A Simple Theory of Defensive Patenting

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Abstract

A simple litigation game is constructed to study the strategic enforcement of patent rights. We first establish the benchmark result that when two symmetric parties hold patents of the same power, with non-zero legal expense a truce equilibrium exists such that, although each has a credible threat to unilaterally enforce its patent, along the equilibrium path no litigation will be initiated. This equilibrium behavior is applied to two issues: the defensive patenting phenomenon, and a firm's choice between the patent protection and trade secrecy. It is found that defensive patenting can alleviate the hold-up threat from the other's patent, and (i) firms' patenting decisions may be strategic complements or substitutes; but (ii) it may reduce the return of the inventor. For the former, we further show that patents can facilitate firms' coordination in investment when they are strategic substitutes; but the industrial-wide investment performance is independent of the outcome of the patenting game when strategic complements. For the latter, we offer an explanation why the 'pro-patent' policy shift in the U.S. since 1980s might actually reduce the incentive power of the patent system.

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1 Introduction

The patent system is widely viewed as an incentive scheme. It aims to spur innovation and information dissemination. But instead of giving monetary prize, its reward is indirect and can be realized only through the patent owner's enforcement action, or at least a credible threat to do so. Factors affecting the enforcement environment then are crucial to the incentive power of patents. Consider the following quote from von Hippel (1988), in a discussion of strategic enforcement in the semiconductor industry:

> Firm A's corporate patent department will wait to be notified by attorneys from firm B that it is suspected that A's activities are infringing B's patents. ... Firm A therefore responds-and this is the true defensive value of patents in the industry-by sending firm B copies of "a pound or two" of its possible germane patents with the suggestion that, although it is quite sure it is not infringing B, its examination shows that B is in fact probably infringing A. The usual result is cross-licensing ...

In a study of British patent system, Taylor and Silberston (1973) also mentioned the defensive usage in the electronic engineering field in 1960s. This counter-suit threat from the defendant is the focus of our paper.

To be sure, for patents to perform the function of 'defensive fences', its feasibility and usefulness depend upon both technology and legal features. Semiconductor and electronic engineering are two examples of 'complex technologies': multiple inventions have to be integrated into a product; and one technology, say, manufacturing process may be covered by multitude of patents with different owners. No single firm can develop or redo all the technologies required, and access to others' technologies is necessary. Plus, these fields also exhibit intrinsic difficulties facing the court in determining the validity or actual boundary of a patent. The mapping from technological to legal landscape is one with 'fuzzy boundaries', where everyone needs several pieces of technologies but no one can be sure whether they have infringed others' patents or not.

Moreover, in the U.S., since the past two decades this problem is exacerbated by a series of reforms and legal trends in the patent law arena.[1] With the creation of Court of Appeals for the Federal Circuit (CAFC) in 1982, it is generally agreed that the U.S. patent system has been 'strengthened' in several aspects: the patentable subjects expanded; the patent validity backed by the court more often; and the power of patent-holders increased via the grant of injunction. Another trend worth noting is that, as

[1] For a recent summary, see Jaffe and Lerner (2004).

some authors have claimed, the U.S. Patent and Trademark Office (USPTO) has been issuing low quality patents in the past decade.[2] Combining these policy shifts with technology features, the result is that firms get patents more easily, but also infringe others' patent rights more easily. In the word of Shapiro (2001), a 'patent thicket' is grown up. Several solutions have been devised to curb this problem.[3] Here we deal with one at the individual level, namely, the accumulation of patents.

To study the strategic enforcement and derived incentive to pursue patents, we first construce a simple litigation game. Patents are endowed with the conventional role to generate licensing income, but more interesting and pertinent to our concern is its potential to deter enforcement. A 'truce equilibrium' is found such that patent disputes are entirely eliminated along the equilibrium path, although each patentee has a credible enforcement threat. It will exist if both parties build patent portfolios with the same power, and if the enforcement cost is strictly positive. The intuition is similar to the nuclear weapon deterrence: everyone holds a weapon means no one will gain from exercising it, and so a peaceful life is maintained.

This equilibrium behavior is applied to two issues. In section 5 we study defensive patenting against the hold-up problem. When patents are pursued by a firm to protect its large scale investment from the hold-up threat of other patent-holders, as in the semiconductor industry (Hall and Ziedonis, 2001), we may expect patenting activity to exhibit strategic complementarity: for its defensive value, a patent is more useful if facing higher risk from other's patent threat. Our analysis shows that this is true when the industrial-wide investment performance is not affected by firms' patenting behavior. In this case, an 'offensive' patent serves solely to bring licensing revenue. On the other hand, when patents influence investment decisions, its strategic property depends crucially on firms' *joint* interest over investment performance of the whole industry: the condition guaranteeing the joint profit maximization of both investing (only one firm invests) coincides with the condition leading to strategic complementarity (strategic substitutability, respectively) of patents. Moreover, with strategic complementarity

[2]For example, Quillen and Webster (2001) shows that after taking into account the continuation application and continuation-in-part applications, the allowance rate (the number of applications allowed divided by the number filed) for the USPTO in mid-1990s (applications allowed in fiscal years 1995-1998 for original applications filed in fiscal years 1993-1996), is 95%, while 68% and 65% for the European and Japanese Patent Offices, respectively.

Possible reasons of this trend are: the explosion of patent applications increases the workload of the patent office; the emergence of applications in new fields requires new expertise and searching database, while PTO has not yet well-equipped with proper capacity; the resources constraint facing the PTO; the high turn-over among the examiners; and inadequate incentive scheme for examiners.

[3]For example, different collective property rights institutions such as patent pools and cross-licenses. For a general discussion, see Shapiro (2001).

the investment performance is independent of the equilibrium in the patenting stage, and it is optimal for firms to agree not to spend resources in acquiring patents. In the case of strategic substitutability, on the contrary, patents provide an opportunity of upstream collusion, i.e. for firms to coordinate on their investment decisions. This is true under restrictions on licensing space to preclude contracting directly on investment or royalties affecting downstream pricing.

The second point to be addressed is the negative impact of defensive patenting on the incentive power of the patent system. Since in a truce equilibrium no patents are enforced, when an inventor needs to be compensated, e.g. for her disclosure of the technology, a potential licensee or infringers' ability to get a defensive patent and mute potential dispute *weakens* her incentive to do so. It follows that a 'pro-patent' reform which makes defensive patenting a viable choice, as what has undergone in the U.S. since 1980s, might be detrimental to the very purpose of the system. Firms may rush to the patent office, but no one actually benefits from holding patents; they simply cannot afford not having one. In section 6, a simple example of a firm's choice between patent protection or trade secrecy is provided to illustrate this argument.

The paper is organized as follows: in the next section we briefly review relevant empirical and theoretical literature; in section 3 the basic model is presented; the enforcement subgame and particularly the 'truce equilibrium' is analyzed in section 4; the next two sections apply results in section 4 to hold-up and strategic patenting (section 5), and IPRs choice (section 6). Section 7 concludes.

2 Relevant Literature

At the heart of our analysis is the patent enforcement between two parties. It differs us from most previous works on patent litigation. Studies such as Meurer (1989) and Crampes and Langinier (2002) consider one patent-holder versus one infringing party. In Choi (2003) two patentees are considered, but they are not technology users; instead, there is a pool of downstream licensees from whom to extract licensing income. Here we consider two firms possessing patentable technologies, and can make investment infringing the other's patent with a probability. A suit is brought by one against the other. In follows that in our model it doesn't matter whether a patent is invalidated or no infringement is found;[4] while in Choi (2003), the only litigation type allowed is one of invalidation, although presumably both types need to be considered and have different effects.

[4]But certainly the two types of litigations have different plaintiffs.

Other studies closely related are Bessen (2003) and Ménière and Parlane (2004). Especially in the latter the authors also get a non-monotonic relationship and a negative effect of the patent power on investment incentives. But besides somewhat different focus, both share very different modeling features from us.

First, there is no enforcement cost in their models. Patent-holders always bring an infringement suit when the other present in the market. Here, by bringing back the enforcement cost we are able to construct a 'truce equilibrium', and most of what we get hinge on this equilibrium behavior. In a sense, our results are driven by strictly positive enforcement expense.

Second, both consider the case of single market/product where monopoly profit is greater than that of duopoly, and so a firm is forced to exit if it only infringes. Instead, we assume the opposite and a license is granted so that the infringing firm always stays in the market. Nevertheless with some qualifications our insights extend to the alternative industrial structure. In fact our modelling choice not only complements the previous literature, but also gives us a richer set of outcomes. In the single product environment, patents are much more likely to be strategic substitutes. Strategic complementarity results in only when enforcement cost is large enough, and investment cost small enough.

Several empirical findings inspire our inquiry into the defensive patenting. Besides anecdotal stories as quoted above, there are a few interview and statistical analysis demonstrating this phenomenon.[5] Especially interesting, and important on the policy ground, is the impact of the U.S. 'pro-patent' policy shift since 1980s. In Hall and Ziedonis (2001), it is shown that 'a surge in the patent propensities of semiconductor firms has indeed taken place since the "pro-patent" shift U.S. legal environment in the early 1980, and that the surge is driven by the aggressive patenting activities of large-scale manufacturing firms as well as the increased reliance on patents by entrant firms.' Since manufacturing firms incurred large investment in manufacturing facility and would suffer greatly from patent litigation threat, they have legitimate concerns to amass patent portfolios in order to shield away from litigation risk, or avoid a large balance payment in a cross-license.

On patent enforcement, using the data covering U.S. patent litigations in all technology fields during 1978-1999, Lanjouw and Schankerman (2003) found that an infringement suit is less likely to be filed based on a patent belonging to a larger owner (in terms of the employment size) or an owner with a larger patent portfolio. The latter

[5]For example, Levin *et al.* (1987) and Cohen *et al.* (2000) are two large-scale interview projects on the R&D departments of U.S. manufacturing firms in the 80s and early 90s, respectively.

result (on patent portfolio size) cannot be used directly to support or disapprove our findings, since the distinction between an 'offensive' or 'defensive' suit (a counter-suit) is critical in our model, but absent in their empirical analysis. Given characteristics of the rivaling party, a larger patent portfolio increases the power of a patent-holder both to attack or defend, with the former increases while the latter decreases the litigation probability. Concerning the firm size, however, one may reasonably argue it is consistent with our prediction: the defensive patenting strategy works better against a larger firm with a bigger hold-up stake, and this makes the truce equilibrium more relevant.

The counter-suit is explicitly considered in Somaya (2003), which contains patent suits filed in the U.S. federal district courts between 1983 and 1993 in the computer and research medicine industries. A clear pattern is that, in most cases when one suit came with a counter-suit, the two were disposed within one day of each other. Without any legal or administrative factor leading to these two legally separated proceedings, the author suggests a strong strategic concern of counter suits.

Finally, as stated in the introduction, we intend also to shed some lights on the debate concerning the impact of the U.S. patent reforms for the past two decades. It has been seen as a paradox why no robust evidence could be established to show a positive effect on the U.S. innovation activity following this pro-patent policy shift (Jaffe, 2000). We offer one story suggesting it might actually *weaken* the incentive power of the system.

3 Model

We study defensive patenting in a three-stage framework. In the basic model, there are two identical firms F_1 and F_2 each holds a basic technology, A_1 and A_2, eligible for patent protection. A basic technology brings positive revenue; and the level of revenue is higher if further investment is made to better exploit the technology. For example, A_i may represent new functionalities or improved manufacturing process. Additional development expenditures may be incurred in order to design new products that fit better with these functionalities, or to build new factories/equipments with an enhanced process. Endowed with A_i, each F_i faces a series of decisions: whether to apply for a patent; whether to invest; and when holding a patent, whether to enforce it. For simplicity, all decisions are observable, no asymmetric information is involved, and consider only pure strategies. The sole uncertainty in the model is the litigation outcome, as will be specified later.

At each of the patenting and investment stage, firms make a binary choice simultaneously. Let $p_i, e_i \in \{0,1\}$ be F_i's patenting and investment decisions, $i = 1, 2$. When $p_i = 1$, F_i gets a patent at a cost $K \geq 0$. Denote the patent profile in the industry as $P = (p_1, p_2)$. Similarly, let $c \geq 0$ be the investment cost when $e_i = 1$, and $E = (e_1, e_2)$ the investment profile.

In the basic model we assume that no technology transfer is needed between the two firms. For example, A_1 and A_2 may be different routes to similar functionality, and so each F_i needs only A_i to reach the market efficiently. However, this doesn't mean infringement will never occur. As discussed in the introduction, complicated technology issues make the boundary of patent claims difficult to clarify, and this uncertainty is exacerbated by the application of 'doctrine of equivalents,' which extends the scope of a patent beyond its written claims. Furthermore, unlike in the case of trade secrets, independent invention is not an effective defense against a patent infringement challenge. For these different reasons, a firm may be prohibited from using in-house technology.[6]

Two further assumptions about the litigation are imposed. (i) We assume that a firm can be found liable for infringement only if it invests. That is, the technology enchancement may infringe on the other firm's intellectual property (if patented). And (ii) as to the remedy, we assume the court grants permanent injunctive relief to the infringed party. A patent-holder prevailing in court can exclude the infringing firm from utilizing its investment, which serves as the threat point in the post-infringement bargaining.

With these specifications, the enforcement stage is constructed as follows. Assume a continuous and infinite time structure. For simplicity, suppose a patent never expires, and at most one suit can be initiated based on the same patent against the same party. The patent-holder's enforcement policy consists of the timing to sue, given the other has invested.

To enforce its patent right, the plaintiff sends a 'cease-and-desist' letter to the defendant. Upon receiving the letter, the latter may decide to terminate the employment of investment, so that no litigation will be arisen,[7] or continue utilizing the established

[6]The assumption of no technology transfer will be relaxed later in section 6. There, the two firms will no longer be symmetric and F_1 will be assumed to hold another invention B beneficial to F_2.

