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: when two symmetric parties hold patents of equal power and legal expense is strictly positive, a truce equilibrium exists so that, although each holds a credible threat to enforce its patent unilaterally, no litigation will be initiated along the equilibrium path. A theory of defensive patenting is developed based on this equilibrium behavior. It is found that defensive patenting can alleviate a hold-up threat from another firm's patent, and (i) firms' patenting decisions may be strategic complements or substitutes; but (ii) it may reduce the return of the inventor from patenting. Concerning the former, we further show that patents can facilitate firms' investment coordination when they are strategic substitutes. However, the industry-wide investment performance is independent of the outcome of the patenting game when strategic complements. Concerning the latter, we offer an explanation of why the "pro-patent" policy shift in the United States since the 1980s might actually have reduced the incentive power of the patent system.

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1 Introduction

As an incentive scheme, a prominent feature of the patent system is how the reward is implemented.[1] In order to profit from her patents, a patent holder needs to be equipped with some enforcement capacity. Factors underlying the enforcement process necessarily have an impact on both individual firms' strategies and the aggregate performance of the system. This paper studies strategic enforcement between multiple patent holders, with two applications to firms' investment decisions, and the incentive power of the patent system.

The strategic enforcement we are considering is the accumulation of a patent portfolio and the use of credible countersuits to settle potential patent disputes. The study of von Hippel (1988) of the semiconductor industry provides a good illustration:

> *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 their study of the British patent system, Taylor and Silberston (1973) also mentioned the defensive usage in the field of electronic engineering in the 1960s.

To be sure, the feasibility and usefulness of this "defensive patenting" strategy depend on both technology and legal factors. On the technological side, semiconductor and electronic engineering are two leading examples of "complex technologies": multiple inventions are integrated to fabricate a product, and one technology (say, a manufacturing process) may be covered by a multitude of patents in the hands of different owners. No firm has the capacity to develop or redo all the technologies, and gaining access to others' technologies becomes necessary. These fields also exhibit intrinsic difficulties for the court to determine the validity and actual boundary of a patent. Therefore, everybody needs several pieces of technologies but nobody can be sure whether they will infringe on others patent holders' rights.

On the legal side, a series of reforms and legal trends in the United States since the 1980s have worsened the situation.[2] With the creation of the Court of Appeals for

[1] The U. S. Constitution, Article 1, Section 8, Clause 8 states that "Congress shall have the Power... To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries."

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

the Federal Circuit (CAFC) in 1982, it is generally agreed that the U.S. patent system has been "strengthened" in several ways: the number of patentable subjects has been expanded, the validity of a patent is more often backed by the court, and the power of patent holders has increased through the grant of injunction. Another trend worth noting is that, as some authors have claimed, the U.S. Patent and Trademark Office (USPTO) has been issuing low-quality patents over the past decade.[3] Combining these policy shifts with technology features, the result is, in the words of Shapiro (2001), a "patent thicket": firms can get patents more easily, but may also infringe on others' patent rights more easily. Several solutions have been devised to curb this problem;[4] the accumulation of patents is one at the individual level.

We first construct a simple litigation game to analyze the strategic enforcement (section 4). Patents are endowed with the "offensive" role of generating licensing income. But more interesting and pertinent to our concern is its potential to deter such offensive enforcement. A "truce equilibrium" is established with the property that patent disputes are entirely eliminated along the equilibrium path, although each patentee has a credible threat to sue. The intuition is similar to the nuclear deterrence: if various parties possess nuclear weapons, it follows that no one gains from using them, and so peace is maintained.

This equilibrium behavior is applied to two issues. In section 5, we study the impact of firms' ability to shield the hold-up threat through defensive patenting. For symmetric firms, we show that patents lower the incentive of firms to engage in downstream investment, and the strategic property of investment may be changed from strategic substitutes to strategic complements, but not the other way around. However, along the equilibrium path, only when patents are strategic substitutes will the aggregate investment performance depend on the result of the patenting game. In that case, patents provide an opportunity for collusion: firms can coordinate their investments (assumed to be non-contractible) by granting, or refusing to grant a license. On the other hand, when patents are strategic complements, the best thing for firms to do is

[3]For example, Quillen and Webster (2001) shows that after taking into account the continuation application and continuation-in-part applications, the USPTO's allowance rate (the number of applications allowed divided by the number filed) in the mid-1990s (applications allowed in the fiscal years 1995–1998 for original applications filed in the fiscal years 1993–1996) is 95%, compared to 68% and 65% for the European and Japanese patent offices, respectively. Possible reasons are (i) that the explosion of patent applications increased the patent office's workload; (ii) that the emergence of applications in new fields of industry required new expertise and searching database, while the PTO did not have the proper capacity; (iii) the resource constraints facing the PTO; (iv) the high turn-over among the examiners; and (v) the inadequate incentive schemes imposed on examiners. See Merges (1999).

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

to agree not to spend resources on acquiring patents.

The second point to be addressed is the negative impact of defensive patenting on the incentive power of the patent system. By deterring patent enforcement, the truce equilibrium implies that no patent holders can profit directly from the patent system, even when they need to be compensated for either their R&D effort or information disclosure. Section 6 presents an example of a firm's choice between patent protection and trade secrecy. It shows that an increase in patent power may induce a firm to switch to trade secrecy for its valuable invention, and thereby reduce the dissemination of information. This argument serves to illustrate that a "pro-patent" reform, which makes defensive patenting a viable choice, might be detrimental to the very purpose of the system. Such a reform has actually been occurring in the United States since the 1980s.

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

2 Literature

At the heart of our analysis is the patent enforcement between two patent holders. This feature differs our study 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 introduced in the model, but they are not users of technology; instead, there is a pool of downstream licensees from whom to extract licensing income. We consider two firms that possess patentable technologies, and can make investment infringing on the other's patent with a probability. A suit is brought by one against the other. Hence it doesn't matter whether a patent is invalidated or no infringement is found. Choi (2003), on the other hand, allows only the invalidation, although presumably the two types have different effects.

Other closely related papers are Bessen (2003) and Ménière and Parlane (2004). Especially in the latter study the authors also obtain a non-monotonic relationship and a negative effect of patent power on investment incentives. But besides having a somewhat different focus, the two studies are conducted in a rather different economic environment than ours.

First, there are no enforcement costs in their models. Patent holders always enforce their patent rights. Here, by bringing back the enforcement costs we find a "truce equilibrium", which is critical to our results.

Second, both consider the case of a single market or single product, where monopoly profit is greater than aggregate duopoly profit. Consequently, a firm is forced to exit the market if it only infringes. We consider the opposite case instead: a license is granted, so that the infringing firm stays in the market. Nevertheless, with some qualifications, our insights extend to the alternative single-market structure. In fact, our modeling choice not only complements previous research, but also gives a richer set of outcomes. In a single-market environment, patents are much more likely to be strategic substitutes. Strategic complementarity occurs only when enforcement costs are large enough, and investment costs small enough.

Several empirical findings have inspired this paper. Besides anecdotal stories as quoted above, a few interviews and statistical analyses demonstrate the phenomenon of defensive patenting.[5] Examining the effect of policy changes, Hall and Ziedonis (2001) shows that *"a surge in the patent propensities of semiconductor firms has occurred during the period associated with stronger U.S. patent rights, and that the surge is driven by more aggressive patenting by large-scale manufacturers in our sample."* Since manufacturing firms have incurred large investment in manufacturing facilities and would suffer greatly from a patent-litigation threat, they have legitimate concerns to amass patent portfolios in order to shield themselves from litigation risks or avoid large balance payments in cross-licenses.

Using the data of U.S. patent litigations in all technological fields during 1978–1999, Lanjouw and Schankerman (2003) find that an infringement suit is less likely to be filed when a patent belongs to a larger firm (in terms of the employment size) or an owner with a larger patent portfolio. The latter relationship, concerning the size of the patent portfolio, cannot be used directly to support or reject our results, since the distinction between an "offensive" or "defensive" suit (a countersuit) is critical in our model, but absent in Lanjouw and Schankerman (2003)'s empirical analysis. Given the characteristics of the rival party, a larger patent portfolio improves the patent holder's ability to *both* attack and defend: the former increases and the latter decreases the probability of litigation. On the other hand, one might reasonably argue that the finding of a firm's size is consistent with our prediction: the strategy of defensive patenting works better against a larger firm with a bigger hold-up stake, which makes the truce equilibrium more relevant.

