A Simple Theory of Defensive Patenting*

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Abstract

This paper examines innovating firms' incentives to engage in defensive patenting. It first establishes a "truce equilibrium" in patent enforcement: when litigation is costly, the equal strength of two symmetric parties' patent portfolios deters any patent disputes along the equilibrium path. This equilibrium behavior generates two benefits of defensive patenting, namely, to prevent licensing outlays and to protect downstream investments. In addition, firms can use patents to coordinate non-contractible investment decisions. Depending on the joint interests, they can either reach a license in order to guarantee high investment incentives, or agree *not* to grant a license so that investments are deterred by the litigation threat. On the other hand, the strategic patenting concern may generate a bandwagon of patent accumulation, where firms rush to the patent office to get a patent, but the subsequent investment performance is the same as when there is no patent at all.

The paper also argues that defensive patenting may weaken the effectiveness of patents as an appropriation scheme. This offers an explanation that the "pro-patent"

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policy shift in the United States since the 1980s may actually have undermined the incentive power of the patent system.

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1 Introduction

Conventional wisdom tells us that, to benefit from her patents, a patent-holder needs to take an aggressive stance. She needs to enforce, or at least to show the willingness to enforce her patent rights against potential infringers, either to extract licensing income or to prevent them from spoiling her competitive advantage in downstream markets through unpermitted imitation. Besides this traditional "offensive" view, another incentive to pursue patents, namely, defensive patenting, has long been driving firms' intellectual property rights (IPR) management in different industries.

By defensive patenting, we mean the accumulation of a patent portfolio for the purpose of settling IPR disputes or deterring patent attacks in the first place. For example,

> *At Microsoft, we used to pay little attention to patents–we would just make new things, and that would be it. Then we started getting worried–other big competitors (much bigger than we were at the time) had been patenting their inventions for some years, and it made us vulnerable. ... One of these big companies could dig through their patent portfolio, find something close to what we had done, then sue us, and we would have to go through an elaborate defense and possibly lose. So Microsoft did what most big companies do, which is start to build what is called a 'defensive' patent portfolio. So if a big company tried to sue us, we could find something in our portfolio they were afoul of, and countersue. ... since it was intolerable for all parties to engage, it resulted in a state called 'détente', or 'standoff'. This is what you see today for the most part in lots of industries.* (Chris Prateley, 2004)[1]

Despite its practical importance, defensive patenting has received little attention on the theoretical front. Accordingly, many open questions remain to be answered. For instance, the quoted Microsoft story and interview studies, e.g. Cohen *et al.* (2000), Hall and Ziedonis (2001), have identified the "freedom of operation" as a prominent motivation for pursuing this strategy. When equipped with a patent shield, firms can invest in production facilities or further R&D fearless of threats from others' patent attacks. Questions then arise: What is the impact of defensive patenting on product

[1]Chris Prateley is a group program manager at Microsoft. This story is quoted from his blog: http://blogs.msdn.com/Chris_Pratley/archive/2004/05/01/124586.aspx (last visit on October 22, 2005). Similar stories can be found in von Hippel (1988)'s study in the semiconductor industry, and Taylor and Silberston (1973)'s in electronic engineering in the 1960s.

market competition? Does it generate bandwagons in patenting, and is it responsible for recent patent surge? And ultimately how does it alter incentives for innovation? This paper takes a first pass at these issues.

In a simple two-firm-three-stage model (section 2), we assume firms have already completed the R&D stage and hold a basic technology. They first choose whether to patent the basic technology, then make an investment decision. This downstream investment is subject to infringement risk. At the last stage of the game, patent-holders make enforcement decisions. A patent's defensive value is established by a truce equilibrium in strategic patent enforcement, in which any offensive enforcement is fully deterred and no patent disputes ensue along the equilibrium path (section 3). The intuition is similar to nuclear deterrence: if two countries possess nuclear weapons, no one gains from using them, and so peace is maintained.