[7]Note that we assume the court doesn't grant monetary damage for past infringement. Our purpose is to construct a game structure so that a defensive patent can deter litigation (the truce equilibrium in Proposition 1). We present one such possibility. The same result can be reached if, for example, patent term is finite $[0, T)$ so that no one takes the last move, and monetary damage is rewarded for past infringement, where the damage is set at the same level as the licensing payment derived later in Lemma 1.

investment and prepare for a court fight.[8] If the defending party doesn't 'retreat', an infringement suit starts and both parties incur a strictly positive legal expense $L > 0$. The probability the patentee F_i prevails is $\alpha_i \in (0, 1], i \in \{1, 2\}$. For simplicity, assume the whole process, from sending the 'cease-and-desist' letter, deciding whether to retreat, the resolution of litigation uncertainty, to the bargaining after infringement (see below), takes place instantaneously at the moment chosen by the patent-holder (its enforcement policy). Different suits are tried independently. Furthermore, in sections 4 and 5, firms have common $\alpha = \alpha_1 = \alpha_2$.

Due to the injunction remedy and more generally the infringement suit threat, firms may want to bargain a license, or a cross-license in case of mutual-blocking. Referring to Figure 1, bargaining may occur at different stages of the game: *ex ante* licensing takes place before investment decisions are made, but after at least one firm has patented; *interim* licensing takes place after firms have chosen whether to invest, but before the enforcement stage;[9] while an *ex post* license is negotiated only after a patent is declared infringed by the court. In each round, we adopt the Nash bargaining solution with equal bargaining power. To make things interesting, we assume *ex ante* investment decisions are non-contractible. *Ex post* licensing will be our main concern, and the other two are discussed in section 5.3.

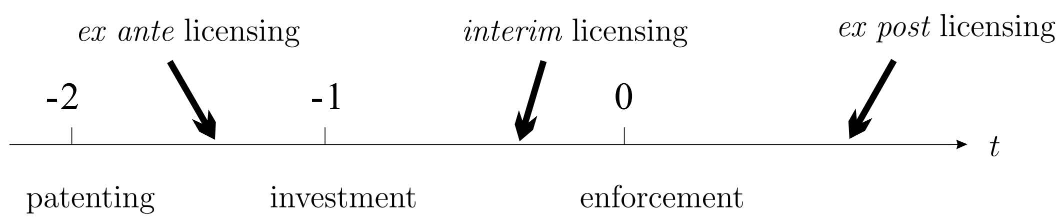

Figure 1: timing

Beginning at the enforcement stage, a stream of revenue accrues to each firm according to the prevailing investment profile. To make things simple, suppose once the cost c has been incurred, an investment can be 'switched' on or off without additional cost or depreciation, and at any point of time, the value accruing to firms depends only on the investment that is 'switched on' at this particular moment. For example, when interpreted as new product introduction, the status of a product–on the shelf (investment 'switched on') or prohibited from marketing ('switched off')–can be changed at

[8]We don't consider the plaintiff's decision whether to bring a suit, given the rival not retreat. Since there is no uncertainty about a patent-holder's type, a cease-and-desist notice will simply be ignored if the patentee has no credible threat of enforcement.

[9]This can be seen as the pre-trial settlement bargaining.

zero cost. And firms revenue depend only on how many products are on the market at that moment of time.

Assume the market starts at time 0 and is stationary. Slightly abusing the notation, we use also E to denote the industry investment utilization (e.g. the products in the market). Given $E = (e_1, e_2)$, let $\hat{v}_{e_1e_2}$ be the instantaneous value accruing to F_1, $\hat{V}_{e_1e_2}$ the joint value, and $r > 0$ the common interest rate. Assume firms are symmetric in payoffs, so that F_2 gets $\hat{v}_{e_2e_1}$. Then $\hat{V}_{e_1e_2} = \hat{v}_{e_1e_2} + \hat{v}_{e_2e_1}$. Normalize the initial date of the enforcement stage to $t = 0$. For the same E, e.g., equals to $(0, 1)$, at a particular point of time the same $\hat{v}_{01}$ and $\hat{V}_{01}$ apply regardless of the scenario leading to this profile: it may be the case that F_1 didn't invest but F_2 did, and there is no patent dispute till now; or both has invested, but after some court fight only F_1 is declared infringing and the two fail to agree on a license; or only F_2 has invested, it is sued and declared infringing, but secured a license. Implicit in this assumption is a restriction on the licensing space over which firms can bargain *ex post*. In particular, we rule out the facilitation of downstream collusion by patents. For instance, if E represents firms' product introduction decisions, no price coordination clauses such as a running royalty changing the cost structure or the field-of-use constraints are allowed.

Denote the discounted present value of the market revenue $\int_0^\infty \hat{v}_{e_ie_j} e^{-rt} dt = \hat{v}_{e_ie_j}/r$ as $v_{e_ie_j}$, and $\hat{V}_{e_ie_j}/r$ as $V_{e_ie_j}$, where $i, j \in \{1, 2\}, i \neq j$. Throughout the paper we restrict our attention to the case where *ex post* efficiency requires full utilization of any established investment, but a firm's investment exerts a negative externality on the other. The following assumption summarizes these relationships:

Assumption **1.** For any $e_1, e_2 \in \{0, 1\}$, we have $v_{1e_2} \geq v_{0e_2} \geq 0,\ v_{e_10} \geq v_{e_11} \geq 0$, and $V_{11} \geq V_{10} = V_{01} \geq V_{00}$.

While *ex post* efficiency guarantees that *ex post* licenses always emerge as the bargaining outcome, the negative impact makes the infringed firm's shut-down threat credible had the two failed to reach an agreement. These two together make patents a licensing-fee-generating device rather than a tool for protecting one's own market niche.

Note that if firms could sign an enforceable contract on their investment decisions, joint profit maximization would result from the program $\max\{V_{11} - 2c, V_{10} - c, V_{00}\}$. Depending on the size of c, the optimal investment profile may not be $E = (1, 1)$.

Example 1. (Multi-products competition) F_1 and F_2 each possesses an original version of a product in its own market segment. Each market is composed of homogeneous consumers of mass one, the two firms compete *à la* Bertrand, but are able to charge different prices in different markets. For simplicity, suppose the original version has a value v for home-market consumers, but is worthless for consumers in the other segment. Each firm is the monopolist in the home-market. Assume zero production cost. Therefore with original versions of both goods, each firm charges a price v, which is also the profit level. In the previous notation, $v_{00} = v$.

Now, suppose each can incur cost c to make an improvement, which has an additional value $\triangle v$ for consumers in home market, and $\gamma \triangle v$ for consumers in the other segment, $\gamma \in [0, 1]$. Assume the improvement is combined with own original version, but not drastic enough to replace the other's old product, $\gamma \triangle v < v$. By price competition it restrains the maximal price the rivaling monopolist can charge at the latter's home market. When both invest the equilibrium prices at each market are $v + (1 - \gamma)\triangle v$ for the improved home product, and zero for the 'invading' product; while if only one firm invests, it can charge the monopoly price $v + \triangle v$ in its own market, competes with its new functionality in the adjacent market and sets a price to zero, while the old version in that market can only charge $v - \gamma \triangle v$. The investment revenues are then: $v_{11} = v + (1 - \gamma)\triangle v$, $v_{10} = v + \triangle v$, and $v_{01} = v - \gamma \triangle v$. Summing up, $V_{11} - V_{10} = (1 - \gamma)\triangle v$. ■

4 Enforcement and the Truce Equilibrium

This section analyzes the enforcement stage, which starts once firms have made their patenting and investment decisions, and no prior agreements exist to waive out patent-holders' suing rights. For a patent to matter, at least one firm must hold a patent and the other must have invested. We derive payoffs of different histories of the game according to how many suits can possibly be brought.

□ **Patent is irrelevant:** this is the case when no firm holds any patent, or when some firm has chosen to patent but the other didn't invest. The game ends with the investment being chosen. Given investments e_1 and e_2, the payoff of F_i is $\pi_i = v_{e_i e_j} - ce_i$, where $i, j = 1, 2, j \neq i$.

□ **Only one patent matters:** this is the case when only one firm patents and the other invests, or both hold patents but only one firm invests. Suppose $e_2 = 1$, F_1 has a patent and $e_1 \in \{0, 1\}$.

Consider if F_1 enforces its patent at time $T_1 \geq 0$, and F_2 not retreats so that a suit initiated. Prior to that date, the revenue streams accruing to F_1 and F_2 are $\hat{v}_{e_1 1}$ and

$\hat{v}_{1e_1}$, resepectively. Both firms incur legal expense with discounted value Le^{-rT_1}. With probability $1-\alpha$, there is no infringement, no bargaining takes place and so revenue streams remain the same. With probability α, the court finds that F_2 infringes F_1's patent. In this case, from ASSUMPTION 1 post-infringement bargaining involves only a fee transfer while the investment profile $E = (e_1, 1)$ is unchanged. The following lemma determines the transfer.

LEMMA 1. *When F_2 infringes at time T_1 and there is no counter-suing threat, the bargaining results in a license from F_1 to F_2. F_2 pays a licensing fee with the present discounted value equal to fe^{-rT_1}, where $f = \frac{1}{2}(v_{10} - v_{01})$, independent of F_1's investment.*

Proof. If F_2 cannot secure a license from the patentee, by ASSUMPTION 1, $\hat{v}_{e_10} \geq \hat{v}_{e_11}$ so that F_1 will credibly exercise its injunctive power, and so the threat point revenue stream is $\hat{v}_{e_10}$ for F_1 and $\hat{v}_{0e_1}$ for F_2. Since their cooperative joint revenue stream is $\hat{v}_{e_11} + \hat{v}_{1e_1}$, there is a joint bargaining surplus to be obtained from licensing. The two parties agree to let F_2 exploit investment e_2, so the investment outcome is $E = (e_1, 1)$.

Although the magnitude of the bargaining surplus depends on the value of e_1, the licensing fee is the same: when splitting the bargaining surplus equally, F_1 gets

$$\int_{T_1}^{\infty} \left[\hat{v}_{e_10} + \frac{\hat{v}_{e_11} + \hat{v}_{1e_1} - \hat{v}_{e_10} - \hat{v}_{0e_1}}{2}\right] e^{-rt} dt = \left(v_{e_11} + \frac{v_{e_10} + v_{1e_1} - v_{e_11} - v_{0e_1}}{2}\right) e^{-rT_1}.$$

Define $f \equiv \frac{1}{2}(v_{e_10} + v_{1e_1} - v_{e_11} - v_{0e_1})$, it is easy to see that $f = \frac{1}{2}(v_{10} - v_{01})$ for both values of e_1. *Q.E.D.*

This lemma implies that, if F_1 enforces its patent rights at time T_1, the expected litigation gain is αfe^{-rT_1}, regardless of its own investment level. In a more general setting this independence property should not be expected to hold.[10] Nevertheless, our special case of binary choice leads to a simple way to introduce the assumption of patent rights enforcement, for the same condition can be applied without reference to the patent-holder's investment level.

ASSUMPTION **2.** (i) $\alpha f \geq L$; (ii)[11] $\forall e \in \{0, 1\}, v_{0e} \leq v_{1e} - (\alpha f + L)$.

[10]This can be seen from the term $v_{e_10} + v_{e_2e_1} - v_{e_1e_2} - v_{0e_1}$ in the proof of LEMMA 1 (where $e_2 = 1$). This expression shows that

$$v_{e_10} + v_{e_2e_1} - v_{e_1e_2} - v_{0e_1} = (v_{e_2e_1} - v_{0e_1}) + (v_{e_10} - v_{e_1e_2}),$$

the first term represents the gain F_2 realizes when allowed to use its investment, and the second term reflects the negative impact this investment exerts on F_1. Both could be dependent on e_1.

[11]Thank to Richard Schmidtke for this point.

The first part says that F_1 has a credible action to sue; and from the second part, F_2 won't retreat and stop utilizing its investment when facing the litigation threat. Then litigation takes place following F_1's enforcement effort. Note that absent ASSUMPTION 2(i), patents become irrelevant in our model; and we will comment later what if ASSUMPTION 2(ii) is not held.

From this assumption, in the absence of *interim* licensing F_1 brings a suit at the earliest possible date, $T_1 = 0$. The expected payoffs for F_1 is $v_{e_1 1} + (\alpha f - L)$ and $v_{1 e_1} - (\alpha f + L)$ for F_2.

□ **Two relevant patents:** when $P = E = (1,1)$ each firm can bring an infringement suit. Assume that at most one suit can be brought at any point of time, and that there is a reaction lag $\triangle > 0$, such that if, for example, F_1 brings the first suit against F_2 at T_1, then the earliest possible time for F_2 to counter-sue is time $T_1 + \triangle$. This serves only as an artificial device to facilitate the discussion, and we'll focus on the limiting case where $\triangle \to 0$.

Fixing $\triangle > 0$, without loss of generality let F_1 be the 'first mover.' Suppose that there has been no patent dispute until $T_1 \geq 0$, and that F_1 decides to bring an infringement suit. In the absence of *ex ante* or *interim* licenses, F_2 is endowed with a right to sue as well. Its enforcement policy is the date to counter-sue. Since we adopt the assumption that *ex post* licensing takes place only when a patent is infringed, the bargaining at T_1, which happens when F_2 infringes F_1's patent, therefore makes no agreement upon F_2's un-exercised patent rights.[12] LEMMA 2 shows that it is optimal for F_2 to set this date as early as possible, i.e. at $T_1 + \triangle$, and lists expected payoffs. The proof is relegated to Appendix A. Note that payoffs contain only those starting from date T_1, but are discounted to the date of $t = 0$.