[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 1980s and early 1990s, respectively.

The countersuit was considered by Somaya (2003). The data covers patent suits in the computer and research medicine industries filed in the U.S. federal district courts between 1983 and 1993. An interesting stylized fact is that, in most cases, when one suit was countered by a countersuit, the two were disposed of within a day of each other. Without any legal or administrative factor leading to these two legally separated proceedings, the author suggests a strong strategic concern for counter suits.

Finally, as stated in the introduction, our results also shed some light on the debate about the impact of U.S. patent reforms. 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 have *weaken* the incentive power of the system.

3 Model

We adopt a two-player, three-stage framework. The structure and key elements of the model are summarized in FIGURE 1.

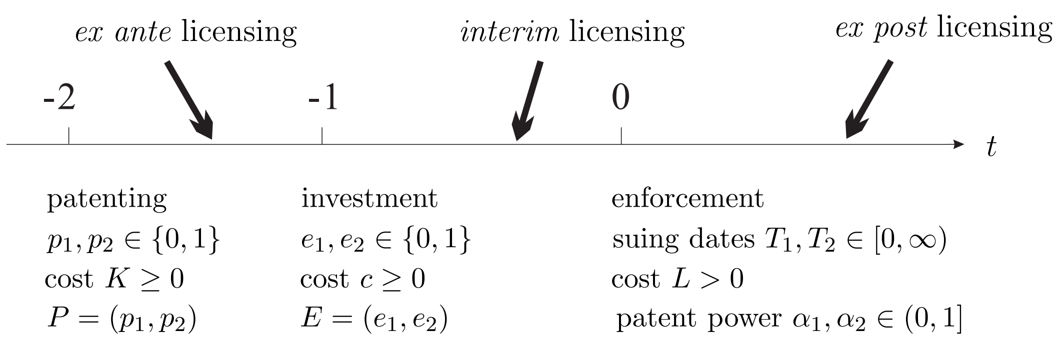

Figure 1: Timing

□ **Players and timing:** two firms, F_1 and F_2, each hold a basic technology, A_1 and A_2, eligible for patent protection. In the basic model, the two firms are identical. 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 an 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 or equipments adopting the improved process. Endowed with A_i, each F_i faces a series of decisions: whether to apply for a patent; whether to invest; and when possessing a patent, whether to enforce it.

For simplicity, all decisions are observable, no asymmetric information is involved, and only pure strategies are considered. The only uncertainty in this model is the litigation outcome (to be specified later).

At each of the patenting and investment stages, 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 obtains 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. The enforcement subgame is described below.

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

The assumption of no technology transfer is relaxed in section 6. There, firms are no longer symmetric, in that, besides A_1, the firm F_1 holds another invention B, which is beneficial to F_2 and has greater power if patented. Assume that trade secrecy provides perfect protection, with the drawback of no licensing opportunity. On the other hand, patent protection is imperfect, but licensing is possible. The question, then, is when the patent system can facilitate technology flow by encouraging patenting and disclosure.

□ **Patent enforcement and licensing:** the following assumptions are imposed concerning the enforcement subgame.

- A patent never expires and, at most, one suit can be initiated on the basis of the same patent against the same party.
- A firm can be found liable for infringement only if it has invested at the previous stage.
- An infringement suit costs both parties $L > 0$. The probability the the patentee F_i prevails is $\alpha_i \in (0, 1], i \in \{1, 2\}$. Different suits are tried independently.
- Concerning the remedy, we assume that the court grants a permanent injunctive relief to the infringed party. A prevailing patent-holder can prevent the infringing

firm from using its investment, which serves as the threat point in the post-infringement bargaining (see below).

- The enforcement stage exhibits a continuous time structure, from time 0 to infinity (see FIGURE 1). However, at no point in time can firms bring suits against each other simultaneously.

With these specifications, a patent holder F_i's enforcement policy consists of the timing to sue, $T_i \in [0, \infty)$, and we have $T_1 \neq T_2$.[6]

More precisely, to enforce its patent right, the plaintiff, say F_1, sends a cease-and-desist letter to the defendant, F_2. Upon receiving the letter, the latter may decide to stop using its investment, so that no litigation will ensue, or continue the employment of established investment and prepare for a court fight. If F_2 doesn't retreat, an infringement suit starts. Both incur cost L, with α_1 the probability of infringement. In this case, the two bargain for a license. For simplicity, assume the whole process, from sending the cease-and-desist letter, deciding whether to retreat, and the resolution of litigation uncertainty to the bargaining after infringement takes place instantaneously at the enforcement date, T_1, chosen by the patent holder. Furthermore, in sections 4 and 5, firms have common $\alpha = \alpha_1 = \alpha_2$.

Due to the injunction remedy and, more generally, the threat of litigation, firms may want to bargain for a license, or a cross-license in the case of mutual-blocking. Refer to FIGURE 1. Bargaining may occur at different stages of the game: *ex ante* licensing takes place before investment decisions are made, but after the patenting stage; *interim* licensing takes place after firms have chosen whether to invest, but before the enforcement stage;[7] and an *ex post* license is negotiated only after a patent is declared infringed by the court. We adopt the Nash bargaining solution with equal bargaining power. To make things interesting, assume *ex ante* investment decisions are not contractible. *Ex post* licensing will be our main concern, and the other two licensing options will be discussed in section 5.3.

☐ **Payoffs:** beginning at time 0, a stream of revenue accrues to each firm according to the prevailing investment profile. To make things simple, suppose once incurred the cost c, an investment can be "switched on" or "switched off" without additional costs

[6] Note that we assume that the court doesn't grant monetary damages for past infringements. Our purpose is to construct a game structure in which a defensive patent deters litigation (PROPOSITION 1). We present one such possibility. The same result can be reached if, for example, the patent term is finite over $[0, T)$, but reaction lag small enough so that a countersuit is always possible; and monetary damages are rewarded for past infringements, where the damage is set at the same level as the licensing payment derived later in LEMMA 1.

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

or depreciation, and, at any point in time, the value accruing to firms depends only on the investment that is switched on at that particular moment.[8]

Assume the market is stationary. Slightly abusing the notation, we also use E to denote the industry's investment use.[9] 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 $\hat{v}_{e_2e_1}$ and $\hat{V}_{e_1e_2} = \hat{v}_{e_1e_2} + \hat{v}_{e_2e_1}$.

Given E at a particular point in time, e.g. $E = (0, 1)$, the same $\hat{v}_{01}$ and $\hat{V}_{01}$ apply regardless of the scenario leading to this profile: it may be that only F_2 has invested, and there is no patent dispute till now. Or both have invested, but after some court fight, only F_1 is declared to infringe and the two fail to agree to a license. Or only F_2 has invested, is sued and declared to infringe, but has secured a license. Implicitly we restrict the licensing space over which firms can bargain *ex post*. In particular, we rule out the facilitation of downstream collusion by patents.[10]

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 consider the case where *ex post* efficiency requires the full utilization of any established investment, but a firm's investment exerts a negative externality on the other. That is, we impose the following assumption:

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 if the two firms had failed to reach an agreement. These two make patents a device to generate licensing fees rather than a tool for protecting a firm's 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 possess an original version of a product in their own markets. Each market is composed of homogeneous consumers of mass one; the two firms compete *à la* Bertrand, but can charge different prices in

[8]For example, when interpreted as the introduction of new product, the status of a product–on the shelf (investment "switched on") or withdrawn from the market ("switched off")–can be altered at zero cost. A firm's revenue depends only on how many products are on the market at that moment.

[9]For example, the products in the market.

[10]In the example of new product introduction, no price-coordination clauses such as a running royalty changing the cost structure or the field-of-use constraints are allowed.

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 holds a monopoly in its home market. Assume no production cost. Therefore, with original versions of both goods, each firm charges a price v, which is also the profit level ($v = v_{00}$ in the previous notation).