We apply this equilibrium behavior to two issues. In section 4, defensive patenting is considered as a counter measure to the other patentee's hold-up threat. We show that, indeed, a defensive patent alleviates the hold-up threat and partially restores investment incentives. For symmetric firms, in addition, we find that patents can help firms to coordinate the non-contractible investment decisions. According to their joint interests, firms can agree to grant a license in order to preserve the investment incentives, or *refuse* to grant a license, so that the investment is deterred by the litigation threat. Alternatively, the strategic patenting concern may induce a bandwagon of socially wasteful patent accumulation. That is, firms rush to the patent office to acquire patents, but the overall investment performance along the equilibrium path is the same as when there is no patent at all.

Section 5 identifies an harmful effect of defensive patenting on innovation incentives. When the truce equilibrium's deterrence power is available to her potential licensees or imitators, an inventor loses the option to employ the patent system as the compensation channel for her R&D efforts or technology disclosure. Through a simple example, we show that increasing patent protection could induce a potential licensee to patent defensively, and so an inventor would substitute from patent to trade secrecy for her valuable invention. When trade secrecy provides little licensing opportunity, say, due to Arrow problem, technology flow is hampered in a "strong" patent regime. This example illustrates that a "pro-patent" reform, as in the Unites States in the 1980s, may be detrimental to the very purpose of the patent system.

To conclude the chapter, section 6 provides some policy implications of our results and discusses future research. Appendix A collects proofs.

☐ **Institutional background:** Both technology and legal factors are crucial to the defensive patenting strategy. On the technological side, a "complex technology" field breeds this strategy, where a firm's survival hinges on the access to others' technologies. In the semiconductor and software industry, for instance, it is a typical case that multiple inventions are integrated to fabricate a product, and one technology, say, a manufacturing process, is covered by a multitude of patents in the hands of different owners. These fields also pose intrinsic difficulties for courts to determine the validity and actual boundary of a patent, and so nobody can be sure whether they will infringe on others' patent rights.

On the legal side, since 1980s the U. S. patent system has been strengthened in several ways: the number of patentable subjects has been expanded, the court has more frequently validated disputed patents, and the power of patent-holders has increased through injunction grants. Another trend worth noting is that, as some authors claim, the U.S. Patent and Trademark Office (USPTO) has been issuing low quality patents over the past decade.[2] Combining these policy shifts with technology features, what we have is, in the words of Shapiro (2001), a "patent thicket": firms can get patents more easily, but also more likely infringe on others' patent rights. Several solutions based on technology sharing have been suggested to curb this problem;[3] meanwhile, firms continue patent accumulation for licensing as well as defensive purposes.

☐ **Related literature:** Among the patent litigation literature, our construction of strategic enforcement between two patent-holders differentiates this paper from most previous works. In Meurer (1989), Crampes and Langinier (2002), Choi (2003??), patents are enforced against non-patent-holding technology users. In contrast, our firms have the dual roles of patent-holders and technology users, and the lawsuit is filed by one

[2]See Jaffe and Lerner (2004) for a general discussion. Concerning the patent quality, 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 is 95%, compared to 68% and 65% for the European and Japanese patent offices, respectively. Possible reasons are: the explosion of patent applications; the emergence of applications in new fields where PTO hasn't acquired proper capacity, e.g. technology expertise and searching database; the resource constraints and the perverse incentives facing the USPTO; the high turn-over among the examiners; and the inadequate incentive schemes imposed on examiners. See Merges (1999) .

[3]Two typical collective IPRs arrangements are patent pools and cross-licenses. See Shapiro (2001).

against the other.[4] This feature can also be found in Bessen (2003), Ménière and Parlane (2004). Especially in the second paper, the authors also obtain a negative effect of patent protection on investment incentives. But the two studies are conducted in a rather different economic environment than ours. First, due to costless litigation, enforcement always follows patenting in their models. By contrast, we bring back enforcement costs and find a "truce equilibrium," which, as we shall see, is the driving force of our results. Second, both papers consider cases where monopoly profit is greater than the aggregate duopoly profit, and so, with one-sided infringement, the infringer is forced to exit the market. We consider the opposite case: the infringing firm secures a license and stays in the market. Nevertheless, we will show that, with some qualifications, our insights extend to the alternative environment.