LEMMA 2. *Suppose $P = E = (1,1)$ and* ASSUMPTION *2 is held. If F_1 brings the first suit at $T_1 \geq 0$,*

(i) (Optimal counter-suit) the optimal enforcement policy for F_2 is to bring the counter-suit at date $T_1 + \triangle$;

(ii) the expected payoffs are:

$$\pi_1^s = \left[v_{11} + \alpha f (1 - e^{-r\triangle}) - L(1 + e^{-r\triangle}) \right] e^{-rT_1}, \tag{1}$$

$$\pi_2^s = \left[v_{11} - \alpha f (1 - e^{-r\triangle}) - L(1 + e^{-r\triangle}) \right] e^{-rT_1}, \tag{2}$$

where the superscript 's' means that F_1 sues F_2.

[12] This assumption is chosen in order to be consistent with the case that the negotiation to use F_1's patent won't happen without completing the court fight when only *ex post* licensing is allowed.

The intuition of this lemma is quite simple. Once the rival has exercised its patent rights, the counter-suing decision reduces to a unilateral attack as in the previous case and entails no more strategic consequence for the remaining game. ASSUMPTION 2 guarantees the optimality of counter-suing. Since delaying the litigation only retards the realization of this gain, it is optimal for F_2 to bring a suit at the earliest possible date, $T_1 + \triangle$.

Next, consider the two expressions (1) and (2). When F_1 sues at T_1, the licensing income it could expect now is smaller than $\alpha f e^{-rT_1}$ (in present value). Since F_2 also holds a patent with infringing probability α and can bring a suit at time $T_1 + \triangle$, the expected transfer here should reflect the threat from F_2's patent. But the negative impact decreases as the threat gets remote. For example, if $\triangle \to \infty$, then F_1 can get the full $\alpha f e^{-rT_1}$. On the other hand, the coefficient of the expected legal expense, $1 + e^{-r\triangle}$ comes from the fact that F_2 brings a counter-suit with a delay. To sum up, by being the first to sue F_1 enjoys a 'first-mover advantage' $\alpha f(1 - e^{-r\triangle})$, but this advantage vanishes as F_2 can respond quickly ($\triangle \to 0$).

With this lemma, we show the main result at the enforcement stage, the existence of the truce equilibrium. See APPENDIX A for its proof.

PROPOSITION 1. (*Litigation deterrence and the truce equilibrium*) *Consider the enforcement stage when $P = E = (1, 1)$. A war equilibrium always exists, in which both firms initiate an infringement attack at the earliest possible date.*

However, if $\triangle$ is small enough, there is another, Pareto-dominant subgame perfect equilibrium (the truce equilibrium) without any litigation ever arises on the equilibrium path. The symmetric strategy supporting the truce equilibrium is: do not sue if one has not been sued till now, and if one has been sued, bring a couter-suit at the earliest possible date.

For both firms, when $\triangle \to 0$ the equilibrium payoffs are $\pi^w = v_{11} - 2L$ in the war equilibrium, and $\pi^t = v_{11}$ if truce equilibrium prevails.

When firms are willing to sue (when ASSUMPTION 2 is held), they can always do so unilaterally. The war equilibrium always exists. But in net both may suffer from engaging in this unilateral enforcement, as when firms are symmetric. In this case, a peaceful life is in their joint interest and can be maintained by both firms adopting the counter-suing-only strategy. The counter-suit threat is credible because it amounts to a unilateral decision.

REMARK 1. Although not unique, we will let the truce equilibrium prevail whenever it exists. Two reasons justify this selection. First, it is clear from π^t and π^w that the truce equilibrium Pareto dominates the war one. Both firms gain from coordinating to the truce equilibrium. And second, it is possible to introduce some small and reasonable perturbation into the game to eliminate the war equilibrium. See Appendix B.

Remark 2. We show the existence of the truce equilibrium under symmetry assumption, but this should not be a critical constraint. In general, the same argument goes through when firms get no positive gains in expectation from engaging in litigation war. In section 6 firms will be asymmetric, but we still rely on the truce equilibrium heavily.

A simple corollary is a non-monotonic relationship between the number of patents and infringement suits.

Corollary 1. *When the truce equilibrium prevails, the number of suits and number of patents may follow a non-monotonic relationship: no litigation when either no patent or both firms patent, and one infringement suit when only one firm holds a patent and the other has invested.*

5 Hold-up and Strategic Patenting

Let us now move back to the investment and patenting stages. We first show that defensive patenting indeed can alleviate the hold-up menace posed by the other's patent. But a more general concern is the impact of patents on the investment performance. For the patenting stage, the issue is the strategic relationship between firms' patenting decisions. The main body of discussion proceeds with *ex post* licensing; the *interim* and *ex ante* licensing is introduced in section 5.3.

5.1 Investment

A firm's investment decision depends on the patent profile P and the other's investment level. This subsection derives investment criteria in different situations.

⋄ When no one holds a patent, $P = (0, 0)$, the investment is determined solely by $\{v_{\cdot}\}$. If $e_2 = 0$, F_1 invests if and only if $c \leq c_0^* \equiv v_{10} - v_{00}$; and if $e_2 = 1$, the criterion to invest is $c \leq c_1^* \equiv v_{11} - v_{01}$.

⋄ When only one firm, e.g. F_1 has a patent, $P = (1, 0)$. Only F_2 faces the litigation threat, and so investment criteria for F_1 are the same: $c_{e_2}^*$, with $e_2 \in \{0, 1\}$. For F_2, on the other hand, from the previous section the patent-holder F_1 will enforce its patent rights against F_2 as long as $e_2 = 1$. This enforcement decision as well as the expected licensing payment αf are both independent of e_1 according to Lemma 1. This expropriation of return decreases F_2's investment incentive: given $e_1 \in \{0, 1\}$, F_2 invests if and only if $c \leq \underline{c}_{e_1} \equiv c^*_{e_1} - (\alpha f + L) < c^*_{e_1}$.

⋄ When $P = (1, 1)$, both firms hold a patent. Under the truce equilibrium, a firm secures full return on its own investment if the other also invests. If $e_2 = 0$, F_1's patent is irrelevant, and the hold-up issue arises again. F_1 adopts the criterion $\underline{c}_0$. When $e_2 = 1$, by investing F_1 gets $v_{11} - c$ because the litigation will be deterred; however, if it chooses not to invest, then F_1 can hold up F_2, and the expected profit from doing so is $v_{01} + \alpha f - L$. In this case, F_2's patent poses no threat to F_1, but F_1 may want to keep a low profile in order to share F_2's investment fruit via patent enforcement. The investment threshold for F_1 is then $\hat{c} \equiv c^*_1 - (\alpha f - L)$. From Assumption 2, $\underline{c}_1 < \hat{c} \leq c^*_1$, the hold-up problem is alleviated, but another incentive to under-invest appears. Firms may want to keep small and aggressive in order to realize the expected gain from litigation.

Absent patents, investment decisions are strategic complements if $c^*_0 < c^*_1$ in that one firm's investment increases the other's incentive to do so; and strategic substitutes if $c^*_0 > c^*_1$. But at $P = (1, 1)$, since $\hat{c} - \underline{c}_0 = c^*_1 - c^*_0 + 2L$ the strategic property of investment decisions may be changed, relative to other profiles. When $P \neq (1, 1)$, this strategic property is determined by the relative size of c^*_0 and c^*_1; but when everyone has a patent, strategic complementarity results in as long as $c^*_0 < c^*_1 + 2L$. Indeed, as long as L is large enough, there exist cases where investment decisions are strategic substitutes when $P \neq (1, 1)$ and become strategic complements when $P = (1, 1)$, but not the reverse.

Proposition 2. *Patents can transform investment decisions from strategic substitutes into strategic complements, but not the other way around.*

While the two thresholds c^*_0 and c^*_1 are non-negative by assumed parameter values, the introduction of patents could dissuade firms from investing. All the other three thresholds could have negative values. In addition, the two institutional factors α and L exert different impacts on these thresholds. The hold-up problem is exacerbated by higher α and L ($\underline{c}_0$ and $\underline{c}_1$ decreasing in both). On the other hand, the profitability of a 'lean and hungry' strategy depends on the expected gains of patent enforcement, therefore $\hat{c}$ is decreasing in α but *increasing* in L. A higher enforcement cost L makes it rather unattractive to refrain from investing in order to earn licensing payment, and so boosts the investment incentive.

Now, we can combine these criteria and consider the investment profile emerges.

Suppose all thresholds are positive, also ignore the uninteresting case in which no firm invests because c is too large ($c > \max\{c_0^*, c_1^*\}$).

$\diamond$ When $c \le \min\{\underline{c}_0, \underline{c}_1\}$, both invest whatever the profile P. Patents have no impact on firms' investment decisions.

$\diamond$ When c lies in the intermediate range, $c \in (\min\{\underline{c}_0, \underline{c}_1\}, \max\{c_0^*, c_1^*\}]$, multiple patterns could emerge. We consider here only one scenario specified in TABLE 1. It is applicable as long as $\underline{c}_1 < c \le \min\{\hat{c}, c_0^*\}$, whether c_0^* is greater, smaller, or equal to c_1^*.[13] In this case, both firms invest in the absence of patent, $P = (0, 0)$. If only one firm patents, $P = (1, 0)$ or $(0, 1)$, only the patent-holder invests due to the hold-up concern. However, defensive patenting fully solves this problem, while the incentive to 'play small' is not too high, therefore when both patent the equilibrium investment is again $E = (1, 1)$.

In the empirical study (for example, Hall and Ziedonis, 2001), for big manufacturing firms defensive patenting is usually associated with an intention to safeguard investment. This suggests a case in which the 'freedom of operation' is preserved, i.e. patent disputes can be eliminated, and both firms invest. In this case, $E = (1, 1)$ at $P = (1, 1)$ is a reasonable focus to study.[14] [15] Note that $E = (0, 0)$ doesn't appear in any P.

p_1 \ p_2	0	1
0	$(1, 1)$	$(0, 1)$
1	$(1, 0)$	$(1, 1)$

TABLE 1: investment profile E for intermediate c

EXAMPLE 1 (CONTINUED). When $P \neq (1, 1)$, investment decisions are strategically independent. Both $c_1^* = c_0^* = \triangle v \equiv c^*$ and $\underline{c}_1 = \underline{c}_0 = \triangle v - (\alpha f + L) \equiv \underline{c}$, with $f = (1 + \gamma)\triangle v/2$. However, when $P = (1, 1)$, patents are strategic complements, for

[13]For example, when $\underline{c}_1 < \hat{c} < \underline{c}_0 < c_1^* < c_0^*$ or when $\underline{c}_0 < \underline{c}_1 < \hat{c} < c_0^* < c_1^*$, and for both case if $c \in (\underline{c}_1, \hat{c}]$.

[14]One interesting case omitted here is the consequence of the defensive party's underinvestment on the offensive party's investment choice: the latter's enforcement may backfire when $c_0^* < c_1^*$. For example, consider $P = (1, 0)$ and $\underline{c}_0 < \underline{c}_1 < c_0^* < \hat{c} < c_1^*$ with $c \in (c_0^*, \hat{c}]$. The defensive firm F_2 doesn't invest, and this decreases F_1's return on investment ($c_1^* > c_0^*$). By the chosen range of c, the investment profile emerges is $E = (0, 0)$, no one invests. On the other hand, if $c_0^* \ge c_1^*$, then F_2's underinvestment can only (weakly) boost F_1's incentive to invest.

[15]A caution is that for empirical studies like this, patent numbers are usually treated as the dependent variable and capital investment as the explanatory variable. Therefore the timing may be different from the setting in this paper. However, these two variables exhibit a positive and significant statistical relationship.

$\hat{c} = \triangle v - (\alpha f - L) > \underline{c}$. When $c \leq \underline{c}$, both firms invest regardless of P. TABLE 1 is the investment outcome when $c \in (\underline{c}, \hat{c}]$. ■

5.2 Patenting

Let us now turn to firms' patenting decisions. Again, $c > \max\{c_0^*, c_1^*\}$ is the uninteresting case where no firm would ever want to invest, and the unique investment outcome is $E = (0,0)$. No firms patent, $P = (0,0)$.

□ **Low** c**:** when $c \leq \min\{\underline{c}_0, \underline{c}_1\}$, the unique investment outcome is $E = (1,1)$ for all P. Table 2 shows the payoff matrix for each patent profile, but ignores the patenting cost K. By symmetry, it suffices to write down only F_1's payoff.

p_1 \ p_2	0	1
0	$v_{11} - c$	$v_{11} - c - (\alpha f + L)$
1	$v_{11} - c + (\alpha f - L)$	$v_{11} - c$

Table 2: Payoffs for small c

The incentive to patent here hinges solely on the litigation concern. Since investment outcome not affected by patents, different Ps involve at most a zero-sum transfer between firms plus the legal expense. So, for example, when $P = (1,0)$, the expected loss of the non-patenting party is greater than the expected gain of the patent-holder, $\alpha f + L > \alpha f - L$, so long as $L > 0$. It then follows that a patent is more valuable for its defensive role (when the rival holds a patent) than for its offensive role (when the rival doesn't have any patent). Patents are strategic complements.

PROPOSITION 3. *If firms invest with or without the presence of patents, and if patents can deter litigation (the truce equilibrium prevails), then patenting decisions are strategic complements.*

□ **intermediate** c**:** if $\min\{\underline{c}_0, \underline{c}_1\} < c \leq \max\{c_0^*, c_1^*\}$ and the investment outcome is as specified in Table 1, then payoffs are those in Table 3. In this case no litigation takes place along the equilibrium path, for either the only non-patenting firm does not invest, or the truce equilibrium prevails.