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

4 Enforcement and the Truce Equilibrium

This section analyzes the enforcement stage, which begins after firms have made their patenting and investment decisions, and no prior agreements exist to waive patent holders' rights to sue. 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 according to how many suits can be brought.

□ **Patent is irrelevant:** this is the case when no firm holds a patent, or when a firm has chosen to patent but the other hasn't invested. The game ends at the investment stage. 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 holds a patent and the other has invested, or both hold patents but only one firm has invested. Suppose $p_1 = e_2 = 1$ and $e_1 \in \{0, 1\}$.

Consider the case that F_1 enforces its patent at time $T_1 \geq 0$, and F_2 doesn't retreat, and so a suit follows. Before that date, the revenue streams accruing to F_1 and F_2

are $\hat{v}_{e_1 1}$ and $\hat{v}_{1e_1}$, respectively. Both firms incur legal expense with discounted value Le^{-rT_1}. With probability $1-\alpha$, there is no infringement, and no bargaining takes place. The revenue streams remain the same. With probability α, the court finds that F_2 infringes on F_1's patent. The following lemma determines the outcome at this event.

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

Proof. If F_2 couldn't secure a license from the patentee, by ASSUMPTION 1, $\hat{v}_{e_1 0} \geq \hat{v}_{e_1 1}$, F_1 would credibly exercise its injunctive power, and so the threat point revenue stream is $\hat{v}_{e_1 0}$ for F_1 and $\hat{v}_{0e_1}$ for F_2. Since their cooperative joint revenue stream is $\hat{v}_{e_1 1} + \hat{v}_{1e_1}$, bargaining surplus is positive. The two parties agree to exploit F_2's investment, 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

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

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

By this lemma, F_1's expected litigation gain is $\alpha f e^{-rT_1}$, regardless of its own investment level. In a more general setting this independence property would not hold.[11] The following assumption guarantees the enforcement of patent rights.

ASSUMPTION **2.** (i) $\alpha f \geq L$; (ii)[12] $\forall e \in \{0, 1\}, v_{0e} \leq v_{1e} - (\alpha f + L)$.

The first part of the assumption guarantees F_1 has a credible action to sue; and from the second part, F_2 won't retreat when facing the litigation threat. Litigation takes place following F_1's sending of the cease-and-desist letter. Note that without ASSUMPTION 2(i), patents become irrelevant in our model. We will comment later on what happens if ASSUMPTION 2(ii) is not held.

[11] This can be inferred from the term $v_{e_1 0} + v_{e_2 e_1} - v_{e_1 e_2} - v_{0e_1}$ in the proof of LEMMA 1 (where $e_2 = 1$). The expression shows that

$$v_{e_1 0} + v_{e_2 e_1} - v_{e_1 e_2} - v_{0e_1} = (v_{e_2 e_1} - v_{0e_1}) + (v_{e_1 0} - v_{e_1 e_2}),$$

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.

[12] Thanks to Richard Schmidtke for this point.

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

□ **Two relevant patents:** when $P = E = (1, 1)$ each firm can bring an infringement suit. We introduce a reaction lag $\triangle > 0$, so that if, for example, F_1 brings the first suit against F_2 at T_1, the earliest possible time for F_2 to countersue is date $T_1 + \triangle$. 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 "bfirst 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 keeps the rights to sue as well. Since we have assumed that *ex post* licensing takes place only when a patent is infringed, the bargaining at T_1, if F_2 infringes on F_1's patent, can make no agreement on F_2's patent rights. LEMMA 2 shows that it is optimal for F_2 to set this date as early as possible, that is, 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 date 0.

LEMMA 2. *Suppose $P = E = (1, 1)$ and* ASSUMPTION *2 is held. If F_1 sues at T_1,*

(i). F_2 optimally brings a countersuit at date $T_1 + \triangle$; and

(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.

The intuition of this lemma is quite simple: once the rival has exercised its patent rights, the decision to counter-sue is reduced to a unilateral attack. ASSUMPTION 2, then, guarantees the optimality of countersuing with the least delay.

Next, consider the two expressions (1) and (2). When F_1 sues at T_1, the expected benefit is smaller than $\alpha f e^{-rT_1}$ (in present value), due to the threat from F_2's patent. 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 ($\triangle \to 0$). On the other hand, the coefficient of the expected legal expenses, $1 + e^{-r\triangle}$, is derived from the fact that F_2 brings a countersuit with a delay.

We are now ready to show the main result at the enforcement stage, the existence of the truce equilibrium (see Appendix A for the 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 their earliest possible dates.*

However, if $\triangle$ is small enough, there is another, Pareto-dominant subgame perfect equilibrium (the truce equilibrium), in which there is no litigation on the equilibrium path. The symmetric strategy supporting the truce equilibrium is the following: do not sue if you have not been sued till now, but if you have been sued, bring a counter-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 the 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 both may suffer from this unilateral enforcement. In that case, a peaceful life is in their joint interest and can be maintained by both firms adopting the counter-suing-only strategy.

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 equilibrium. 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 the assumption that firms are symmetric, but this should not be a critical constraint. The same argument goes through when no firms get a positive profit in expectation from a litigation war. In section 6, we will relax the symmetry assumption, but still rely heavily on the truce equilibrium.

We conclude this section with a simple corollary.

Corollary 1. *When the truce equilibrium prevails, the number of suits and patents may follow a non-monotonic relationship: no litigation will ensue when neither firm has a patent or when both firms have patents, and one infringement suit when only one firm holds a patent and the other has made investments.*

Alternatively, a non-monotonic relationship may exist between investment and patent litigation: suppose $P = (1, 1)$, there is no litigation when neither or both make investments, but there is one suit when only one firm invests.

5 Hold-up and Strategic Patenting

Let us now move back to the investment and patenting stages. At the investment stage, we show that defensive patenting indeed alleviates the hold-up menace posed by the other patent, and examine how patents change the strategic property of the investment subgame. For the patenting stage, we first derive the strategic relationship of firms' patenting decisions, then characterize the equilibrium of the whole game with respect to this relationship. We pay special attention to the equilibrium investment level.

The main discussion proceeds with *ex post* licensing. *Interim* and *ex ante* licensing are analyzed in section 5.3.

5.1 Investment

We use firms' investment criteria to deduce their investment incentives and the strategic property of investment decisions.

☐ **Investment criteria:** for the benchmark case of no patents, $P = (0, 0)$, investment decisions depend only on $\{v.\}$. 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 $c \leq c_1^* \equiv v_{11} - v_{01}$. For the strategic property, investments are strategic complements if $c_0^* < c_1^*$. For one firm's investment increases the other's incentive to do so; and strategic substitutes if $c_0^* > c_1^*$.

We next introduce patents, and consider how many patents are granted.

In the case of only one firm, for example F_1 has a patent, $P = (1, 0)$. Facing no litigation threat, the patent holder's investment criteria remain the same, $c_{e_2}^*$, with $e_2 \in \{0, 1\}$. For F_2, on the other hand, a patent suit follows its investment (as seen in the previous section), and so incentives to invest decrease: given $e_1 \in \{0, 1\}$, F_2 invests if and only if $c \leq \underline{c}_{e_1} \equiv c_{e_1}^* - (\alpha f + L)$. Apparently $\underline{c}_{e_1} < c_{e_1}^*$.

The strategic property of investment is unaffected, though. The difference $\underline{c}_e - c_e^*$ is the same for both $e = 0$ and 1, and so $\underline{c}_1$ is greater (smaller) than $\underline{c}_0$ if and only if c_1^* is greater (smaller, respectively) than c_0^*.

Finally, consider when both firms hold a patent, $P = (1, 1)$. When the other firm doesn't invest, one's own patent becomes useless and hold-up concerns reappear. The investment criterion is $\underline{c}_0$. When the other invests, although by the truce equilibrium a firm secures full return on its own investment, its investment incentives are still lower than under no patent. The investment criterion is $\hat{c} \equiv c_1^* - (\alpha f - L)$. From Assumption 2, $\underline{c}_1 < \hat{c} \leq c_1^*$. Although the hold-up problem is alleviated, another incentive to under-invest emerges. A firm may refrain from investing in order to share the other's investment return through a patent attack.