Several empirical findings have inspired this paper. Concerning the patent litigation, Lanjouw and Schankerman (2003) finds that an infringement suit is less likely to be filed based on a patent held by a larger firm.[5] Although the critical difference in our model, i.e. an offensive *vs.* a defensive patent, is absent in their empirical analysis, one could reasonably argue that this finding is consistent with our prediction: the defensive patenting strategy works better against a larger firm with a bigger hold-up stake; the truce equilibrium is more likely to be played, and so less suits are filed involving these firms. Somaya (2003) explicitly considers countersuits and finds an interesting stylized fact: in most cases, when a suit is countered by a countersuit, the two are disposed of within a day of each other.[6] Without any legal or administrative factor underlying these two legally separated proceedings, it suggests a strong strategic concern for countersuits.

Concerning patenting and investment, Hall and Ziedonis (2001) shows that the recent surge of patenting propensities in the semiconductor industry is driven by large-scale manufacturers' aggressive patent accumulations. Since manufacturing firms' large investments in production facilities make them vulnerable to the litigation threat, they have legitimate concerns to amass patent portfolios in order to shield from this risk or avoid huge balance payments in cross-licenses.

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[4] Hence in our model it doesn't matter whether a patent is invalidated or no infringement is found. Choi (2003??) allows only the invalidation, although the two outcomes have different effects in his model. That is, when a patent is invalidated, the technology is free to all users. But for heterogeneous products, a ruling of no infringement may apply only to a subset of users.

[5] Their data cover U.S. patent litigations in all technological fields during 1978–1999.

[6] The data cover patent suits in the computer and research medicine industries filed in the U.S. federal district courts between 1983 and 1993.

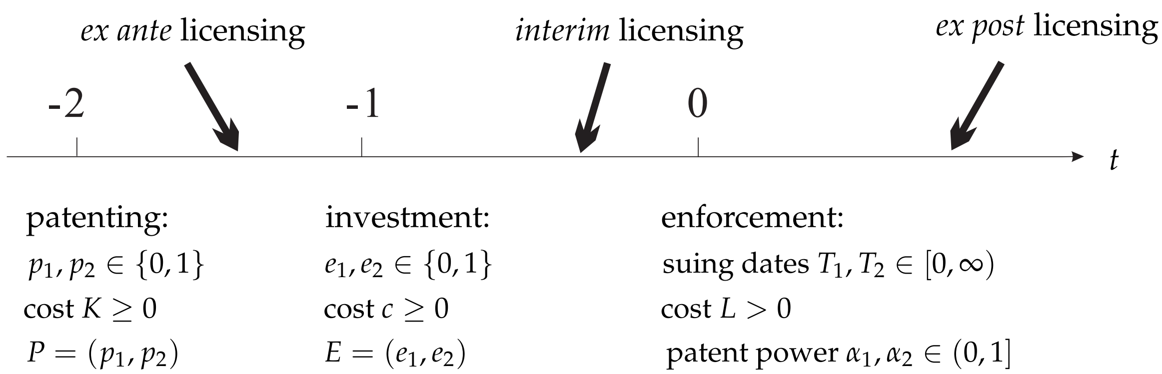

Figure 1: Timing

Finally, our results also shed some light on the debate about the impact of U.S. patent reforms. It has been seen as a paradox that 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 may actually have reduced the incentive power of the system.

2 Model

We adopt a two-player, three-stage framework, with key elements summarized in Figure 1. Assume that two firms, F_1 and F_2, each holds a basic technology, A_1 and A_2, eligible for patent protection. The two firms are symmetric except in section 5. A basic technology brings positive revenue, and the revenue is higher if further investment is made. For example, A_i may represent new functionalities and F_i can design new products that fit better with these functionalities; or A_i is an improved manufacturing process, and F_i can build new factories or equipments using the new process. 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, the only uncertainty is the enforcement outcome, and only pure strategies are considered.