In contrast with the previous case, firms' patenting decisions here are driven by the concern about investment performance. Although no licensing transfer is involved, an

$p_1 \backslash p_2$	0	1
0	$v_{11} - c$	v_{01}
1	$v_{10} - c$	$v_{11} - c$

Table 3: Payoffs for intermediate c

offensive patent deters investment, and this results in a non-negative benefit $v_{10} - v_{11}$. On the other hand, when the rivaling firm does hold a patent, a defensive incentive to get a patent is its own investment return $v_{11} - v_{01} - c$. Comparing the two, patents are strategic complements if and only if

$$v_{11} - v_{01} - c > v_{10} - v_{11} \Rightarrow V_{11} - c > V_{10}.$$

The strategic relationship of patents is determined by which investment profile feasible under the patent system, $E = (1,0)/(0,1)$ or $(1,1)$, gives rise to a higher *joint* profit!

Since it is required that $c \in (\min\{\underline{c}_0, \underline{c}_1\}, \max\{c_0^*, c_1^*\}]$, a necessary condition of strategic complementarity is:

$$\min\{\underline{c}_0, \underline{c}_1\} < V_{11} - V_{10} \Rightarrow \min\{0, (v_{10} - v_{00}) - (v_{11} - v_{01})\} + (v_{10} - v_{11}) < \alpha f + L. \quad (3)$$

It is more likely to be satisfied if patents are more powerful (α higher) or enforcement is more costly (L higher).

PROPOSITION 4. *When the investment cost is in the intermediate range and relevant payoffs as in Table 3,*

- *Necessary and Sufficient Condition: patents are strategic complements (strategic substitutes) if and only if* $V_{11} - c$ *is greater (smaller, respectively) than* V_{10}*;*
- *Sufficient condition of strategic substitutability: if inequality (3) fails, patents are strategic substitutes.*

Let us re-introduce a positive patenting cost K and consider the resulting equilibrium investment profile, we get another non-monotonic relationship. The proof is in Appendix A.

COROLLARY 2. *Assume the same conditions as* PROPOSITION *4. When patents are strategic complements, the equilibrium investment outcome is* $E = (1,1)$*. Depending on the level of patenting cost* K*, the equilibrium patenting outcome is either* $P = (0,0)$ *or* $(1,1)$.

When patents are strategic substitutes, however, different Es emerge, yielding a non-monotonic relationship of investment with K. For K either low or high so that either both patent or no one patents, $E = (1, 1)$; but when K lies in an intermediate range so that in equilibrium only one firm patents, only the patent-holding firm invests.

Some scholars, for example Merges (1997), have depicted the patenting game in industries such as software as one of prisoners' dilemma. That is, it is a dominant strategy for each firm to pursue patents despite a joint interest of not doing so. Our model shows when this is correct: namely when patents are strategic complements and the patenting cost K is low. With strategic complementarity but K in the intermediate range, patenting becomes a coordination game: no firms has a dominant strategy, multiple equilibria exist, and they can be Pareto ranked. Indeed, in this case whether $P = (0, 0)$ or $(1, 1)$ prevails the subgame perfect equilibrium in investment and enforcement stages are the same, but in the latter equilibrium firms have to incur the patenting cost K and therefore is Pareto dominated by the no-patent equilibrium $P = (0, 0)$.

For the case of strategic substitutes, things are rather different. Since now the investment profile is sensitive to the patenting equilibrium, joint profit maximization may require one firm to be held up and not invest. To see this, note that when $K < v_{11} - v_{01} - c$ both firms patent and invest, and the joint profit is $V_{11} - 2c - 2K$. If the patenting cost raised to some level $K' \in (v_{11} - v_{01} - c, v_{10} - v_{11}]$, then the joint profit is $V_{10} - c - K'$. As long as the relationship $K' - 2K < V_{10} + c - V_{11}$ is satisfied the industrial-wide profit is increased even with an increase in the patenting cost $K' > K$. The same thing could happen with strategic complements only if after increasing K firms succeed in coordinating to the no patenting equilibrium.

5.3 Alternative Licensing Opportunities

Now consider if firms can engage in *ex ante* or *interim* licensing. The case of *interim* licensing is examined first, i.e. when firms try to resolve patent disputes before going to court. It will illustrate the role of the enforcement cost in our model. For the *ex ante* licensing, we show that this opportunity can be exploited by firms to coordinate their investment decisions. In this sense, patents together with *ex ante* licensing serve to facilitate upstream collusion.

□ *Interim* **licensing:** suppose that firms can bargain before going to court. In general it is cheaper to resolve patent disputes outside the court, and we consider first if *interim* bargaining incurs no cost.

For the enforcement subgame. When there is litigation, for example, when $e_2 = 1$ and only F_1 holds a patent, the threat point joint profit at the *interim* bargaining is $V_{e_1 1} - 2L$, $e_1 \in \{0, 1\}$; the cooperative joint profit is $V_{e_1 1}$. The bargaining surplus is the litigation expense $2L$. With equal bargaining power, firms save the litigation cost by engaging in *interim* licensing. F_1 gets payoff $v_{e_1 1} + \alpha f$ and F_2 gets $v_{1e_1} - \alpha f$, the same as putting $L = 0$ in the previous derivation. On the other hand, if no litigation will ever take place, firms won't bother engaging in bargaining at this stage. The truce equilibrium is robust to the introduction of *interim* licensing opportunity. Even if some party sends a letter inviting the other to talk, the receiver can simply ignore it because no firms would want a war anyway.

For the investment stage. Investment thresholds $\{c_e^*\}_{e=0,1}$ are unaffected by *interim* licensing; while $\{\underline{c}_e\}_{e=0,1}$ increased to $c_e^* - \alpha f, e \in \{0, 1\}$, which we denote as $\underline{c}_e^{in.}$. Although there is still a licensing fee αf, the saving of L decreases the licensee's loss from a patent attack, and this boosts the incentive to invest. As to the criterion $\hat{c}$, it decreases to $c_1^* - \alpha f = \underline{c}_1^{in.}$. Without actually incurring the enforcement expense a firm is more willing to keep 'small' to be aggressive. Therefore when $P = (1, 1)$, both firms employ the investment criteria $\underline{c}_e^{in.}$ given the rival's investment e. A potentially offensive firm has as strong incentives to underinvest as a defensive one in fear of the hold-up problem. And this in turn makes investment outcomes Table 1 almost impossible to attain. Before showing this, we follow the order of previous discussion and digress to the case when c is small so that $E = (1, 1)$ always prevails.

For Proposition 3,[16] the strategic complementarity property is lost if no enforcement cost, $L = 0$. Patents now become strategically independent. In the present situation, the strategic property is determined by comparing the loss to the licensee with the gain of the licensor, in the case of asymmetric patent status ($P = (1, 0)/(0, 1)$). But since a license here involves only a zero-sum transfer between the two parties, strategic complementarity can be restored by any $L > 0$. On the contrary, strategic substitutability requires the licensee incurs a cost level higher than the licensor, which seems less likely.

When P has an impact on E,[17] without enforcement cost Table 1 and so Table 3 are not feasible except a marginal case. To see this, consider the required investment outcomes when $P = (1, 0)$ and $(1, 1)$. To have $E = (1, 0)$ in the former profile, given $e_1 = 1$, for F_2 (the firm not having a patent) not to invest, it should be $c > \underline{c}_1^{in.}$. But to

[16] The corresponding condition now is $c \leq \min\{\underline{c}_0^{in.}, \underline{c}_1^{in.}\}$.

[17] The condition is $c \in (\min\{\underline{c}_0^{in.}, \underline{c}_1^{in.}\}, \max\{c_0^*, c_1^*\}]$.

have $E = (1, 1)$ in the latter case, when $e_2 = 1$, say, to induce $e_1 = 1$ we need $c \leq \underline{c}_1^{in.}$. Except when $c = \underline{c}_1^{in.}$ and firms decide whether to invest 'correctly', we won't have Table 1 as the outcome.

Nevertheless, all these are true only when *interim* licensing is costless. If there is some positive bargaining cost, previous results are re-gained, as we could simply re-interpreting L as the cost for each party engaging in *interim* licensing. From this, what we consider here relates more to the role of enforcement cost in our model than the exact timing of licensing. And it shows that the introduction of enforcement cost L is a non-trivial consideration when thinking about the patent system. Put differently, our results are driven by the enforcement cost.

To have positive *interim* bargaining cost, we can think of it as the contracting cost, including the management time and effort spending in negotiation and crafting out appropriate licensing terms, or the enforcement cost up to a pre-trial settlement. Another way is to keep the assumption that *interim* licensing is costless, but instead introduce an asymmetric information element at the *interim* bargaining stage, as in Bebchuk (1984). One example is presented in Appendix C.[18]

Proposition 5. *Suppose interim licensing is available at no cost. When the investment cost is low so that firms always invest, patenting decisions are strategic independent. When investment decision is sensitive to patent profiles (investment cost in the intermediate range), the investment profiles in* Table *1 is not feasible as an equilibrium except a marginal case.*

However, all qualitative results are re-gained with non-zero interim licensing cost. This may come from (i) contracting cost; or (ii) bargaining failure due to asymmetric information.

☐ *Ex ante* **licensing:** suppose no *interim* licensing and $L > 0$. Consider if firms can bargain before the investment stage with a lower cost $l \in [0, L]$. Different from

[18] Consider if after the investment stage, a patentee receives a piece of private information about her own α. It may be the quality of her patent, or the extent to which her patent 'reads on' the rivaling firm's investment. It is possible to have cases such that: (i) for any possible values of α, a patent-holder still has a credible enforcement threat, i.e. Assumption 1 is held for all α; (ii) when there are two relevant patents, the truce equilibrium prevails in spite of the asymmetric information. That is, in expectation the rival's α is high enough so that a litigation war has negative expected return even for a 'good-type' patent-holder (high α), and so no *interim* licensing is needed; and (iii) when only one patent dispute is concerned, the uninformed party (the potential licensee) makes the licensing offer (a take-it-or-leave-it offer) and has an incentive to screen among different types by fighting in the court with non-zero probability. With this structure, a payoff of $v_{11} - c$ is guaranteed when $P = E = (1, 1)$ from the prevalence of the truce equilibrium; but when only one patent is relevant, with a positive probability bargaining fails, the two firms go to court and incur the litigation cost L. Investment criteria need to be modified accordingly, but qualitative results we've got keep intact. See Appendix C for more details.

the *interim* bargaining, an *ex ante* licensing provides firms an opportunity not only to preclude future patent disputes in a less expensive way, but also to coordinate their investment decisions. Although we don't allow e_1 and e_2 be written into a contract, this coordination can be done by *not* granting a license so that the potential infringer refrains from investment.

The case of small c is uninteresting now since firms invest whatever the patent profile. The *ex ante* licensing is used by firms to save on enforcement cost when $l < L$. The stated coordination scenario happens only in the intermediate range of c so that E is dependent on P. Consider payoffs in Table 3.

PROPOSITION 6. *Suppose ex ante licensing is available at a cost* $l \in [0, L]$, *and* c *in the intermediate range, then*

(i) when only one firm patents, such an ex ante license will be granted only for the case where, at the patenting stage, patents are strategic complements, and $l \leq \frac{1}{2}(V_{11} - c - V_{10})$*;*

(ii) when both firms hold patents, no cross-license is observed if $l > 0$*. When patents are strategic complements, no licenses are granted; while when strategic substitutes, the only possible outcome is for one firm to give up its patent rights, and held up by other so that it won't invest later. It happens when* $l \leq \frac{1}{2}[V_{10} - (V_{11} - c)]$.

Proof. With a total expenditure $2l$, an *ex ante* license commits the patent-holder not to enforce her patent rights, in exchange of possibly some fee. When only one firm holds a patent, the outcome without such license is $E = (1, 0)$ and the joint profit $V_{10} - c$. If a license is granted the investment outcome will be $E = (1, 1)$ with joint profit $V_{11} - 2c$. Therefore the condition to reach a license is identical to when patents are strategic complements.

When $P = (1, 1)$, the no license outcome is $E = (1, 1)$, the same as when a cross-license is reached, but the latter has a cost $2l$. If patents are strategic complements, no license dominates the unilateral license outcome $E = (1, 0)$. However, when $V_{10} - c > V_{11} - 2c$, the same condition as for patents to be are strategic substitutes, firms can improve their joint profit by letting one firm give up its suing rights and being held up. This firm needs can be compensated given a higher payoff jointly is reached when $2l$ smaller than the surplus $V_{10} - (V_{11} - c)$. *Q.E.D.*

From this proposition, patents can facilitate upstream collusion in investment.Even in the case of small K so that patenting is a dominant strategy, the two can increase their joint profit with *ex ante* bargaining, and this is done in a more subtle way: by *not* granting a license and letting hold-up happen.

5.4 Remarks

Remark 1. Due to a binary choice setting, to determine the strategic property of patenting decisions the comparison is made between the benefit of an offensive patent (when the other doesn't have a patent) and a defensive one (when the other has one). Strategic complementarity (substitutabiliy) results in if the latter is greater (smaller, respectively). The two payoff matrix in consideration, Table 2 and 3, represent two polar cases regarding the effect of an offensive patent.

In Table 2, an offensive patent is used to extract licensing income. But this revenue has to be subtracted by the enforcement cost to reflect the net gain of an offensive infringement attack. On the other hand, a defensive patent saves for its owner not only the licensing payment, but also the expense on patent dispute. Strategic complementarity therefore results from a strictly positive enforcement cost.

In Table 3, patents change the industrial-wide investment performance. An offensive patent prevents the other firm from investing, while the defensive patent restores investment incentives. The comparison then necessarily involves payoffs from different investment pairs. In addition, due to the symmetry assumption individual payoffs are aggregated into joint profit, and so the criterion reduces to which investment profile leads to higher joint profit maximization. Strategic complementarity follows if private efficiency requires both firms to invest, $V_{11} - c > V_{10}$.

Note that in our simple model, a firm can fully exclude the other's patent attack by either not investing or holding a patent. This is the reason in Table 3 no enforcement cost is involved.

In general, an offensive patent may have both effects. Our insights carry over to the mixed case: a higher enforcement cost or a higher joint profit from higher investment tilt patents toward strategic complementarity.