In this case, the strategic property of investment may be changed. Since $\hat{c} - \underline{c}_0 = c_1^* - c_0^* + 2L$, we have strategic complementarity as long as $c_0^* < c_1^* + 2L$. Indeed, with L 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 other way around.

PROPOSITION 2. *When patents are introduced,*

- *firms' investment incentives decrease for two reasons: the hold-up threat, and the appropriation of the other firm's investment return; and*
- *investment decisions may transform from strategic substitutes into strategic complements, but not the other way around.*

REMARK 1. The non-negativity of the three thresholds, $\underline{c}_0$, $\underline{c}_1$, and $\hat{c}$, is guaranteed by ASSUMPTION 2(ii).[13] This should not be surprising, since incurred investment can be "switched off" at no cost. When a firm decides whether to retreat from a potential litigation by "switching off" its investment, it is as if the investment decision were made again with zero cost. No retreat condition implies that firms will invest absent investment cost c: $\underline{c}_e \geq 0$.

REMARK 2. The two institutional parameters α and L influence the thresholds $\underline{c}_e$ and $\hat{c}$ differently. 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 from patent enforcement. $\hat{c}$ 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 payments, and so boosts investment incentives.

□ **Investment outcome:** our next step is to combine these criteria and consider the prevailing investment profile. We ignore the uninteresting case in which no firm invests because c is too large ($c > \max\{c_0^*, c_1^*\}$).

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

When c is in the intermediate range $c \in (\min\{\underline{c}_0, \underline{c}_1\}, \max\{c_0^*, c_1^*\}]$, multiple patterns could emerge. In this paper, we consider only the scenario specified in TABLE 1.[14] It

[13]For the benchmark thresholds, both c_0^* and $c_1^* \geq 0$ by ASSMUPTION 1.

[14]The complete characterization is available upon request.

is applicable as long as $\underline{c}_1 < c \leq \min\{\hat{c}, c_0^*\}$, whether c_0^* is greater, smaller, or equal to c_1^*.[15] In that case, both firms invest when no patent, $P = (0,0)$. If only one firm has patented, $P = (1,0)$ or $(0,1)$, only the patent holder invests due to the hold-up concern. However, defensive patenting fully solves this problem; in addition, the incentive to "play small" is not so great. Therefore when both have patented, $P = (1,1)$, the equilibrium investment restores to $E = (1,1)$.

We focus on this profile because from the empirical study (for example, Hall and Ziedonis, 2001), big manufacturing firms adopt the defensive patenting strategy usually with an intention to safeguard their investment and preserve their "freedom of operation." That is, high investment is restored if patent disputes are deterred. In that case, $E = (1,1)$ at $P = (1,1)$ is a reasonable choice.[16] [17]

$p_1 \backslash p_2$	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 $c_1^* = c_0^* = \Delta v \equiv c^*$ and $\underline{c}_1 = \underline{c}_0 = \Delta v - (\alpha f + L) \equiv \underline{c}$, with $f = (1+\gamma)\Delta v/2$. However, when $P = (1,1)$, patents are strategic complements, for $\hat{c} = \Delta v - (\alpha f - L) > \underline{c}$. When $c \leq \underline{c}$, both firms invest regardless of P. Table 1 shows 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 hold patents, and $P = (0,0)$.

[15]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 $c \in (\underline{c}_1, \hat{c}]$.

[16]One interesting case omitted here is the impact 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 prevailing investment profile is $E = (0,0)$: no one invests. On the other hand, if $c_0^* \geq c_1^*$, then F_2's underinvestment (weakly) boosts F_1's incentive to invest.

[17]In empirical studies like this, patent numbers are usually treated as the dependent variable and 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.

□ **Strategic property of patents:** again we distinguish between two cases, according to the level of investment costs.

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 costs K. By symmetry, it suffices to write down F_1's payoff.

$p_1 \setminus p_2$	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 litigation concerns. Since investment outcomes are not affected by patents, different P's at the most involve a zero-sum transfer between firms, plus legal expenses. 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 function (when the rival holds a patent) than for its offensive function (when the rival doesn't have any patent). Patents are strategic complements.

Proposition 3. *If firms always invest, and if patents can deter litigation (the truce equilibrium prevails), then patenting decisions are strategic complements.*

Next, when $\min\{\underline{c}_0, \underline{c}_1\} < c \leq \max\{c_0^*, c_1^*\}$ and the investment outcomes are as specified in Table 1, corresponding payoffs are provided in Table 3. Note that no litigation takes place along the equilibrium path. Either the only non-patenting firm does not invest, or the truce equilibrium prevails.

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

Table 3: Payoffs for intermediate c

In contrast with the previous case, here, firms' patenting decisions are driven by investment concerns. Although no licensing transfer is involved, an offensive patent deters investment. This results in a non-negative benefit $v_{10} - v_{11}$. On the other hand, when the rivaling firm holds a patent, the 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, $E = (1,0)/(0,1)$ 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 (equivalently, a sufficient condition of strategic substitutability) 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 if a litigation is more expensive (L higher).

PROPOSITION 4. *When the investment cost c is in the intermediate range and relevant payoffs as in Table 3, then we have a*

- *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.*

☐ **Equilibrium:** let us re-introduce a positive patenting cost K. We obtain the relationship between K and the equilibrium investment outcome. The proof is in APPENDIX A.

COROLLARY 2. *Assume the same conditions as in* 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, this gives rise to different E's, yielding a non-monotonic relationship of investment with K. For K either low or high, so that either both firms hold a patent or no one patents, $E = (1,1)$. On the other hand, when K is in an intermediate range, so that in equilibrium only one firm holds a patent, then only that firm invests.

Some scholars, for example Merges (1997), have depicted the patenting game in the software industry as a prisoners' dilemma: it is a dominant strategy for each firm to pursue patents, despite their joint interest in 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 and 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. 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 $P = (0, 0)$.

In the case of strategic substitutes, things are rather different. The investment profile is sensitive to the patenting equilibrium, and joint profit maximization may require one firm to be held up and not to 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 a 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 industry-wide profit is increased, albeit a higher patenting cost $K' > K$. The same could happen with strategic complements only if after increasing K, firms would succeed in coordinating to the no-patent equilibrium.

5.3 Alternative Licensing Opportunities

This subsection alters the timing of licensing. The case of *interim* licensing is examined first. It illustrates the role of the enforcement cost in our model. With regard to 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:** in general, it is cheaper to resolve legal disputes out of the court. We consider 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 $V_{e_1 1} - 2L$, $e_1 \in \{0, 1\}$; and 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 $v_{1 e_1} - \alpha f$, the same as putting $L = 0$ in the previous derivation. On the other hand, if no litigation would ever occur, firms wouldn't bother bargaining. The truce equilibrium is robust to the introduction of *interim* licensing.

For the investment stage. Investment thresholds $\{c_e^*\}_{e=0,1}$ are unaffected by *interim* licensing; while $\{\underline{c}_e\}_{e=0,1}$ are increased to $\underline{c}_e^{in.} \equiv c_e^* - \alpha f, e \in \{0, 1\}$. Although there is still a licensing fee αf, the saving of L decreases the defensive party's loss from a patent attack, which boosts incentives. But now the criterion $\hat{c}$ *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. This in turn makes the investment outcomes of TABLE 1 almost impossible to attain.

To see this, suppose P has an impact on E,[18] and 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 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 the same outcome as in TABLE 1.

For PROPOSITION 3,[19] on the other hand, strategic complementarity is lost in the case of no enforcement cost, $L = 0$. Patents become strategically independent.

Nevertheless, all this holds true only when *interim* licensing is costless. If there are some positive bargaining costs, previous results are re-gained, since we could simply re-interpret L as the cost of *interim* licensing. From this observation, what we are considering here relates more to the role of enforcement cost in our model than to the exact timing of licensing. 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 cost of enforcement.