At each of the patenting and investment stages, firms simultaneously make a binary choice. Let p_i and $e_i \in \{0, 1\}$ 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 stage, on the other hand, exhibits a continuous time structure from time 0 to infinity.

We say that the industry is characterized by high patent intensity if $P = (1,1)$, low patent intensity if $P = (1,0)$ or $(0,1)$, and no patent if $P = (0,0)$. By the same token, the industry exhibits high investment profile if $E = (1,1)$, low investment profile if $E = (1,0)$ or $(0,1)$, and no investment if $E = (0,0)$.

□ **Market:** Beginning at time 0, a stream of revenue accrues to firms according to the industrial-wide investment profile. To make things simple, suppose that once the investment has been made (with cost c), its operation can be "switched on" or "switched off" at no additional costs or depreciation, and, at any point in time, instantaneous revenues depend only on the investment that is in operation (switched on) at that moment.

Assume the market is stationary. Slightly abusing the notation, we also use E to denote the industry's investment use.[7] Given $E = (e_1, e_2)$, let $\hat{v}_{e_1e_2}$ be the instantaneous value accruing to F_1, and $\hat{V}_{e_1e_2}$ the joint value. By symmetry, F_2 gets $\hat{v}_{e_2e_1}$ and $\hat{V}_{e_1e_2} = \hat{v}_{e_1e_2} + \hat{v}_{e_2e_1}$. Assume common interest rate $r > 0$. Denote the discounted present value of the 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 $i, \in \{1,2\}, i \neq j$. Throughout the chapter, we assume that a firm's investment exerts a negative externality on the other, but *ex post* efficiency requires the full employment of established investment, as summarized below.

Assumption 1. For any $e \in \{0,1\}$, $v_{1e} \geq v_{0e} \geq 0$,$v_{e0} \geq v_{e1} \geq 0$, and $V_{11} \geq V_{10} = V_{01} \geq V_{00}$.

□ **Technology flow:** In section 3 and 4 we assume no technology transfer between the two firms. For example, A_1 and A_2 may serve as different routes to similar functionalities, and each F_i needs only A_i to get to the market efficiently. However, this doesn't exempt F_i from infringement risk. A firm may be prohibited from using inhouse technology for reasons raised in section 1: the boundary of patent claims is hard to predict due to complicated technological issues,[8] and, contrary to trade secrecy, the independent invention defense is not available in patent infringement cases.

[7]For the example of new product introduction, the product can be put on the shelf (investment "switched on") or withdrawn from the market ("switched off") at zero cost. A firm's revenue depends only on the products on the market at that time, denoted as E.

[8]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).

Both assumptions of no technology transfer and symmetric firms are relaxed in section 5. There, in addition to A_1, firm F_1 holds another invention B, which is valuable to F_2. Assume that trade secrecy provides perfect protection, but forecloses any licensing opportunity; in contrast, patent protection is imperfect but enables licensing and technology flow. We are concerned with F_1's decision to protect the valuable technology B as a patent or trade secret.

□ **Patent enforcement:** Consider patent litigation with following properties.

- A patent never expires. If F_i gets a patent on A_i, it can file at most one suit against F_j, $i, j = 1, 2$, $i \neq j$. But F_j can be found liable for infringement only if it has invested at $t = -1$ and put its investment in use.
- When both firms can sue each other, i.e. when $P = E = (1, 1)$, the enforcement stage is partitioned into periods of equal length. At most one suit can be filed per period.
- An infringement suit costs both parties $L > 0$. The patentee F_i prevails with probability $\alpha_i \in (0, 1], i \in \{1, 2\}$. Different suits are tried independently. The probability α_i is referred to as "patent strength" or "patent power." Symmetry, $\alpha = \alpha_1 = \alpha_2$, again, is assumed in sections 3 and 4.
- The court grants a permanent injunctive relief to the infringed party as the remedy, and so a prevailing patent-holder can shutdown the infringing firm's operation associated with the investment made at time -1. This serves as the threat point in the post-infringement bargaining.[9]

With these specifications, a patent-holder F_i's enforcement policy reduces to the suing date $T_i \in [0, \infty)$, with $T_1 \neq T_2$.