Remark 2. When is this condition $V_{11} - c > V_{10}$ more likely to satisfy? Since we assume negative externality at the individual firm level, $v_{e1} \leq v_{e0}$, the private investment return needs to be large enough to compensate for this negative impact, $(v_{11} - v_{01}) - (v_{10} - v_{11}) > c$. The business-stealing effect $(v_{10} - v_{11})$ cannot be too large.

Example 1 (continued). Suppose $c \in (\underline{c}, \hat{c}]$ such that Table 3 is applicable. From $V_{11} - V_{10} = (1-\gamma)\triangle v > \underline{c}$, inequality (3) is satisfied. Also, $\hat{c} \gtreqless (1-\gamma)\triangle v$. Both strategic substitutability and complementarity are possible, and patents are strategic complements if $c < (1-\gamma)\triangle v$: when the substitutability between the two new versions is smaller, and so the competition between the two firms is less severe (γ small); or when the technology improvement is greater ($\triangle v$ large). ■

Remark 3. Although no specification about the consumer demand is made and so we cannot give a thorough welfare analysis, an observation could be derived from Corollary 2.

When conditions are met, the patent system has an impact on the market investment performance only in the case of strategic substitutability. If patents are strategic complements, investment remains the same, and the potential effect of the introduction of patents is for firms to spend K in the patenting game. From this, a rather bold claim is as follows: the introduction of a patent system would not be optimal if it endows patents the property of strategic complementarity. Besides the administration cost of running this system, in a patenting game with strategic complementarity, at best firms succeed in coordinating to *not* pursue patents; but at worst resources are expended in patenting to keep things the same as before the introduction of patents.

Remark 4. To check the robustness of our analysis, let's consider if two of our assumptions are relaxed. First, the assumption that, given its cost has been incurred, investment weakly increases joint profit, $V_{11} \geq V_{10} \geq V_{00}$. What if this is not held? For example, when the two firms compete in a single product market, and e_i is the entry decision of F_i, generally we should expect monopoly profit to be higher than that of duopoly. Previous literature such as Bessen (2003) and Ménière and Parlane (2004) have focused on this case, and it would be interesting to see whether our results are robust in this environment.

With some qualifications, indeed our insights carry over to the single product context. Although truce equilibrium exists only when legal expense L is high enough, as right now there are gains firms can realize only through patent enforcement, the two factors we identified keep exerting the same effect on patents' strategic property. A higher L makes strategic complementarity more likely; and since now joint profit is always higher when only one firm invests (enters), patents are more likely to be strategic substitutes. In particular, when the scenario of Table 1 applies, strategic substitutability is guaranteed. In this sense, the single-product assumption is more restrictive. We leave a more thorough discussion in Appendix D.

Second, suppose Assumption 2(ii) is not held. Especially consider if $v_{01} > v_{11} - (\alpha f + L)$ and $c \leq c_0^*$. Then at $P = (1, 0)$ the firm with no patent will retreat when facing the litigation threat, so will not invest in the first place. This is true even when c closed to zero. The relevant payoff is Table 3, and associated results (Proposition 4 and Corollary 2) apply directly. The only difference is that now potential patent dispute alone deters investment.

Remark 5. The truce equilibrium implies no enforcement, and so no licensing income is earned from holding a patent. Although this is derived under the symmetry assumptions and no need of technology transfer, its logic applies squarely to the case when there is real benefit from technology flow. Then the litigation deterrence of defensive patenting can have a detrimental effect on the very purposes of the patent system. The next section provides an example.

6 Patent *vs.* Trade Secret

In this section, we relax the symmetry assumption: technologies A_i are still of no value to the rivaling firm F_j; but now F_1 holds another invention B, which is valuable to F_2 and efficiency requires it to be incorporated into F_2's production. To encourage technology flow, the enhanced profit has to be shared with F_1, and the patent system provides a sharing mechanism. We show an example how F_2's defensive patenting deters F_1's disclosure incentive by reducing its gain from patent enforcement. In the extreme case, truce equilibrium prevails and eliminates the technology flow.

For simplicity, set $c = 0$ and assume firms always invest. The incentive power of the patent system is determined by the licensing income an offensive patent gathers. Assume the valuable technology B is always eligible for patent protection and has a considerable probability of being infringed. But depending on the patent regime, A_1 and A_2 may or may not be qualified for a patent. Even if patentable, the infringement probability may not be high enough to justify the enforcement cost. Two patent regimes are classified according to whether A_i is patentable and poses a credible threat against F_j. In a 'weak' regime, only B is patentable, while in a 'strong' a patent with non-negligible power is granted based on A_i. Since F_1 can always get a patent on B, the two regimes correspond to whether the defensive patenting strategy is available for F_2.

What we have in mind is the situation before and after 1980s in the U.S.. As described in the introduction, after 1980s' reforms defensive patenting has become a viable option. Despite the general agreement that it amounts to a pro-patent policy shift, we are going to show that the incentive power may nevertheless be decreased in this 'strong' regime. A consequence of defensive patenting is the reduction of invention disclosure.

The model is modified as follows. Firms incorporate all the disclosed information into its investment: F_1 uses both A_1 and B, while F_2 uses A_2 and in addition B if it is patented and disclosed.[19] Assume no patenting cost, $K = 0$, but maintain $L > 0$. In addition, this cost is high enough such that each firm at most brings one infringement suit, and so applies for at most one patent. F_2 chooses whether to patent A_2, and F_1 whether to patent A_1 or B, or none at all. If B is not patented, it is protected as a trade secret, which assumed has no risk of unlawful leakage, but loses the licensing opportunity due to Arrow problem.

Since only technology B will be copied without permission, it is reasonable to assume the probability to infringe B, α_B, is greater than that to infringe technologies A_1 and A_2, which assumed a common α_A. The court grants injunction as infringement remedy, as in previous sections. Let $\alpha = (\alpha_A, \alpha_B)$. In the 'weak' patent regime, $\alpha = (0, \alpha_B)$ with $\alpha_B > 0$. In the 'strong' regime, $\alpha' = (\alpha'_A, \alpha'_B)$, with $\alpha'_A > 0$ and $\alpha'_B > \max\{\alpha'_A, \alpha_B\}$. Later we will consider the case $\alpha' = \alpha + (\triangle\alpha, \triangle\alpha)$. That is, from a weak to a strong regime the infringement probability is increased uniformly.

Payoffs $\{v_{..}\}$ are now not only functions of the investment profile reaching the market, but also technologies incorporated into investment. When B is not available to F_2, it is the same as previous: $v_{e_ie_j}$ to F_i if $E = (e_i, e_j)$, and ASSUMPTION 1 holds. But when F_1 patents B, payoffs are modified such that: given e_1,

- if $e_2 = 0$, nothing changed, v_{e_10} for F_1 and v_{0e_1} for F_2;
- if $e_2 = 1$, the access to technology B increases F_2's but decreases F_1's profit, while joint profit is increased. The payoffs of F_1 and F_2 are modified to βv_{e_11} and bv_{1e_1}, respectively. Let $\beta \leq 1 \leq b$.

Since $\beta \leq 1$ the technology B will be protected as trade secret in the absence of proper compensation to F_1 for disclosure.

Consider threat point and cooperative joint profit at different *ex post* bargaining after these modifications. When F_2 infringes, the joint profit at threat point is V_{10} if F_1 not infringes and V_{00} if mutual blocking, whether B is accessible to F_2 or not. V_{10} also applies when only F_1 infringes but B is not patented. On the other hand, if F_1 patents B but becomes the only infringing party, threat point payoffs are βv_{01} for F_1 and bv_{10} for F_2. For the cooperative profit, it depends on the IPRs form chosen for B: $(\beta + b)v_{11}$ if B is patented and V_{11} if not. The following assumption is introduced so that information disclosure and full utilization of established investment are in line with joint interest, and no firms retreat and shut down investments when facing the litigation threat.

[19] Since we consider the case joint profit maximization requires B to be utilized by F_2, it will employ this invention *before* a license is negotiated whenever available, i.e. when B is patented. At worst F_2 pays a licensing fee; but if no infringement, it uses the technology for free.

Assumption 3. $\beta + b \geq 2$; $(\beta + b)v_{11} \geq \beta v_{01} + bv_{10} \geq V_{00}$.

□ **Weak patent regime:** at a weak patent regime $\alpha = (0, \alpha_B)$, no firms pursue a patent of A_i. We need only consider the condition leading F_1 to patent technology B.

If F_1 holds B as a trade secret, no licensing opportunity and each gets v_{11}. If F_1 patents B, without any compensation from F_2 its payoff is βv_{11}. The patent protection α_B should be high enough to induce the patenting and disclosure of B. The following lemma gives conditions that F_2 won't retreat and F_1 patents B. Its proof is in Appendix A.

Lemma 3. *At the weak patent regime, no firm patents A_i. And*

- *F_2 not retreats if*

$$v_{01} \leq bv_{11} - \frac{\alpha_B}{2}\left[(b-\beta)v_{11} + (v_{10} - v_{01})\right] - L; \tag{4}$$

- *given (4), F_1 patents B only when α_B is high enough,*

$$\frac{\alpha_B}{2}\left[(b-\beta)v_{11} + (v_{10} - v_{01})\right] - L \geq (1-\beta)v_{11}; \tag{5}$$

- *the expected payoffs when B is patented are*[20]

$$F_1: \quad \beta v_{11} + \frac{\alpha_B}{2}\left[(b-\beta)v_{11} + (v_{10} - v_{01})\right] - L, \tag{6}$$

$$F_2: \quad bv_{11} - \frac{\alpha_B}{2}\left[(b-\beta)v_{11} + (v_{10} - v_{01})\right] - L. \tag{7}$$

□ **Strong patent regime:** switch to the strong patent regime $\alpha' = (\alpha'_A, \alpha'_B) > \alpha$. Possible patent profiles are $P = (p_1, p_2)$, where $p_2 \in \{0, 1\}$ and $p_1 \in \{0, A_1, B\}$. F_2 decides whether to get a patent; F_1 has two patentable inventions with different exclusive power but patents at most one. We next derive payoffs for each P.

◇ If $p_1 \neq B$, by setting $e_1 = e_2 = 1$ results at section 5 directly apply. Payoffs are the same as in Table 2, with $c = 0$ and $\alpha = \alpha'_A$. When no patenting cost, acquiring a patent weakly dominates having no patent.[21]

◇ Suppose F_1 patents B, and α'_A is high enough to make the threat to sue credible. If instead F_2 doesn't patent, it has no weapon to fight back and payoffs are those of (6)

[20] A new term $(b-\beta)v_{11}$ appears in the licensing fee, which reflects the contribution of B to F_2, netting of the negative impact on F_1.

[21] If $\frac{\alpha'_A}{2}(v_{10} - v_{01}) < L$ so that a patent of A_i is irrelevant, it makes no harm to have one. But if $\frac{\alpha'_A}{2}(v_{10} - v_{01}) \geq L$, it is strictly better to have a patent.

and (7), with a higher infringement probability α'_B. If F_2 holds a patent, a counter-suing threat is credible, and F_1's profit is reduced. Either there are still gains from a war but the expected licensing transfer decreases; or no such gain exists compared with the enforcement cost, and so the litigation is deterred. In the former case, the net gain from patent enforcement has to compared with the loss in revenue to patent B, $(1-\beta)v_{11}$; in the latter, the truce equilibrium prevails and F_1 is not compensated for its disclosing technology B. Since $\beta \leq 1$, in both scenarios F_1 may switch to patent A_1. Technology flow is hindered after a shift to the strong patent regime.

The following lemma lists conditions leading to a litigation war, where we consider only the case F_1 has a positive expected licensing income from a war. Since this expected income is zero-sum between the two parties, and by patenting A_1 the truce equilibrium prevails, if this is not true F_1 can guarantee itself a higher payoff by patenting A_1. The proof is relegated to Appendix A.

LEMMA 4. *When $P = (B, A_2)$,*

- *conditions of credit counter-suing threats are*

$$F_1: \quad \frac{\alpha'_B}{2}\left[(1-\alpha'_A)(b-\beta)v_{11} + (1-\alpha'_A)(v_{10}-v_{01}) + \alpha'_A(bv_{10}-\beta v_{01})\right] \geq L, \quad (8)$$

$$F_2: \quad \frac{\alpha'_A}{2}\left[\alpha'_B(v_{10}-v_{01}) + (1-\alpha'_B)(bv_{10}-\beta v_{01}) - (1-\alpha'_B)(b-\beta)v_{11}\right] \geq L; \quad (9)$$

- *given no retreat of the other firm from a war, conditions of no retreat are*

$$\begin{aligned} F_1 \ &: \ \beta(v_{11}-v_{01}) + \frac{\alpha'_B}{2}\left[v_{10}-v_{01}-b(v_{10}-v_{11})-\beta(v_{11}-v_{01})\right] \\ &\quad -\frac{\alpha'_A}{2}\Big\{\alpha'_B(v_{10}-v_{01}) + (1-\alpha'_B)\left[(bv_{10}-\beta v_{01})-(b-\beta)v_{11}\right]\Big\} \geq L, \quad (10) \\ F_2 \ &: \ bv_{11} - \frac{\alpha'_B}{2}\left[(b-\beta)v_{11}+(v_{10}-v_{01})\right] + \frac{\alpha'_A}{2}(1-\alpha'_B)\big[(bv_{10}-\beta v_{01}) \\ &\quad -(v_{10}-v_{01})-(b-\beta)v_{11}\big] \geq v_{01}+L. \quad (11) \end{aligned}$$

Suppose these conditions are held, and only F_1 has a positive expected licensing income from a litigation war, there is a litigation war (initiated by F_1) if and only if

$$\begin{aligned} &\frac{1}{2}\Big\{\alpha'_B[(b-\beta)v_{11}+(v_{10}-v_{01})] - \alpha'_A\big\{\alpha'_B(v_{10}-v_{01}) \\ &\qquad + (1-\alpha'_B)\left[(bv_{10}-\beta v_{01})-(b-\beta)v_{11}\right]\big\}\Big\} \geq 2L. \quad (12) \end{aligned}$$

Assume inequalities (5), (4), and (8)-(11) are satisfied. Under the weak regime F_1 patents B, and under the strong one F_2 has a dominant strategy of patenting A_2, while for F_1 no patent strategy is dominated by patenting A_1. We focus on whether and when F_1 switches to patent A_1 in a strong patent regime. But instead of a complete analysis, we present a numerical example.