Positive *interim* bargaining costs could come from contracting costs, including the management time and effort spent in negotiating and crafting out appropriate licensing terms, or the enforcement cost up to a pre-trial settlement. Another way is to introduce an asymmetric information element at the *interim* bargaining stage, as Bebchuk (1984) (see APPENDIX C).

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

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

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

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

information.

□ *Ex ante* **licensing:** suppose no *interim* licensing and $L > 0$, but firms can bargain before the investment stage with a lower cost $l \in [0, L]$. Different from the *interim* bargaining, an *ex ante* licensing provides an opportunity not only to preclude future patent disputes in a less expensive way, but also to coordinate investment decisions. Although we don't allow e_1 and e_2 to be written into a contract, this coordination can be done by *not* granting a license, so that a potential infringer refrains from investing.

The small c case is uninteresting here since firms make investments whatever the patent profile. The *ex ante* licensing is used by firms to economize on enforcement costs when $l < L$. The described scenario happens only in the intermediate range of c. The following proposition states the main result (see APPENDIX A for proof).

PROPOSITION 6. *Suppose ex ante licensing is available at a cost $l \in [0, L]$, and c is 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 and $l > 0$, no cross-license is observed. When patents are strategic complements, no licenses are granted; but when patents are strategic substitutes, the only possible outcome is a one-way license so that only one firm invests at the next stage. This happens when $l \leq \frac{1}{2}[V_{10} - (V_{11} - c)]$.

From this proposition, patents can facilitate collusion in investment. This is done in a more subtle way, namely by *not* granting a license and letting hold-up work.

5.4 Remarks

REMARK 1. To determine the strategic property of patents in a binary choice setting, a comparison is made between the benefit of an offensive patent (when the other firm doesn't have a patent) and a defensive patent (when the other firm has a patent). Strategic complementarity (substitutability) results in if the latter is greater (smaller, respectively). The two payoff matrixes, TABLE 2 and 3, represent two polar cases regarding the effects of an offensive patent.

In TABLE 2, an offensive patent is used to extract licensing income. But this revenue has to be subtracted from the enforcement cost to reflect the net gain of an offensive enforcement. On the other hand, a defensive patent saves its owner not only the licensing payment, but also the patent-dispute expenses. Strategic complementarity, therefore, is a result of strictly positive enforcement costs.

In TABLE 3, patents change the industry-wide investment performance. An offensive patent prevents the other firm from investing, while a defensive patent restores investment incentives. The comparison, then, necessarily involves payoffs from different investment pairs. Thanks to the symmetry assumption, individual payoffs are aggregated into joint profits. It then suffices to consider joint profit maximization. Strategic complementarity follows if private efficiency requires both firms to invest, $V_{11} - c > V_{10}$.

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 be satisfied? Since we assume negative externality, $v_{e1} \leq v_{e0}$, the individual investment return needs to be large enough to compensate for this effect, $(v_{11} - v_{01}) - (v_{10} - v_{11}) > c$.

EXAMPLE 1 (CONTINUED). Suppose $c \in (\underline{c}, \hat{c}]$ so that TABLE 3 is applicable. From $V_{11} - V_{10} = (1-\gamma)\Delta v > \underline{c}$, inequality (3) is satisfied. Also, $\hat{c} \gtreqless (1-\gamma)\Delta v$. Both strategic substitutability and complementarity are possible.

Patents are strategic complements if $c < (1-\gamma)\Delta v$: when the substitutability between the two new versions is smaller, and so the competition is less severe (γ is small); or when the technology improvement is greater (Δv is large). ■

REMARK 3. Without specifying consumer demand, we cannot provide a thorough welfare analysis. Nevertheless, we can derive an observation from COROLLARY 2.

When conditions are met, the patent system influences the market investment performance only in the case of strategic substitutability. If patents are strategic complements, investments remain the same, and the potential effect of the introduction of patents is for firms to spend K in acquiring them.

From this observation, a rather bold claim is that: the introduction of a patent system would not be optimal if it endows patents with the property of strategic complementarity. In a patenting game with strategic complementarity, besides the administrative costs, firms can, at best, succeed in coordinating *not* to pursue patents. At worst, resources are expended in patenting to maintain the situation from before the introduction.

REMARK 4. To check the robustness of our analysis, let's relax two of our assumptions in turn. First, consider that the relationship $V_{11} \geq V_{10} \geq V_{00}$ is not held. For example, when the two firms compete in a single product market, and e_i is F_i's entry decision, then, in general, we would expect monopoly profit to be higher than duopoly profit. Previous research, such as Bessen (2003) and Ménière and Parlane (2004), is conducted in this environment. It would be interesting to see whether our results could survive this modification.

With some qualifications, our insights carry over to the single product context. A truce equilibrium exists when the legal expense L is high enough; and the two forces identified above exert the same effects on the strategic property of patents. A higher L makes strategic complementarity more likely; and since joint profits are always higher when only one firm invests (enters), patents are more likely to be strategic substitutes. In particular, when TABLE 1 applies, strategic substitutability is guaranteed. In this sense, the single-product assumption is more restrictive (for a thorough discussion, see APPENDIX D).

Second, suppose ASSUMPTION 2(ii) is not held, and consider if $v_{01} > v_{11} - (\alpha f + L)$ and $c \leq c_0^*$. Then at $P = (1, 0)$ the firm having no patent will retreat when facing a litigation threat, and so, will not invest in the first place. This is true even when c is close to zero. TABLE 3 describes the payoffs, and associated results (PROPOSITION 4 and COROLLARY 2) apply directly. A potential patent dispute alone deters investment.

REMARK 5. The truce equilibrium implies no enforcement, and so no patent holders earn any licensing income. This implication could be detrimental to the very purposes of the patent system. The next section provides an example.

6 Patent *versus* Trade Secret

In this section, we relax two assumptions. Firms are no longer symmetric, and technology flow is introduced. In addition to technologies A_i, which are still of no value to F_j, we let F_1 hold another invention B. Assume B is valuable to F_2, and joint profit maximization requires it to be incorporated into F_2's production. To induce disclosure, the patent system serves as a mechanism for F_1 to share the benefit of technology flow. We show an example of how F_2's defensive patenting deters F_1's disclosure by reducing its gain from patent enforcement.

For simplicity, we set $c = 0$ and assume firms always invest. An offensive patent brings in licensing income, and the incentive power of the patent system is determined by the income generated. Assume the valuable technology B is always eligible for patent protection with a considerable probability of being infringed on. But, depending on the patent regime, A_1 and A_2 may or may not be qualified for a patent. Even if they are, the infringement probability may not be high enough to justify the enforcement cost. Two patent regimes are classified accordingly: under a "weak" regime, only B is patentable; but under a "strong" regime, a patent with non-negligible power can be granted to A_i. The defensive patenting strategy is available for F_2 only under the strong regime.

What we have in mind is the situation before and after the U.S. patent reform. As described in the introduction, after the reforms in the 1980s, defensive patenting became a viable option. Despite the general agreement that these are pro-patent reforms, we are going to show that the incentive power may nevertheless have decreased. This is a consequence of defensive patenting.

The model is modified as follows. Assume no patenting cost, $K = 0$, but maintain $L > 0$, and there is no *ex ante* or *interim* licensing. Let L be high enough so that each firm, at most, brings one infringement suit, and so applies for, at most, one patent. 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.

Firms incorporate all the disclosed information into its investment: F_1 uses both A_1 and B; and F_2 uses A_2 and in addition B if it is patented and disclosed.[20]

Since only technology B will be copied without permission, it is reasonable to let the probability to infringe B, α_B, be greater than to infringe technologies A_1 and A_2 (which assumed a common α_A). The court grants injunction as an infringement remedy, as in previous sections. Let $\alpha = (\alpha_A, \alpha_B)$. Under the "weak" patent regime, $\alpha = (0, \alpha_B)$ with $\alpha_B > 0$. Under 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 $\alpha' = \alpha + (\Delta\alpha, \Delta\alpha)$. That is, from a weak to a strong regime the infringement probability is increased uniformly.

