $(1-T)r^{BM}$ for the remaining period. In contrast, the marginal loss from

redesigning is equal to $(1-T)\Delta^D + F$. The downstream firm redesigns if the former marginal loss is greater than the latter, and pays the ongoing royalties otherwise. In cases such that $\Delta^P \le \Delta^D$, $r^{BM} = \Delta^P + \beta(\Delta^D - \Delta^P)$. Thus,

$$(\text{A-20}) \qquad (1-T)\{\Delta^P + \beta(\Delta^D - \Delta^P)\} \le (1-T)\Delta^D < (1-T)\Delta^D + F,$$

which implies that the downstream firm would pay the ongoing royalties in this case. If we investigate the remaining cases ($\Delta^D \le \Delta^P \le \Delta^D + \frac{F}{1-T}$ and $\Delta^D + \frac{F}{1-T} \le \Delta^P$) in a similar way, it is straightforward to conclude that the downstream firm's optimal decision is characterized as stated in Proposition 4. It is also straightforward to derive the patent holder's payoff based on the above result; accordingly, we omit the details of the derivation. *Q.E.D.*

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