The point we want to address is that an increase of patent power leading to the feasibility of F_2's defensive patenting may actually weaken the incentive power of the patent system. This in turn reduces the inventor's incentive to disclose the useful invention. In addition, considering a uniform shift, $\alpha'_B = \alpha_B + \triangle\alpha$ and $\alpha'_A = \triangle\alpha$, we may observe a non-monotonic relationship between the increase of infringing probability $\triangle\alpha$ and F_1's patenting decision: B is patented when $\triangle\alpha$ is small or large; for $\triangle\alpha$ in an intermediate range, A_1 is patented.

EXAMPLE 2. Consider the set of parameters: $\alpha_B = \frac{1}{3}, \beta = .99, b = 1.2, v_{11} = 100, v_{10} = 120, v_{00} = v_{01} = 0$, and $L = 13$. These values satisfy ASSUMPTION 1 and 3. Also, inequalities (5) and (4) are held, so B is patented when weak regime and F_1 is compensated through litigation; inequalities (10) and (11) are held for any α'_A and α'_B, so that no firm would suspend its investment when facing a litigation war. We consider F_1's payoff by holding a patent of B over the range $\triangle\alpha \in [0, \frac{2}{3}]$. Its decision to patent B or A_1 is made by comparing this payoff with 100, what can be secured by patenting A_1. FIGURE 2 summarizes the result.

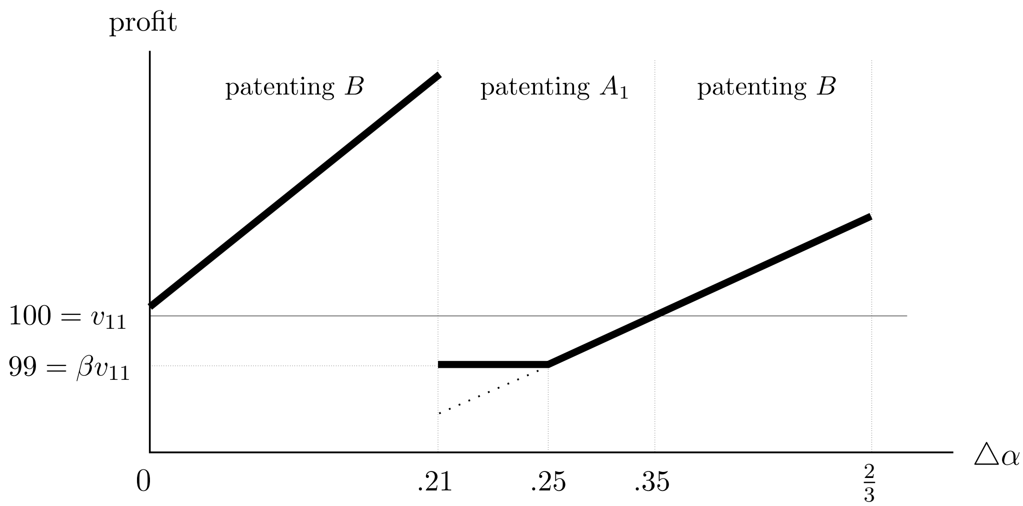

Figure 2: Patent Power and Patenting Decision

The thick line represents F_1's payoff when patenting B.[22] Comparing it with the payoff $v_{11} = 100$, it is clear that F_1's patenting decision is non-monotonic in $\triangle\alpha$: it patents B when $\triangle\alpha \in [0, .21)$ or $[.35, \frac{2}{3}]$; while in the intermediate range $\triangle\alpha \in [.21, .35)$

[22]It can be shown that with these parameter values, F_1 has no incentive to bring two suits, and so no incentive to patent both technologies.

it switches to A_1. The story is that, defensive patenting is not available until $\triangle\alpha$ exceeds the critical value .21, which is determined by condition (9). Before that level, only F_1 is benefited from the general strengthening of patent rights, and continues patenting B. When $\triangle\alpha \geq .21$, a patent on A_2 is powerful enough and F_1 faces a war if enforcing the patent B. By differentiating the left-hand side of inequality (12), the expected licensing fee from a war is increasing in $\triangle\alpha$ with chosen parameters. But for intermediate $\triangle\alpha$ either the gain is too small to warrant the enforcement cost; or even if the net profit from a war is positive, it can't compensate for the loss from disclosing B, $(1-\beta)v_{11} = 1$ here. The intermediate range is accordingly further divided into two cases: $[.21, .25)$ and $[.25, .35)$, where the value .25 is determined by condition (12) binding. The former corresponds to the prevalence of truce equilibrium, and without any enforcement action patenting B renders F_1 a payoff $\beta v_{11} = 99$; while in the latter case a litigation war takes place, but the net return is smaller than 1. Only when $\triangle\alpha \geq .35$ will F_1 go back to patent B. This value is determined by the profit engaging in a litigation war greater than one. ■

PROPOSITION 7. *When the patent rights get strengthened, the number of patents (weakly) increases but a firm may switch to trade secrecy for its valuable inventions. The information dissemination function of patent system may be hampered.*

If the power of patents is strengthened uniformly, there may exhibit a non-monotonic relationship between the patent power and technology flow.

Also, a non-monotonic relationship may be observed between $\triangle\alpha$ and patent enforcement: enforcement takes place when either $\triangle\alpha$ high or low, and a truce prevails for intermediate $\triangle\alpha$.

7 Concluding Remarks

To evaluate the performance of the patent system, a better understanding of how firms operate within it is necessary. Although rather special assumptions are imposed, we believe our analysis is quite robust and provides some insights about the functioning of the patent system. Its complexity can also be illustrated from the various non-monotonic relationships we've found: the number of patents and suits (COROLLARY 1), the patenting cost, number of patents, and aggregate investment (COROLLARY 2), and the patent power and technology flow (PROPOSITION 7).

To repeat, we have identified two factors underlying the determination of the strategic property of patents. Namely, the enforcement cost and joint profit maximization over industrial-wide investment. Strategic complementarity is more likely to be the case with higher enforcement cost and higher joint profit from private investment. The logic comes from, again, the comparison between the benefit of an offensive with a defensive patent, and the two employ different channels corresponding to two typical competitive advantages of the offensive patenting.

When used to generate licensing income (PROPOSITION 3), the existence enforcement cost shrinks the gain from an offensive patent enforcement, and increases the benefit the defensive party enjoys by deterring litigation. Therefore patents exhibits strategic complementarity. On the other hand, if investment incentives are perturbed by offensive patenting (PROPOSITION 4), since by safeguarding the 'freedom to operate,' defensive patenting restores the investment level, the strategic property necessarily involves comparison of different investment profiles. In the special case of symmetric firms this comparison reduces to one at the joint profit level. Higher joint profit from more aggregate investment leads to strategic complementarity.

Besides theoretical interests, the dichotomy of strategic relationships has policy implications. In general, and strictly so with symmetric firms, we could expect symmetric outcomes under strategic complementarity and asymmetric ones under strategic substitutability. The strategic complementarity transforms the patenting stage into a coordination game, but with the prevalence of truce equilibrium the accumulation of patents has no impact on the investment. Firms are jointly better off refraining from pursuing patents. On the other hand, in the case of strategic substitutability we've shown that the introduction of patents can have an effect in the economic performance. This together with *ex ante* licensing provide firms an interesting and more subtle way to collude in their investment. That is, patents may facilitate upstream collusion by some patent-holder *not* granting a license and so the other doesn't invest in fear of future patent dispute.

Another important argument in this paper is the negative effect of defensive patenting on the patent system (Section 6). From this, we would argue that although widely viewed as a 'pro-patent' shift, the reform in the U.S. since 1980s might actually weaken the incentive power of patents. To be clear, this reform is composed of several ingredients, and two of them are relevant here: USPTO's issuing more patents with arguably lower quality, and CAFC's more willing to uphold issued patents. Since the premise of defensive patenting is the ability to build patent portfolio with non-negligible infringing probability, our result supports why the 'flooding' of a large amount of bogus patents should be among those responsible for a 'broken' U.S. patent system, in Jaffe and Lerner's word.

Related to this, in an important paper Lemley (2001) forwards the view that current patent examination quality exercised by USPTO may be optimal, albeit abundant critiques. The author argues from empirical experience that most issued patents are not economically important in that they have neither been licensed nor enforced, and it would be optimal to let firms self-select which patents are worth detailed examination through expensive litigation, instead of spending more resources on each patent. But as we have seen here, one problem of this reasoning is its very starting point. In section 6, an important patent could be ended in a truce equilibrium and classified as 'economically unimportant' according to Lemley (2001) precisely after the PTO starts issuing low quality patents and the court upholds them more often. Therefore no enforcement cannot be interpreted as the irrelevancy of these patents. Instead, if CAFC keeps its current position of high presumed validity of issued patents, the calculation should be tilted toward weeding out bad patents within PTO.

For future research, one might want to re-exam the issue of optimal patent policy, especially the optimal patent scope under the presence of the defensive patenting. Previous literature on cumulative innovation (among others, Green and Scotchmer, 1995, and Chang, 1995) has ignored the second-generation inventor's ability to build a defensive patent portfolio against the first-generation invention's enforcement effort, and so holds the view that increasing the patent power benefits the latter. Our result cautions this logic, especially when the first-generation inventor is also a technology user, and we believe it would be interesting as well as important on the policy ground to bring defensive patenting into the optimal patent scope analysis.

Lastly, as have argued earlier, a non-zero enforcement cost is the driving force of our results. This shows the importance and non-triviality of bringing back this cost into patent-related issues. But if one sticks to zero-cost tradition, the fact that at the *interim* licensing stage we may not have both firms invest when both have patents suggests an interesting question: whether firms are endowed with too much incentives in order to 'play small' and hold up rivals. Alternatively, whether the strengthening of patent system has encouraged vertical disintegration or the entry of firms specializing in design, which have no manufacturing capacity and presumably less vulnerable to patent threats; and whether the entry of this class of firms is optimal relative to that of manufacturing firms. To discuss these issues a model of ownership is needed, which is left future study as well.

Appendix

A Proofs

□ LEMMA 2

Proof. Formally, after entering into the enforcement stage we partition the time into intervals with equal length $\triangle > 0$. At most one suit can be initiated by each player, and suppose F_1 can bring a suit at $2n\triangle$ and F_2 at $(2n+1)\triangle$, with $n = 0, 1, 2, \dots$. We are looking for the subgame perfect equilibrium in the litigation sub-game.

Without loss of generality, let F_1 be the party to bring the first suit. Suppose F_1 decides to enforce its patent rights at time $T_1 = N_1\triangle, N_1 \in \{0, 2, 4, \dots\}$. From the discussion in the main text, F_2's enforcement strategy is the date to sue, which we denote as $T_2 = N_2\triangle$ with $N_2 \in \{1, 3, 5, \dots\}$ and $N_2 \geq N_1 + 1$.[23] Consider possible events at T_1:

◇ With probability $1-\alpha$, the court finds no infringement of F_1's patent and no bargaining takes place. At time T_2 an infringement suit is brought by F_2 against F_1. It is a unilateral attack and LEMMA 1 directly applies.

Between time T_1 and T_2 the market investment profile is $E = (1, 1)$. Each firm gets stream revenue $\hat{v}_{11}$. At time T_2 player F_2 executes its enforcement policy: with probability α it wins and demands a licensing fee with a stream value $\hat{f} = \frac{1}{2}(\hat{v}_{10} - \hat{v}_{01})$. Adding these events and weighted by the probability, the expected payoffs are: (the superscript $1-\alpha$ indicates the event F_1 loses its case at date T_1)

$$\begin{aligned}
\pi_1^{1-\alpha} &= \int_{T_1}^{T_2} \hat{v}_{11}e^{-rt}dt + \alpha \int_{T_2}^{\infty} (\hat{v}_{11} - \hat{f})e^{-rt}dt + (1-\alpha)\int_{T_2}^{\infty} \hat{v}_{11}e^{-rt}dt - L(e^{-rT_1} + e^{-rT_2}) \\
&= (v_{11} - L)e^{-rT_1} - (\alpha f + L)e^{-rT_2}, \\
\pi_2^{1-\alpha} &= (v_{11} - L)e^{-rT_1} + (\alpha f - L)e^{-rT_2}.
\end{aligned}$$

It is clear that for F_2, as long as *Assumption 2* is held, it should bring the suit at the earliest possible date. The optimal $T_2 = T_1 + \triangle$.

◇ With probability α, it is held that F_2 infringes F_1's patent and the two enter into bargaining. Given F_2's patent enforcement at date T_2, we need to determine the threat point and cooperative profits.

[23]More rigorously, F_2 could choose the suing time contingent on whether it infringes F_1's patent. But by assumption at T_1 the two firms cannot bargain over F_2's patent rights, so for both events F_2's decision reduces to a unilateral enforcement one. The optimal suing dates are the same whether F_2 infringes or not.

For the threat point, if the bargaining fails, F_2 is prohibited from using the investment. Over the period $[T_1, T_2)$ the stream of revenue is $\hat{v}_{10}$ to F_1 and $\hat{v}_{01}$ to F_2. At T_2, F_2 executes its counter-suit threat. Again, with probability $1-\alpha$ there is no infringement, the investment utilization profile keeps at $E = (1, 0)$. With probability α the patent of F_2 is infringed by F_1, the two firms meet and bargain again.