Payoffs $\{v_{..}\}$ are now functions of both the investment profile reaching the market, and technologies incorporated. Nothing is changed when B is not available to F_2: $v_{e_i e_j}$ to F_i if $E = (e_i, e_j)$. Assumption 1 is held. But when F_1 patents B, then, given e_1,

- if $e_2 = 0$, we still have, $v_{e_1 0}$ for F_1 and $v_{0 e_1}$ 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 $\beta v_{e_1 1}$ and $b v_{1 e_1}$, respectively. Let $\beta \leq 1 \leq b$.

By $\beta \leq 1$, the technology B will be protected as a trade secret if F_1 cannot be properly compensated for its disclosure.

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

After these modifications, at different *ex post* bargaining:

- the joint profit at threat points are, given F_2 infringes, V_{10} if F_1 doesn't infringe, 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; and
- the cooperation joint profits are $(\beta + b)v_{11}$ if B is patented, and V_{11} if not.

The following assumption guarantees information disclosure and full utilization of investment are in line with joint interests, and no firms retreat and shut down investments when facing the threat of litigation.

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

□ **Weak patent regime:** under a weak patent regime $\alpha = (0, \alpha_B)$, no firms pursue a patent of A_i. If F_1 holds B as a trade secret, there is 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 (proof can be found in APPENDIX A).

LEMMA 3. *Under a 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 patenting B are*

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

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

A new term $(b - \beta)v_{11}$ appears in the licensing fee in (6) and (7), which reflects the contribution of B to F_2, netting of the negative impact on F_1.

□ **Strong patent regime:** switch to the strong patent regime $\alpha' = (\alpha'_A, \alpha'_B) > \alpha$. F_2 decides whether to get a patent; F_1 has two patentable inventions with different exclusive powers but patents one at most.

If B is not patented, results at section 5 directly apply by setting $e_1 = e_2 = 1$. Payoffs are the same as in Table 2 by setting $c = 0$ and $\alpha = \alpha'_A$. And, without patenting costs, 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 F_2 holds no patent, it has no weapon to fight back and payoffs are those of (6) and (7), with a higher infringement probability α'_B. If F_2 holds a patent, F_1's profit is reduced. The credible countersuit threat decreases the expected licensing transfer, and could possibly eliminate enforcement. We may still have the truce equilibrium.

The following lemma provides conditions of a litigation war (the proof is relegated to Appendix A).[22]

Lemma 4. *When B and A_2 are patented,*

- *conditions of credible countersuing threats are*

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

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

- *given the other firm doesn't retreat from a litigation 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

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

[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.

[22] We consider only the case in which 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.

□ **Regime shift and technology flow:** assume inequalities (5), (4), and (8)-(11) are met. Under a weak regime, F_1 patents B. Under a strong regime, F_2 has a dominant strategy of patenting A_2, while for F_1, no patent strategy is dominated by patenting A_1. Whether the technology flow is unaffected by the regime shift depends on whether F_1 keeps patenting B in the strong regime.

After the regime shift, the technology flow may be terminated in two cases: either the truce equilibrium prevails, and so F_1 is not compensated for the disclosure of technology B; or there is still positive profit from a litigation war, but the net gain is smaller than the loss in revenue to patent B, $(1-\beta)v_{11}$. Since $\beta \leq 1$, F_1 may switch to patent A_1 in both scenarios.

Example 2 provides an illustration of this argument. For simplicity we consider a uniform shift of patent power, $\alpha'_B = \alpha_B + \Delta\alpha$ and $\alpha'_A = \Delta\alpha$, with a numerical example.

Example 2. Consider the parameter values of $\alpha_B = \frac{1}{3}$, $\beta = .99, b = 1.2, v_{11} = 100, v_{10} = 120, v_{00} = v_{01} = 0$, and $L = 13$. Assumption 1 and 3 are satisfied; so are inequalities (5) and (4). B is patented at the weak regime. In addition, 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.

To consider F_1's choice between patenting B or A_1 over the range $\Delta\alpha \in [0, \frac{2}{3}]$,[23] the decision is made by comparing the payoff from patenting B with 100, the level F_1 can secure by holding a patent A_1. Figure 2 summarizes the result. The thick line represents F_1's payoff when patenting B. We can see that the optimal decision is non-monotonic in $\Delta\alpha$: F_1 patents B when $\Delta\alpha \in [0, .21)$ or $[.35, \frac{2}{3}]$; when in the intermediate range $\Delta\alpha \in [.21, .35)$, it switches to A_1.

The story as follows: defensive patenting is not available until $\Delta\alpha$ exceeds .21, which is determined by condition (9). Before that level, only F_1 benefits from a general strengthening of patent rights: it extracts more licensing payment from F_2. When $\Delta\alpha \geq .21$, a patent on A_2 is powerful enough and F_1 faces a litigation war if enforces its patent rights. Given that B is patented, from the left-hand side of inequality (12), the gain from a war, the expected licensing fee, is still increasing in $\Delta\alpha$ with chosen values. But if $\Delta\alpha$ is not large enough either (i) the gain is too small to warrant the enforcement costs, and truce equilibrium prevails for $\Delta\alpha \in [.21, .25)$; or (ii) even if the profit is positive, it cannot compensate for the loss from disclosing B ($(1-\beta)v_{11} = 1$), and this is the case for $\Delta\alpha \in [.25, .35)$. The value .25 is determined by condition (12)

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

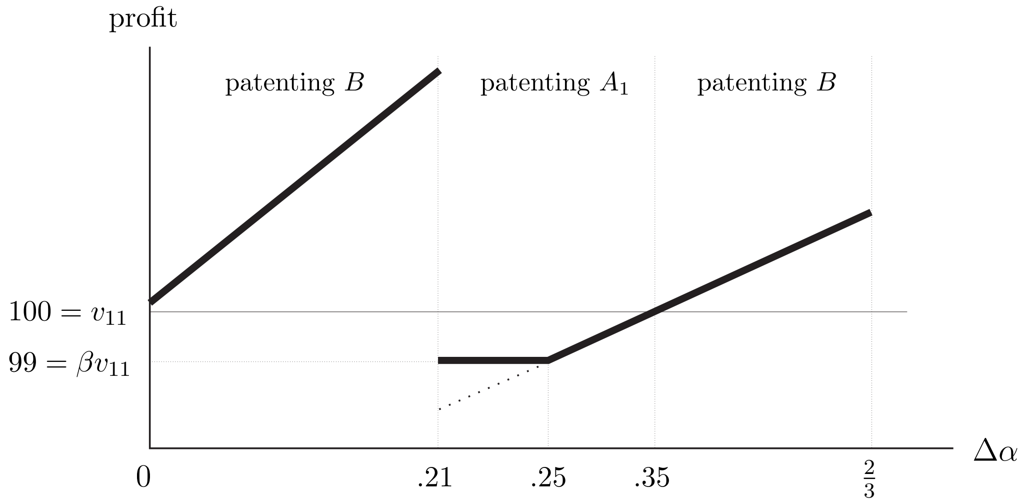

Figure 2: Patent Power and Patenting Decision

binding; and .35 by the profit from a litigation war equals one. In both cases, F_1 switches to patent A_1. Only when $\Delta\alpha \geq .35$ will F_1 go back to patent B. ■

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

Again, two non-monotonic relationships may be observed: when the patent power is enhanced uniformly by $\Delta\alpha$, technology flow and patent enforcement may take place only for a high or low value of $\Delta\alpha$, and are eliminated for an intermediate value of $\Delta\alpha$.

7 Concluding Remarks

To evaluate the performance of the patent system, we need to understand how firms operate in it. The various non-monotonic relationships derived in this paper illustrate the complexity of the issue, and we believe have some policy implications.

On the basis of the defensive patent's ability to mute enforcement, that is, the truce equilibrium (PROPOSITION 1), we have raised the possibility that the introduction of patents may have no effect other than inducing firms to engage in the socially wasteful accumulation of patent portfolios (COROLLARY 2); and counter-intuitively, an increase of patent power may weaken the incentive power of the patent system (PROPOSITION 7).