More precisely, to enforce its patent right, the plaintiff, say F_1, sends a cease-and-desist letter to the defendant F_2 at date T_1. Upon receiving the letter, the latter decides whether to stop using its investment. If F_2 stops, no litigation will ensue; and if F_2 doesn't "retreat," the legal process begins and both parties incur costs L. The court makes the infringement decision according to the probability α_1. If there is infringement, the two bargain for a license. For simplicity, assume the whole process takes place instantaneously at the enforcement date T_1.

[9]We exclude monetary damages for past infringements. Our purpose is to construct a game structure in which a defensive patent deters litigation (Proposition 1). See footnote 16 for an alternative structure.

☐ **Licensing:** Due to the injunction remedy and, more generally, the litigation risk, firms may want to bargain for a license, or a cross-license in the case of mutual-blocking. We rule out downstream collusion through licensing.[10] Given E at a point in time, e.g. $E = (0, 1)$, the instantaneous revenues $\hat{v}_{01}$ and $\hat{V}_{01}$ are assumed to be path independent, i.e. not affected by the history leading to this profile.[11] Referring to Figure 1, bargaining may occur at different stages of the game: *ex ante* licensing takes place before investment decisions are made, but after the patenting stage; *interim* licensing takes place after firms have chosen whether to invest, but before the enforcement stage;[12] and an *ex post* license is negotiated only after the court declares that the patent is infringed. We adopt the Nash bargaining solution with equal bargaining power. To make things interesting, assume investment decisions are not contractible at an *ex ante* bargaining stage. A license merely exempts the licensee from future litigation. Most of the analysis is conducted with *ex post* licensing; the other two options are discussed in section 4.4.

Example 1. (Multi-product competition) F_1 and F_2 each has 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 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. With original versions of both goods, each firm charges a price v. In the previous notation, $v_{00} = v$.

Suppose with cost c each party can make an improvement, which can be consumed with firm's own original version and has an additional value Δv for home market consumers, and $\gamma \Delta v$ for consumers in the other segment, $\gamma \in [0, 1]$. The improvement is 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 on 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

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

[11]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 on a license; or only F_2 has invested, is sued and declared to infringe, but has secured a license.

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

new functionality at a price zero in the adjacent market, while the old version in that market charges only $v - \gamma\Delta v$. The investment revenues are: $v_{11} = v + (1-\gamma)\Delta v$, $v_{10} = v + \Delta v$, and $v_{01} = v - \gamma\Delta v$. Summing up, $V_{11} - V_{10} = (1-\gamma)\Delta v$. $\|$

3 Enforcement and the Truce Equilibrium

This section analyzes the enforcement stage. Assume that there is no prior agreement which waives patent-holders' rights to sue. We derive payoffs of the game according to how many suits can be filed.

☐ **Patents are irrelevant:** When $p_1 e_2 = p_2 e_1 = 0$, no one can file a suit; the game ends after the investment stage. Given investments, F_i's payoff is $\pi_i = v_{e_i e_j} - ce_i$, where $i, j = 1, 2, j \neq i$.

☐ **One effective patent:** 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 $p_1 = e_2 = 1$, $p_2 e_1 = 0$, and F_1 files a suit at time T_1. Before that date, the revenue streams accruing to F_1 and F_2 are $\hat{v}_{e_1 1}$ and $\hat{v}_{1 e_1}$, respectively. At date T_1, each party incurs legal fee L. With probability $1-\alpha$, the court finds no infringement and so no bargaining takes place, revenue streams remain the same. With probability α, the court finds that F_2 infringes on F_1's patent. The following lemma describes the post-infringement outcome.