Since now there is mutual blocking, F_2 exerts its injunctive power should the bargaining fail again. The threat point has $E = (0, 0)$. As to the cooperative outcome, presumably there are more than one possibilities. The two firms may be able to reach a cross-license and so restore *ex post* efficiency $E = (1, 1)$; or the previous bargaining failure may persist and only $E = (1, 0)$ is feasible. Different choices affect payoffs here and the threat point profit of the bargaining at T_1. However, it can be shown that none of the two results in this lemma is sensitive to this choice. Knowing what investment outcome would emerge should they fail to agree at T_1, the bargaining surplus as well as the threat point are adjusted accordingly. The impact is symmetrically shared between two players, and so the two scenarios end up with the same payoffs. Here we proceed only with the case that the efficient outcome $E = (1, 1)$ is restored.

By this assumption, although firms cannot attain the most profitable outcome $E = (1, 1)$ within the period $[T_1, T_2)$, with probability α they can make an improvement. The bargaining at time T_2 has an cooperative outcome $E = (1, 1)$ and threat point $E = (0, 0)$. With a cross-license, no balance payment is made by symmetry, and each firm gets a stream value of $\hat{v}_{11}$.

Summing up, for the bargaining at T_1, the threat point payoffs are:

$$\begin{aligned}
\pi_1^{th.} &= \int_{T_1}^{T_2} \hat{v}_{10} e^{-rt} dt + \alpha \int_{T_2}^{\infty} \hat{v}_{11} e^{-rt} dt + (1-\alpha) \int_{T_2}^{\infty} \hat{v}_{10} e^{-rt} dt - L(e^{-rT_1} + e^{-rT_2}) \\
&= (v_{10} - L)e^{-rT_1} + [\alpha(v_{11} - v_{10}) - L]e^{-rT_2}, \\
\pi_2^{th.} &= (v_{01} - L)e^{-rT_1} + [\alpha(v_{11} - v_{01}) - L]e^{-rT_2}.
\end{aligned}$$

Following the breakdown of the bargaining at T_1, firms earn a stream of revenue according to $E = (1, 0)$, except a possible change to $E = (1, 1)$ at time T_2, an event of probability α. Adding up $\pi_1^{th.}$ and $\pi_2^{th.}$, the threat point joint profit for the bargaining at T_1 is $(V_{10} - 2L)e^{-rT_1} + [\alpha(V_{11} - V_{10}) - 2L]e^{-rT_2}$.

Next, consider the cooperative profit at T_1. By assumption they can only negotiate a license covering F_1's patent. F_2 is permitted to utilize its investment. At T_2 a suit is brought by F_2 against F_1, but again in the event of infringement a license is secured. The investment utilization profile is kept at $E = (1, 1)$ over the whole period $[T_1, \infty)$.

The joint profit is $V_{11}e^{-rT_1} - 2L(e^{-rT_1} + e^{-rT_2})$. The bargaining surplus is:

$$\begin{aligned} & V_{11}e^{-rT_1} - 2L(e^{-rT_1} + e^{-rT_2}) - \left\{(V_{10} - 2L)e^{-rT_1} + [\alpha(V_{11} - V_{10}) - 2L]e^{-rT_2}\right\} \\ = \; & (V_{11} - V_{10})e^{-rT_1} - \alpha(V_{11} - V_{10})e^{-rT_2} \geq 0. \end{aligned}$$

A license is granted, and by sharing this surplus equally, the expected payoffs when F_1 prevails in its case are:

$$\begin{aligned} \pi_1^\alpha &= (v_{10} - L)e^{-rT_1} + [\alpha(v_{11} - v_{10}) - L]e^{-rT_2} + \frac{1}{2}\left[(V_{11} - V_{10})e^{-rT_1} - \alpha(V_{11} - V_{10})e^{-rT_2})\right] \\ &= (v_{11} + f - L)e^{-rT_1} - (\alpha f + L)e^{-rT_2}, \\ \pi_2^\alpha &= (v_{11} - f - L)e^{-rT_1} + (\alpha f - L)e^{-rT_2}. \end{aligned}$$

Again the optimal $T_2 = T_1 + \triangle$.

Incorporating the optimal counter-suing policy of (i) into payoffs, and weighted $\pi_\cdot^\alpha$ and $\pi_\cdot^{1-\alpha}$ with their probabilities, we get payoffs in (ii). *Q.E.D.*

□ PROPOSITION 1

Proof. Given $\triangle > 0$. By LEMMA 2(i) we have counter-suing as the dominant strategy at the subgame where a firm has been sued. To consider whether a firm should bring the first suit, conditional on the other's strategy, we have two equilibria:

⋄ War equilibrium: suppose enforcement is decided in a non-strategic manner. Each firm sues at the earliest possible dates. To show this as an equilibrium, consider at some time T_1 there has been no patent dispute till now and F_1 decides whether to sue. If it does so, F_1 gets π_1^s by LEMMA 2. If it deviates and not sues, since F_2 sticks to the equilibrium strategy and will sue at time $T_1 + \triangle$ whatever F_1 does, this deviation cannot avoid the patent litigation, but only delays it. F_1 loses its first-mover advantage. The expected payoff following this deviation is:

$$\begin{aligned} \pi_1' &= \int_{T_1}^{T_1+\triangle} \hat{v}_{11}e^{-rt}dt + \left[v_{11} - \alpha f(1 - e^{-r\triangle}) - L(1 + e^{-r\triangle})\right]e^{-r(T_1+\triangle)} \\ &= \left\{v_{11} - \left[\alpha f(1 - e^{-r\triangle}) + L(1 + e^{-r\triangle})\right]e^{-r\triangle}\right\}e^{-rT_1}. \end{aligned}$$

Compare π_1^s with π_1',

$$\pi_1^s - \pi_1' = (\alpha f - L)(1 + e^{-r\triangle})(1 - e^{-r\triangle})e^{-rT_1} > 0, \quad \forall \triangle > 0.$$

F_1 has no incentives to deviate. On the equilibrium path, a patent dispute takes place at time 0. As $\triangle \to 0$, the equilibrium payoff approaches to $\pi^w = v_{11} - 2L$ for both firms, where the superscript 'w' stands for the war equilibrium.

⋄ Truce equilibrium: again consider at T_1 the enforcement decision of F_1. It still faces a credible counter-suing reaction. But with the rival's adopting 'counter-suing-only' strategy, a strategic concern presents here: sticking to the equilibrium strategy, F_2 will not sue later if F_1 not sue now. Therefore, by employing the equilibrium strategy, F_1 gets $v_{11}e^{-rT_1}$. If F_1 deviates and sues, the expected payoff is π_1^s. Comparing the two:

$$v_{11}e^{-rT_1} - \pi_1^s = -\left[\alpha f(1-e^{-r\triangle}) - L(1+e^{-r\triangle})\right] e^{-rT_1}.$$

As $\triangle$ gets small enough, $e^{-r\triangle}$ approaches to one. F_1 has no incentives to deviate. No litigation occurs along the equilibrium path. The equilibrium payoff is $\pi^t = v_{11}$ for both, where the superscript 't' means the truce equilibrium. *Q.E.D.*

□ COROLLARY 2

Proof. Referring to Table 3, the investment outcome of the whole game and therefore the joint profit realized depend on the equilibrium at the patenting stage, which in turn depends crucially on the strategic property of patents.

When patents are strategic complements, $v_{11} - v_{01} - c > v_{10} - v_{11} \geq 0$. A firm always has nonnegative benefit from holding a patent, while the rival's patent decision affects its magnitude. Depending on the size of K, the patenting equilibrium is: (i) if $K < v_{10} - v_{11}$, then it is a dominant strategy to apply for a patent and $P = (1,1)$ is the unique equilibrium; (ii) if $K \in [v_{10} - v_{11}, v_{11} - v_{01} - c]$ then there are two symmetric equilibria $P = (0,0)$ and $(1,1)$; and, (iii) if $K > v_{11} - v_{01} - c$ then not patenting is the dominant strategy and $P = (0,0)$ is the unique equilibrium. But for both $P = (0,0)$ and $(1,1)$, the equilibrium investment profile is always $E = (1,1)$.

When patents are strategic substitutes, $v_{11} - v_{01} - c < v_{10} - v_{11}$. Since at $P = (1,1)$ the investment outcome specified is $E = (1,1)$, for this to be true we must have $c \leq \hat{c} = v_{11} - v_{01} - (\alpha f - L)$ so that firms will invest. Therefore $v_{11} - v_{01} - c \geq \alpha f - L \geq 0$ and again benefits to patent are non-negative.

The same as the case of strategic complementarity, but with different threshold values, for K either large ($K > v_{10} - v_{11}$) or small ($K < v_{11} - v_{01} - c$), both invest $E = (1,1)$ is the equilibrium outcome, although the patent profiles are different. But now when for intermediate values of $K \in [v_{11} - v_{01} - c, v_{10} - v_{11}]$, strategic substitutability results in two asymmetric equilibria $P = (1,0)$ and $(0,1)$, the resulting investment equilibrium is for only one firm (the patenting firm) to invest. A non-monotonicity of E with respect to K presents: when K small or large, both firms will invest; but when K lies in an intermediate range, only one firm invests. *Q.E.D.*

□ LEMMA 3

Proof. Suppose F_2 not retreats. If patenting B and suing F_2 for infringement, with probability $1-\alpha_B$ the challenge fails and F_1 gets only βv_{11}. But with probability α_B, there is an infringement and a license negotiation follows. The bargaining surplus is $(\beta+b)v_{11}-V_{10}\geq 0$, from ASSUMPTION 1 and 3. Patenting B leaves F_1 a profit of

$$\alpha_B\left(v_{10}+\frac{1}{2}[(\beta+b)v_{11}-V_{10}]\right)+(1-\alpha_B)\beta v_{11}-L,$$

which leads to expression (6). Patenting B is profitable if

$$\beta v_{11}+\frac{\alpha_B}{2}\left[(b-\beta)v_{11}+(v_{10}-v_{01})\right]-L\geq v_{11},$$

and we get condition (5), which is satisfied if α_B is high enough relative to L.

Assume condition (5) is held, F_1 patents B and F_2 gets

$$bv_{11}-\frac{\alpha_B}{2}\left[(b-\beta)v_{11}+(v_{10}-v_{01})\right]-L,$$

which is expression (7), and then it is easy to find condition (4). *Q.E.D.*

□ LEMMA 4

Proof. Suppose F_1 starts the war, the 'reaction time' △ approaches to zero, and ignore for a moment the enforcement cost $2L$. Listing out the four outcomes after a litigation war:

◇ with probability $(1-\alpha'_A)(1-\alpha'_B)$, no infringement. F_1 gets βv_{11} and F_2 gets bv_{11};

◇ with probability $(1-\alpha'_A)\alpha'_B$, only F_2 infringes. The bargaining process is as if F_2 had no patent but F_1 a patent with power 1. Applying expressions (6) and (7), the profits are $\beta v_{11}+\frac{1}{2}[(b-\beta)v_{11}+(v_{10}-v_{01})]$ for F_1 and $bv_{11}-\frac{1}{2}[(b-\beta)v_{11}+(v_{10}-v_{01})]$ for F_2;

◇ with probability $\alpha'_A(1-\alpha'_B)$, only F_1 infringes. To negotiate a license, the threat point is shut-down of e_1, F_1 gets βv_{01} and F_2 gets bv_{10}. The cooperative joint profit is $(\beta+b)v_{11}$. By ASSUMPTION 3, the bargaining surplus is positive. F_1 gets payoff $\beta v_{11}-\frac{1}{2}[(bv_{10}-\beta v_{01})-(b-\beta)v_{11}]$, and F_2 gets $bv_{11}+\frac{1}{2}[(bv_{10}-\beta v_{01})-(b-\beta)v_{11}]$. The licensing fee F_1 pays is $\frac{1}{2}[(bv_{10}-\beta v_{01})-(b-\beta)v_{11}]\geq 0$;

◇ with probability $\alpha'_A\alpha'_B$, there is mutual blocking. A cross-license is needed and the threat point $E=(0,0)$, both firms get v_{00}, the bargaining surplus $(\beta+b)v_{11}-V_{00}$. Each firms gets $\frac{1}{2}(\beta+b)v_{11}=\beta v_{11}+\frac{1}{2}(b-\beta)v_{11}=bv_{11}-\frac{1}{2}(b-\beta)v_{11}$. A balance payment $\frac{1}{2}(b-\beta)v_{11}$ is made from F_2 to F_1.