If we examine the U.S. patent policy shift, two ingredients of the "reform" are crucial to our concerns: the USPTO's issuing of more patents with arguably lower quality, and the CAFC's greater willingness to uphold issued patents. Since the premise of defensive patenting is the ability to build a patent portfolio with non-negligible infringing probability, our results support the argument that the "flooding" of a large amount of bogus patents should be partly responsible for a "broken" U.S. patent system, in Jaffe and Lerner's words.

In a paper related to this matter, Lemley (2001) puts forward the view that the current patent examination quality exercised by USPTO may be optimal, albeit abundant critiques. The author argues from empirical experience that most patents issued are not economically important, because they have neither been licensed nor enforced. Therefore, 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 application at the patent office.

One problem with this reasoning is its very starting point. As we have seen in section 6, an important patent could be "buried" in a truce equilibrium and classified as "economically unimportant" according to Lemley (2001) precisely after the PTO started issuing low-quality patents and the court raised the validity of patents. But the fact that these patents have not been enforced doesn't make them irrelevant. Instead, if the CAFC maintains its position of high presumed validity of issued patents, the calculation should tilt toward weeding out bad patents within PTO.

For future research, one might want to integrate the concerns raised in this paper into the design of optimal patent policy. For instance, the optimal 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. In that way, it propounds the view that increasing the patent power unambiguously benefits the latter. If the first-generation inventor is also a user of technology, this might no longer be true, and it would be desirable to re-exam the optimal patent scope.

Finally, if one sticks to the tradition of no enforcement cost, the fact that, at the *interim* licensing stage, we may not have two rival firms investing when both hold patents (Proposition 5) begs the question: whether firms are endowed with too many incentives to "play small" and hold up rivals. Alternatively, whether the strengthening of the patent system has optimally encouraged vertical disintegration, or the entry of firms specializing in design (which have no manufacturing capacity and presumably less vulnerable to patent threats). To discuss these issues, we need a model of ownership, a topic for future study.

Appendix

A Proofs

□ LEMMA **2**

Proof. Formally, we partition the enforcement stage into time intervals with equal length $\triangle > 0$. Suppose F_1 can bring a suit at $2n\triangle$ and F_2 at $(2n+1)\triangle$, with $n = 0, 1, 2, \ldots$. We are looking for the subgame perfect equilibrium in the litigation subgame.

Without loss of generality, let F_1 be the first mover and decide to bring a suit at time $T_1 = N_1\triangle, N_1 \in \{0, 2, 4, \ldots\}$. Denote F_2's enforcement date as $T_2 = N_2\triangle$, $N_2 \in \{1, 3, 5, \ldots\}$, and $N_2 \geq N_1 + 1$.[24] 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. 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 F_2 executes the unilateral attack again F_1. LEMMA 1 directly applies. Expected payoffs are:

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

where the superscript $1-\alpha$ indicates the event F_1 loses its case at date T_1, and $\hat{f} = \frac{1}{2}(\hat{v}_{10} - \hat{v}_{01})$. It is clear that as long as ASSUMPTION 2 is held, F_2's optimal policy is $T_2 = T_1 + \triangle$.

⋄ With probability α, the two firms bargain for F_2 infringes F_1's paten. We need to determine the threat point and cooperative profits given F_2's enforcement at date T_2.

For the threat point. If no agreement, 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, $E = (1, 0)$ prevails to the end of the game. With probability α the patent of F_2 is infringed, the two firms meet and bargain again.

If the bargain fails again, F_2 exerts its injunctive power and the threat point is mutual blocking, $E = (0, 0)$. As to the cooperative outcome, the two firms may be able

[24] 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. The optimal suing dates are the same for both events.

to reach a cross-license and restore *ex post* efficiency $E = (1, 1)$; or previous bargaining failure persists and only $E = (1, 0)$ is feasible. Different choices affect payoffs here and the threat point profit of the bargaining at T_1. But the results in this lemma are not sensitive to this choice.[25] Here we proceed with the case of restoring the efficient outcome $E = (1, 1)$.

By this assumption, the bargaining at time T_2 has the 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 $E = (1, 0)$, and have an opportunity to improve to $E = (1, 1)$ with probability α at time T_2. 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 negotiate a license covering only F_1's patent. 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 $E = (1, 1)$ 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 the expected payoffs when F_1 prevails at T_1 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.*

[25] Knowing what investment outcome would emerge should they fail to license at T_1, the bargaining surplus as well as the threat point are adjusted accordingly. The impact is equally shared between two players, and so the two scenarios end up with the same payoffs.

□ Proposition **1**

Proof. Given $\triangle > 0$. Lemma 2(i) guarantees the optimality of counter-suing. To consider whether a firm should bring the first suit, conditional on the other's strategy, we have two equilibria:

⋄ war equilibrium: if enforcement is decided in a non-strategic manner, then each firm sues at the earliest possible dates.

To show this is an equilibrium, consider at 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 but delay a litigation war. F_1 loses its first-mover advantage. The expected payoff following this deviation is:

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

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, patent disputes take place at time 0 and $\triangle$. 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 the enforcement decision of F_1 at T_1. If the rival adopts '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:

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

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 firms, 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 equilibrium joint profit depend on the equilibrium at the patenting stage, which can be characterized in terms of 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, but the magnitude is affected by the rival's patent decision. 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. $P = (1, 1)$ is the unique equilibrium; (ii) if $K \in [v_{10} - v_{11}, v_{11} - v_{01} - c]$, there are two symmetric equilibria $P = (0, 0)$ and $(1, 1)$; and, (iii) if $K > v_{11} - v_{01} - c$, then no one gets any patent and $P = (0, 0)$ is the unique equilibrium. But for both $P = (0, 0)$ and $(1, 1)$, the equilibrium investment profile is $E = (1, 1)$.

When patents are strategic substitutes, $v_{11} - v_{01} - c < v_{10} - v_{11}$. For $E = (1, 1)$ to be the investment outcome at $P = (1, 1)$, we must have $c \leq \hat{c} = v_{11} - v_{01} - (\alpha f - L)$. Therefore $v_{11} - v_{01} - c \geq \alpha f - L \geq 0$ and benefits to patent are non-negative.

Similar to the case of strategic complementarity, for K either large ($K > v_{10} - v_{11}$ here) or small ($K < v_{11} - v_{01} - c$), the investment equilibrium is $E = (1, 1)$. 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 the patenting firm to invest. A non-monotonicity of E with respect to K exists when patents are strategic substitutes. *Q.E.D.*

□ Proposition **6**

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 an agreement is $E = (1, 0)$ and the joint profit is $V_{10} - c$. If a license is granted the investment outcome is $E = (1, 1)$, with joint profit $V_{11} - 2c$. The condition to reach a license coincides with that of strategic complementarity of patents.

When $P = (1, 1)$, by truce equilibrium $E = (1, 1)$ is achievable without any bargaining; no cross-licensing is needed. The only way to increase joint profit by spending $2l$ and engaging in *ex ante* is to change the investment outcome to $E = (1, 0)/(0, 1)$, and this is done with one-way license so that hold-up is in force. The condition leading the firms to choose $E = (1, 1)$ ($E = (1, 0)/(0, 1)$) coincides with the condition that patents are strategic complements (strategic substitutes, respectively). *Q.E.D.*

□ Lemma **3**

Proof. Suppose F_2 not retreats. If F_1 patents B and sues F_2 for infringement, with probability $1-\alpha_B$ the challenge fails and it 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); it is profitable if

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

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 initiates a litigation war, the 'reaction time' $\triangle$ approaches to zero, and ignore for a moment the enforcement cost $2L$. Consider the four possibilities of a 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. We can use directly the result in LEMMA 3, with $\alpha_B=1$. By 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 profits are F_1 for βv_{01} and F_2 for bv_{10}, because e_1 is shut down. The cooperative joint profit is $(\beta+b)v_{11}$. By ASSUMPTION 3, we have positive bargaining surplus. 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. Firms negotiate for a cross-license. The threat point is $E=(0,0)$; both firms get v_{00}. The bargaining surplus is $(\beta+b)v_{11}-V_{00}$. 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, the expected payoffs from a litigation war are

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

for F_1, and

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

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

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

It is the condition (12).