Lemma 1. *When F_2 infringes at time T_1 and there is no countersuing threat, F_2 secures a license from F_1 with a payment fe^{-rT_1} (in present value), where $f = \frac{1}{2}(v_{10} - v_{01})$. The licensing fee is independent of F_1's own investment e_1.*

By this lemma, F_1's expected litigation gain is $\alpha f e^{-rT_1}$.[13] We impose the following assumption:

Assumption 2. (i) $\alpha f \geq L$; (ii)[14] $\forall e \in \{0, 1\}, v_{0e} \leq v_{1e} - (\alpha f + L)$.

[13] The fact that f is independent of e_1 is a special case due to our two-point investment assumption. In general, the licensing fee should reflect the term $(v_{e_2 e_1} - v_{0 e_1}) + (v_{e_1 0} - v_{e_1 e_2})$; see the proof of LEMMA 1. The first part represents the gain to F_2 if it is allowed to use e_2, and the second part reflects the negative impact this investment exerts on F_1. Both could be affected by e_1.

[14] I am grateful to Richard Schmidtke for this assumption.

From this assumption, the two parties undergo the complete legal process after F_1 sends the cease-and-desist letter. The first part guarantees that F_1 will credibly sue; and from the second part, F_2 won't retreat when facing the litigation threat. Note that without Assumption 2(i), patents become irrelevant in our model; and in section 4.3 we will discuss the consequence of Assumption 2(ii) failing. This assumption also guarantees that F_1 optimally files a suit at $T_1 = 0$. The expected payoffs are $v_{e_1 1} + (\alpha f - L)$ for F_1 and $v_{1 e_1} - (\alpha f + L)$ for F_2.

□ **A potential litigation war:** When $P = E = (1,1)$, the firms can sue each other. Suppose F_1 (F_2) files a suit at T_1 (T_2, respectively). As stated in section 2, we partition the enforcement stage into periods of equal length $\Delta > 0$, and assume at most one suit at each period. Assume that the two parties alternatively decide whether to sue the other, if they haven't done it yet. This creates a "reaction lag" Δ: if, for example, F_1 brings the first suit against F_2 at T_1, F_2 could countersue at no earlier than $T_1 + \Delta$. We will focus on the limiting case of $\Delta \to 0$.

Fix $\Delta > 0$. Lemma 2 describes the outcome of a litigation war. Without loss of generality, let F_1 be the first mover and file the first suit at T_1 (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 holds. If F_1 sues at T_1, F_2 optimally brings a countersuit at date $T_1 + \Delta$. Expected payoffs are*

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

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

These results are intuitive. After the rival has exercised its patent rights, countersuing reduces to a unilateral attack.[15] Assumption 2(i) guarantees the optimality of doing so with the least delay. For payoffs, due to the threat from F_2's patent, F_1 gets only a "first-mover advantage" $\alpha f(1 - e^{-r\Delta})$ from its earlier enforcement. This advantage vanishes as F_2 can respond almost simultaneously, $\Delta \to 0$. As a consequence, the enforcement subgame admits a truce equilibrium.[16]

[15] 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) makes no agreement on F_2's patent rights.

[16] The same result can be reached with monetary damage reward in an alternative game structure. For example, let the patent term be finite over $[0, T)$, with reaction lag Δ so small 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 in Lemma 1.

Theorem 1. *(Litigation deterrence and the truce equilibrium) At the enforcement stage following $P = E = (1, 1)$,*

- *a war equilibrium always exists, where both firms initiate the infringement attack at their earliest possible dates; and*
- *if Δ is small enough, there is another subgame perfect equilibrium, the truce equilibrium, where there is no litigation on the equilibrium path.*

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

When firms are willing to sue, they can always do so unilaterally. This generates the war equilibrium. But both may suffer from this unilateral enforcement. In that case, a peaceful life is in their joint interests and can be maintained by both firms adopting the "tit-for-tat" strategy: "I won't sue you if you haven't sued me till now; but whenever you sue me, I'll bring a countersuit as early as possible."