Adding up the four events, once engage in a litigation war initiated by F_1, the expected payoffs are

$$\begin{aligned} & \beta v_{11} + \frac{1}{2}\Big\{[\alpha'_B + \alpha'_A(1-\alpha'_B)](b-\beta)v_{11} + (1-\alpha'_A)\alpha'_B(v_{10}-v_{01}) \\ & \qquad - \alpha'_A(1-\alpha'_B)(bv_{10}-\beta v_{01})\Big\} - 2L \\ = \quad & \beta v_{11} + \frac{\alpha'_B}{2}[(b-\beta)v_{11} + (v_{10}-v_{01})] \\ & \quad - \frac{\alpha'_A}{2}\Big\{\alpha'_B(v_{10}-v_{01}) + (1-\alpha'_B)\left[(bv_{10}-\beta v_{01}) - (b-\beta)v_{11}\right]\Big\} - 2L \end{aligned}$$

for F_1 and

$$\begin{aligned} & bv_{11} - \frac{1}{2}\Big\{[\alpha'_B + \alpha'_A(1-\alpha'_B)](b-\beta)v_{11} + (1-\alpha'_A)\alpha'_B(v_{10}-v_{01}) \\ & \qquad - \alpha'_A(1-\alpha'_B)(bv_{10}-\beta v_{01})\Big\} \; - 2L, \\ = \quad & bv_{11} - \frac{\alpha'_B}{2}[(b-\beta)v_{11} + (v_{10}-v_{01})] \\ & \quad + \frac{\alpha'_A}{2}\Big\{\alpha'_B(v_{10}-v_{01}) + (1-\alpha'_B)\left[(bv_{10}-\beta v_{01}) - (b-\beta)v_{11}\right]\Big\} - 2L \end{aligned}$$

for F_2. The optimality of counter-suing requires

$$\frac{\alpha'_B}{2}\left[(1-\alpha'_A)(b-\beta)v_{11} + (1-\alpha'_A)(v_{10}-v_{01}) + \alpha'_A(bv_{10}-\beta v_{01})\right] \geq L,$$

for F_1, which is the condition (8) and

$$\frac{\alpha'_A}{2}\left[\alpha'_B(v_{10}-v_{01}) + (1-\alpha'_B)(bv_{10}-\beta v_{01}) - (1-\alpha'_B)(b-\beta)v_{11}\right] \geq L,$$

for F_2, the condition (9). Assuming both inequalities hold, and assume only F_1 has a positive expected licensing income, then a litigation war arises if and only if

$$\begin{aligned} & \frac{1}{2}\Big\{\alpha'_B[(b-\beta)v_{11} + (v_{10}-v_{01})] - \alpha'_A\big\{\alpha'_B(v_{10}-v_{01}) \\ & \qquad + (1-\alpha'_B)\left[(bv_{10}-\beta v_{01}) - (b-\beta)v_{11}\right]\big\}\Big\} \geq 2L. \end{aligned}$$

It is the condition (12).

To derive condition (10) and (11). For F_1, when facing a litigation war, and suppose F_2 continues using it investment. If F_1 'turns off' its investment, $e_1 = 0$, and sues F_2,

◇ with probability α'_B, there is an infringement. The threat point profit is v_{00} for both; the cooperative joint profit is $\beta v_{01} + bv_{10}$, which is greater than $2v_{00}$ by Assumption 3. By dividing the surplus equally, F_1 gets $\frac{1}{2}(\beta v_{01} + bv_{10})$;

◇ with probability $1-\alpha'_B$, no infringement, and F_1 gets βv_{01}.

So by setting $e_1 = 0$ and sues F_2, the expected payoff for F_1 is

$$\frac{\alpha'_B}{2}(\beta v_{01} + b v_{10}) + (1 - \alpha'_B)\beta v_{01} - L = \beta v_{01} + \frac{\alpha'_B}{2}(b v_{10} - \beta v_{01}) - L.$$

F_1 won't shut down its investment if this term is smaller than its payoff from a litigation war, which leads to condition (10). Similarly, if F_2 retreats by setting $e_2 = 0$ and sues F_1, the expected payoff is $v_{01} + \frac{\alpha'_A}{2}(v_{10} - v_{01}) - L$, by LEMMA 1. Comparing it with the payoff from the litigation war, and then we get condition (11). *Q.E.D.*

B Elimination of the war equilibrium

In this appendix, we present a simple way to eliminate the Pareto dominated war equilibrium in PROPOSITION 1 by introducing asymmetric information about firms' litigation cost.

Assume with probability $1 - \epsilon$ both firms are of the 'normal type' with payoffs specified in the model. With probability $\epsilon \in (0, 1)$, however, firms are the 'purely defensive' type, hesitating to bring the first suit, but having an credible threat to bring a counter-suit.

To justify this behavior, we keep revenue parameters $\{v_{\cdot\cdot}\}$ the same, but modify the enforcement cost so that it exhibits scale economy for the pure-defensive type: the second lawsuit costs less than the first one, and as an extreme case, suppose there is a fixed cost $\bar{L}$ for engaging in patent disputes. This cost is so high that it never worth the purely defensive firm to initiate the first legal suit: $\alpha f < \bar{L}$. But once it has fought an infringement challenge from the rival, the marginal cost for the second suit is zero. Therefore it always brings a counter-suit, and does so as early as possible.

Some empirical studies has suggested that indeed litigation may exhibit 'learning effect' and the scale economy is warranted.[24] Moreover, firms may hesitate to enforce their patent rights offensively from the concern of reputation in an industry with a 'free atmosphere' culture, i.e. patent disputes are rare. Semiconductor and software are two examples until the 1990s. But a counter-suit brings no such harm. Both factors may support our choice of this type.

Suppose its type is private information, each firm can be one of the two according to the identical and independent probability distribution $\{\epsilon, 1 - \epsilon\}$. This structure is common knowledge between players. Fixing $\triangle > 0$ and consider the enforcement decision at time T_1 for the normal type F_1. A counter-suit is guaranteed whatever the type of F_2. So if F_1 sues its expected payoff is π_1^s.

[24]See Lerner (1995) and papers cited there.

If F_1 chooses not to enforce its patent rights, with probability ϵ it encounters a purely defensive rival bringing no future litigation; but with probability $1-\epsilon$ the normal type F_2 may employ the war strategy and not affected by F_1's wish for peace. It suffices to show as long as ϵ is large enough, even if a rival of normal type sticks to the war strategy, a normal type F_1's optimal strategy is 'counter-suit-only' and so doesn't go to the court at T_1.

Given the normal type rival choosing a war, if the normal type F_1 waits and sees, its expected payoff is:

$$\epsilon v_{11}e^{-rT_1}+(1-\epsilon)\left\{v_{11}[e^{-rT_1}-e^{-r(T_1+\triangle)}]+\left[v_{11}-\alpha f(1-e^{-r\triangle})-L(1+e^{-r\triangle})\right]e^{-r(T_1+\triangle)}\right\},$$

where with probability $1-\epsilon$ it can gain a stream value $\hat{v}_{11}$ for a period of length $\triangle$, but at time $T_1+\triangle$ the rival attacks and F_1 loses the first-mover advantage with a payoff as specified in expression (2), but for a different discount factor. Comparing this with π_1^s and ignoring the term e^{-rT_1} leads to:

$$\epsilon e^{-r\triangle}\left[\alpha f(1-e^{-r\triangle})+L(1+e^{-r\triangle})\right]-(1-e^{-r\triangle})(1+e^{-r\triangle})(\alpha f-L).$$

For this term to be strictly positive, ϵ should be high enough:

$$\epsilon>\frac{1-e^{-r\triangle}}{e^{-r\triangle}}\cdot\frac{(1+e^{-r\triangle})(\alpha f-L)}{\alpha f(1-e^{-r\triangle})+L(1+e^{-r\triangle})}\equiv\epsilon_\triangle.$$

As $\triangle\to 0, e^{-r\triangle}\to 1$, the threshold value $\epsilon_\triangle$ approaches to zero as well. When the reaction lag is small enough, only a tiny probability ϵ is required to eliminate the war equilibrium. □

C Asymmetric Information and *Interim* Licensing

In this appendix, we present one example of bargaining failure at the *interim* licensing stage, and show that our results are qualitatively robust to this modification.

We borrow from Bebchuk (1984) a model of settlement bargaining under asymmetric information. Let $\alpha_i, i\in\{1,2\}$ be the infringement probability if the patent-holding firm F_i files an infringement suit. This probability could be high or low: $\alpha_i\in\{\underline{\alpha},\bar{\alpha}\}$, with $\underline{\alpha}<\bar{\alpha}$ and a common probability distribution where the probability of $\bar{\alpha}=p\in(0,1)$. Denote the expected value as α^e. For simplicity, let Assumptopn 2(ii) be held for both $\underline{\alpha}$ and $\bar{\alpha}$. Firms not retreat upon receiving an infringement notice.

Suppose after the investment stage, the patent-holder F_i receives a private signal about its α_i. For example, it may have found some prior arts about the validity of its patent; or after a reverse engineering effort it may have a more precise assessment of the extent to which its patent reads on the investment of the rivaling firm, due to the better knowledge of its patent. This structure is common knowledge between the two firms.

For both values, we assume a patent-holder has a credible litigation threat: $\underline{\alpha}f > L$. To avoid the signaling effect, we assume that when only one patent dispute is possible, say F_1 sues F_2 the uninformed party F_2 makes a take-it-or-leave-it settlement offer. If the offer is rejected, then the two parties fight in the court. Each incurs the full litigation cost L, and the outcome is determined according to the probability α_1. We look for a case where to save on the settlement payment, F_2 screens between the two types of F_1 by litigating with the type $\bar{\alpha}$, and so bargaining fails with probability p. On the other hand, when $P = E = (1, 1)$, we find the condition where the truce equilibrium exists. There is then no need to engage in *interim* licensing.

□ One relevant patent: Consider the only possible patent litigation is F_1 brings a suit against F_2. Suppose F_2 makes a take-it-or-leave-it offer s to F_1. If accepted, the two settles the case and F_1 grants a license to F_2. If rejected, a court fight follows.

Given s, for the F_1 of type-α_1 to accept this offer, it should be high enough: $s \geq \alpha_1 f - L$. Accordingly there are three cases to consider: (i) if $s < \underline{\alpha}f - L$, then no settlement and F_2 is expected to pay $\alpha^e f + L$ in litigation; (ii) if $s \in [\underline{\alpha}f - L, \bar{\alpha}f - L)$ then F_2 settles only with type-$\underline{\alpha}$ patent-holder. With the lowest necessary settlement payment $s = \underline{\alpha}f - L$, F_2 is expected to pay $(1-p)(\underline{\alpha}f - L) + p(\bar{\alpha}f + L)$ when facing F_1's patent threat; and (iii) if $s \geq \bar{\alpha}f - L$, F_2 settles with both types of F_1, with a required minimum licensing payment $s = \bar{\alpha}f - L$.

F_2 has an incentive to screen F_1 if and only if:

$$(1-p)(\underline{\alpha}f - L) + p(\bar{\alpha}f + L) < \bar{\alpha}f - L \Rightarrow 2pL < (1-p)\triangle\alpha f, \tag{13}$$
$$\textbf{and} \quad (1-p)(\underline{\alpha}f - L) + p(\bar{\alpha}f + L) < \alpha^e + L \Rightarrow \underline{\alpha}f - L < \underline{\alpha}f + L,$$

where $\triangle\alpha = \bar{\alpha} - \underline{\alpha} > 0$.

□ The truce equilibrium: When $P = E = (1, 1)$, ignore for a moment the *interim* bargaining. At the enforcement stage by assumption of $\underline{\alpha}f > L$ a war is inevitable if a firm chooses to enforce its patent. Here the expected gains from a war are dependent on the patent power. A truce equilibrium exists if this gain is negative for both types of patent-holders.

With an expectation that the opponent holds a patent with infringing probability α^e, the expected gain from a war is

$$\begin{aligned} \pi(\underline{\alpha}) &= \underline{\alpha} f - \alpha^e f - 2L = -p\triangle\alpha f - 2L < 0, \\ \pi(\bar{\alpha}) &= \bar{\alpha} f - \alpha^e f - 2L = (1-p)\triangle\alpha f - 2L. \end{aligned} \tag{14}$$

Therefore if $\pi(\bar{\alpha}) < 0$, no litigation will ever occur even if firms cannot engage in *interim* licensing. Then firms have no incentive to engage in *interim* licensing.

For our purpose, if both inequality (13) held and the expression (14) negative, then litigation takes place only when there is one relevant patent. The expected gain from holding a patent is $\alpha^e f - L$ for the patent-holder, and the expected loss is $p(\bar{\alpha} f + L) + (1-p)(\underline{\alpha} f - L)$ for the non-patenting firm. When two relevant patents, the truce equilibrium guarantees firms a peaceful life.

It is then easy to show that all our results with *ex post* licensing go through with corresponding modifications.

D Alternative Industrial Structure

Here we consider the alternative that the joint profit part of Assumption 1 is not held, and the only infringing firm cannot secure a license but is driven out of the market.

For simplicity, let us impose the following assumption:

Assumption 1': $v_{10} \geq 2v_{11} \geq 2v_{0e} \geq 0$, for both $e \in \{0, 1\}$.

By interpreting e as the entry decision, this assumption is compatible with the single product framework considered by Bessen (2003) and Ménière and Parlane (2004). If, say, only F_2 infringes F_1's patent, then it won't be able to get a license. F_1 enjoys the monopoly profit v_{10}, and F_2 gets $v_0 \equiv v_{0e}$.

A second consequence immediately follows from this modification is that, if we assume firms split the monopoly rent when there is mutual blocking, then the outcome of a litigation war is no more a zero-sum transfer between the two (besides the enforcement cost). Higher joint payoff $(v_{10} + v_0)$ can only be realized through litigation, and this makes a war more profitable. The truce equilibrium exists only when enforcement cost L is large enough to offset this gain.

To see how our other results are affected, suppose the truce equilibrium exists and consider two cases according to the size of investment cost c.

☐ Small c: when firms always invest, the expected payoff is

$p_1 \backslash p_2$	0	1
0	$v_{11} - c$	$\alpha v_0 + (1-\alpha)v_{11} - c - L$
1	$\alpha v_{10} + (1-\alpha)v_{11} - c - L$	$v_{11} - c$

The offensive value of a patent is $\alpha(v_{10}-v_{11})-L$; the defensive value if $\alpha(v_{11}-v_0)+L$. Since $v_{10} - v_{11} \geq v_{11} - v_0$, we don't necessarily have strategic complementarity as in Proposition 3. But the comparative statics with respect to L still holds: the larger L is, the more likely for patents to be strategic complements.

☐ Intermediate c: when firms invest only if protected by their holding of a patent, the payoff is

$p_1 \backslash p_2$	0	1
0	$v_{11} - c$	v_0
1	$v_{10} - c$	$v_{11} - c$

The offensive value $(v_{10}-v_{11})$ is strictly higher than the defensive value $(v_{11}-v_0-c)$. Patents are strategic substitutes. Note that this result is consistent with Proposition 4. Joint profit concern determines the strategic property of patents, but only strategic substitutability is possible due to the assumption. In this sense, the single product environment leads to a narrower set of results.

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