To derive condition (10) and (11). For F_1, suppose F_2 not retreats. If F_1 'switches off' its investment, $e_1 = 0$, and so eliminates the risk of infringement, by suing F_2,

◇ with probability α'_B, there is an infringement. The threat point profit is v_{00} for both; the cooperative joint profit is $\beta v_{01} + bv_{10} \geq 2v_{00}$ by Assumption 3. 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 with $e_1 = 0$ suing F_2 brings F_1 an expected payoff

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

F_1 won't shut down its investment if this term is smaller than the 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, 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. This is done by introducing asymmetric information about firms' litigation cost.

Assume with probability $1-\epsilon$ a firm is the 'normal type,' with payoffs specified in the model. With probability $\epsilon \in (0,1)$, however, a firms is the 'purely defensive' type: it hesitates to bring the first suit, but has a credible threat to bring a counter-suit.

To justify this behavior, we keep revenue parameters $\{v_{..}\}$ 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. As an extreme case, suppose there is only 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 in the court, the marginal cost for the second suit is zero. Therefore it always brings a counter-suit, and does so as early as possible.

The scale economy of litigation may come from 'learning effect.'[26] Or, firms may hesitate to enforce their patent rights offensively due to the reputation concern in an industry with a 'free atmosphere' tradition. Semiconductor and software are two examples until the 1990s. But a counter-suit makes no such damage.

Assume each firm can be one of the two according to the identical and independent probability distribution $\{\epsilon, 1-\epsilon\}$. Let the type be the firm's private information, and this structure is common knowledge. 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.

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 doesn't attack.

Given a war from the normal type rival, 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 loses the first-mover advantage at time $T_1+\triangle$. The difference with π_1^s is (ignoring the discount factor e^{-rT_1}):

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

When ϵ is large enough, this term is strictly positive. The condition is

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

[26] For empirical evidence, see Lerner (1995) and papers cited there.

As $\triangle \to 0, e^{-r\triangle} \to 1$, the threshold value $\epsilon_\triangle$ approaches to zero. When the reaction lag is small enough, a tiny perturbation suffices to eliminate the war equilibrium. $\square$

C Asymmetric Information in *Interim* Licensing

In this appendix, we borrow from Bebchuk (1984) a model of settlement bargaining under asymmetric information, and show that our results are qualitatively robust to a positive *interim* licensing cost introduced in this way.

Suppose after the investment stage a patent-holder F_i receives some private information regarding the power of its patent, α_i. F_i may have found some prior arts about its validity; or after a reverse engineering effort it has a more precise assessment of the extent to which its patent reads on the investment of the rivaling firm.

Let $\alpha_i \in \{\underline{\alpha}, \bar{\alpha}\}$, with $\underline{\alpha} < \bar{\alpha}$, $i \in \{1, 2\}$. Assume *i.i.d.*, the probability of $\bar{\alpha}$ equals to $p \in (0, 1)$, and denote the expected value as α^e. Assumption 2 is held for both $\underline{\alpha}$ and $\bar{\alpha}$. Litigation threat is credible for both types, and firms never retreat upon receiving an infringement notice. When bargaining, to avoid signaling we let the uninformed party, i.e. the defendant makes a take-it-or-leave-it settlement offer.

We look for a case where (i) when only one patent matters, e.g. $p_1 = e_2 = 1$ and $p_1 \cdot e_2 = 0$, 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; and (ii) when $P = E = (1, 1)$, the truce equilibrium exists. Then there is no need to engage in *interim* licensing.

$\square$ One relevant patent: consider if F_1 threats to sue F_2, and the latter makes a take-it-or-leave-it settlement offer with payment s. If accepted, the case is settled by F_1 granting 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 $(1-p)(\underline{\alpha} f - L) + p(\bar{\alpha} f + L)$; and (iii) if $s \geq \bar{\alpha} f - L$, F_2 settles with both types, and the minimum licensing payment is $s = \bar{\alpha} f - L$.

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

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

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

□ The truce equilibrium: when $P = E = (1, 1)$, the truce equilibrium exists if the profit from a litigation war is negative for both types of patent-holders.

Given the opponent holds a patent with an expected infringing probability α^e, the expected gain from a war depends on one's own type:

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

If $\pi(\bar{\alpha}) < 0$, no litigation will ever occur even if no *interim* licensing. Then firms have no bargain.

For our purpose, if inequality (13) is held and $\pi(\bar{\alpha}) < 0$, litigation takes place with a positive probability 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

In this appendix we consider an alternative market environment such that the joint profit part of Assumption 1 is not held, and the only infringing firm has to shut down investment. 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, it won't be able to secure a license and has to exit the market. F_1 enjoys the monopoly profit v_{10}, and F_2 gets $v_0 \equiv v_{0e}$.

A second consequence of 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 other results are affected, suppose the truce equilibrium exists, and consider two cases for different sizes 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.

References

[1] Bebchuk, L., (1984), "Litigation and Settlement under Imperfect Information," *Rand Journal of Economics,* 15(3): 404-415.

[2] Bessen, J., (2003), "Patent Thickets: Strategic Patenting of Complex Technologies," working paper.

[3] Chang, H. F., (1995), "Patent Scope, Antitrust Policy, and Cumulative Innovation," *RAND Journal of Economics,* 26(1): 34-57.

[4] Cohen, W., R. Nelson, and J. Walsh, (2000), "Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or not)," NBER working paper 7552.

[5] Crampes, C. and C. Langinier, (2002), "Litigation and Settlement in Patent Infringement Cases", *RAND Journal of Economics,* 33(2): 258-274.

[6] Green, J. and S. Scotchmer, (1995), "On the Division of Profit in Sequential Innovation," *RAND Journal of Economics,* 26(1): 20-33.

[7] Hall, B., and R. Ziedonis, (2001), "The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979-1995," *RAND Journal of Economics,* 32(1): 101-128.

[8] Jaffe, A., (2000), "The U.S. Patent System in Transition: Policy Innovation and the Innovation Process," *Research Policy,* 29: 531-557.

[9] Jaffe, A. and J. Lerner, (2004), *Innovation and its Discontents: How Our Broken Patent System is Endangering Innovation and Progress, and What to Do About it,* Princeton University Press.

[10] Lanjouw, J. and M. Schankerman, (2003), "Enforcement of Patent Rights in the United States," *Patents in the Knowledge-based Economy,* W. Cohen and S. Merrill ed., the National Academies Press.

[11] Lemley, M., (2001), "Rational Ignorance at the Patent Office," *Northwestern University Law Review,* 95(4): 1495-1529.

[12] Lerner, J., (1995), "Patenting in the Shadow of Competitors," *Journal of Law and Economics,* 38(2): 563-595.

[13] Levin, R., A. Klevorick, R. Nelson, and S. Winter, (1987), "Appropriating the Returns from Industrial Research and Development," *Brookings Papers on Economic Activity,* 3: 783-831.

[14] Ménière, Y. and S. Parlane, (2004), "A Dynamic Model of Cross Licensing," working paper.

[15] Merges, R., (1997), *Patent Law and Policy: Cases and Materials,* second edition, Michie Press.

[16] Merges, R., (1999), "As Many as Six Impossible Patents Before Breakfast: Property Rights for Business Concepts and Patent System Reform," *Berkeley Technology Law Journal,* 14: 577-615.

[17] Meurer, M., (1989), "The Settlement of Patent Litigation," *RAND Journal of Economics,* 20(1): 77-91.

[18] Quillen, C. and O. Webster, (2001), "Continuing Patent Applications and Performance of the U.S. Patent Office," *Federal Circuit Bar Journal*, 11(1): 1-21.

[19] Shapiro, C. (2001), "Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard-Setting," *Innovation Policy and the Economy,* Volume I, A. Jaffe, J. Lerner, and S. Stern, eds., MIT Press.

[20] Somaya, D. (2003), "Strategic Determinants Of Decisions Not To Settle Patent Litigation," *Strategic Management Journal*, 24: 17-38.

[21] Taylor, C. and Z. Silberston, (1973), *The Economic Impact of the Patent System: A Study of the British Experience,* Cambridge, UK: University Press.

[22] von Hippel, E., (1988), *The Sources of Innovation,* Oxford University Press.