Remark 1. Although not unique, we will let the truce equilibrium prevail whenever it exists. Two reasons justify this selection. First, the truce equilibrium Pareto dominates the war equilibrium, $\pi^t > \pi^w$. Both firms are willing to coordinate on the truce equilibrium. Second, the war equilibrium can be eliminated by introducing some small and reasonable perturbation into the game. If there is small probability that the other firm will not sue first, then not suing becomes a strictly dominant strategy for Δ small enough (see Appendix B). ‖

Remark 2. The symmetry assumption should not be crucial here. The same argument goes through as long as no parties get a positive return in expectation from a litigation war. In section 5, we apply the truce equilibrium to a case with asymmetric firms. ‖

We conclude this section with a simple corollary.

Corollary 1. *When the truce equilibrium prevails, we may observe non-monotonic relationships*

- *between the number of suits and the number of patents: there is no litigation in an industry with either no patent ($P = (0, 0)$) or high patent intensity ($P = (1, 1)$), and one infringement suit when only one firm holds a patent and the other has made investments; and*
- *between investment and patent litigation: in an industry with high patent intensity, there is litigation only with low investment profiles, $E = (1, 0)/(0, 1)$.*

4 Hold-up and Strategic Patenting

Let us now move back to the investment and patenting stages. In this section, we are interested in the impact of defensive patenting on the patenting game and the equilibrium investment performance. The main discussion proceeds with *ex post* licensing. *Interim* and *ex ante* licensing are analyzed in section 4.4. Section 4.3 discusses some robustness issues.

4.1 Investment

We use firms' investment criteria to examine patents' two-fold effects on the level and strategic property of investment.

□ **Investment criteria:** Consider the possible outcomes of the patenting stage.

⋄ No patents: $P = (0,0)$, F_i invests if $c \leq c_e^* \equiv v_{1e} - v_{0e}$, where $e \in \{0,1\}, i = 1,2$. Investments are strategic complements (hereafter SC) if $c_0^* < c_1^*$, i.e. one firm's investment increases the other's incentive to invest; and strategic substitutes (hereafter SS) if $c_0^* > c_1^*$.

⋄ Low patent intensity: under, e.g. $P = (1,0)$, the patent-holder F_1's investment cost cutoffs remain at $c_{e_2}^*$, since it faces no infringement threat.[17] The non-patentee F_2 has lower investment incentives since a suit follows its investment. Given e_1, F_2 invests if $c \leq \underline{c}_{e_1} \equiv c_{e_1}^* - (\alpha f + L) < c_{e_1}^*$. The strategic property of investment is unaffected, though. $\underline{c}_1$ is greater (smaller) than $\underline{c}_0$ if c_1^* is greater (smaller, respectively) than c_0^*.[18]

⋄ High patent intensity $P = (1,1)$: when the other firm doesn't invest, one's own patent becomes useless and hold-up concerns persist. The investment criterion is $\underline{c}_0$. When the other invests, although the truce equilibrium secures a firm its full investment return, investment incentives are still lower than under no patent, due to the benefit $\alpha f - L$ from acting as a pure licensor. The investment criterion is $\hat{c} \equiv c_1^* - (\alpha f - L)$. From Assumption 2 , $\underline{c}_1 < \hat{c} \leq c_1^*$. A firm may find it more profitable not to invest, but instead take the "lean and hungry look" strategy and grab the other's investment return through a patent attack. In other words, a firm may prefer

[17] An implicit assumption is that the value of investment is not affected by whether there is patent dispute or not.

[18] Again, this hinges on the binary investment assumption. See footnote 13.

to be a "patent troll," i.e. a patent-holding entity engages in no production activities but aggressively enforces the IPRs in order to collect licensing payments.

In this case, the strategic property of investment may exhibit a one-way change. Since $\hat{c} - \underline{c}_0 = c_1^* - c_0^* + 2L$, SC ensues as long as $c_0^* < c_1^* + 2L$. Indeed, with L so large that $c_1^* < c_0^* < c_1^* + 2L$, investment decisions are SS when $P \neq (1,1)$ but SC when $P = (1,1)$. Although the rival's investment reduces the intrinsic value of one's own investment ($v_{11} - v_{01} < v_{10} - v_{00}$), it also eliminates the threat of patent attack. This boosts investment incentives by the amount $\alpha f + L$, and outweighs the gains of the "lean and hungry look" strategy $\alpha f - L$. The litigation-induced increment of investment incentives, $2L$, more than compensates the negative externality and transforms investments into SC at $P = (1,1)$.

Proposition 1. *When patents are introduced,*

- *investment incentives decrease because of the hold-up threat ($\underline{c}_e < c_e^*$), and the appropriation of the other firm's investment return ($\hat{c} \leq c_1^*$); and*
- *investment decisions may be transformed from SS into SC, but not the other way around. There are cases where $c_0^* > c_1^*$ and $\hat{c} > \underline{c}_0$, but exist no cases where $c_1^* > c_0^*$ and $\hat{c} < \underline{c}_0$.*

Remark 3. All three thresholds $\underline{c}_0$, $\underline{c}_1$, and $\hat{c}$ are non-negative due to Assumption 2(ii) and the costlessly "switch off" assumption.[19] When a firm decides whether to switch off its investment and retreat from a potential litigation, it is as if the investment were costless. The no retreat condition implies that firms invest in the absence of investment cost: $\underline{c}_e \geq 0$. ‖

The following corollary performs comparative statics with respect to the institutional parameters α and L.

Corollary 2. *Concerning investment incentives, (i) $\underline{c}_e$ are decreasing both in α and L; and (ii) $\hat{c}$ is decreasing in α but increasing in L.*

For (i), more powerful patents (α higher) or more expensive law suits (L larger) exacerbate the hold-up problem. For (ii), the attractiveness of a "lean and hungry look" strategy depends on the expected return from offensive enforcement. A higher α increases this return; but a higher L reduces the return and dissuades a firm from adopting this strategy, and so boosts investment incentives.

[19] c_0^* and $c_1^* \geq 0$ by Assumption 1.

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

Table 1: Investment profile E for intermediate c

□ **Investment outcome:** To derive the prevailing investment profile for each P, let's ignore the uninteresting case of no investment because c is too large ($c > \max\{c_0^*, c_1^*\}$). When $c \leq \min\{\underline{c}_0, \underline{c}_1\}$, patents don't impede investment; $E = (1,1)$ is the unique outcome. 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, but we consider only the scenario specified in Table 1.[20] It applies as long as $\underline{c}_1 < c \leq \min\{\hat{c}, c_0^*\}$, whether $c_0^* \gtrless c_1^*$.[21] In that case, both firms invest when no patent, $P = (0,0)$. If only one firm has patented, $P = (1,0)$ or $(0,1)$, the hold-up concern deters the non-patentee's investment. However, defensive patenting fully solves the hold-up threat, and there are no strong incentives to play "lean and hungry look." $E = (1,1)$ is restored at $P = (1,1)$.[22] The selection of high investment profile at high patent intensity could be justified by firms' desire to safeguard investments and so pursue defensive patenting to preserve their freedom of operation (see the introduction). There is no patent troll in the industry, and so a high investment level results from the deterrence of potential patent disputes.[23]

Example 2. (Multiple-product competition, continued). When $P \neq (1,1)$, investment decisions are strategically neutral. $c_e^* = \Delta v \equiv c^*$ and $\underline{c}_e = \Delta v - (\alpha f + L) \equiv \underline{c}$, with $e \in$

[20] The complete characterization is provided in Appendix C. Note that even when $c < \hat{c}$ at $P = (1,1)$, there may be multiple equilibria in investment. In particular, when $\underline{c}_0 < c < \hat{c}$, both $E = (1,1)$ and $(0,0)$ could be equilibrium outcomes (e.g. case 3 in the appendix). Given our interests in firms with strong investment propensities, we select $E = (1,1)$ in all these cases.

[21] 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 cases if $c \in (\underline{c}_1, \hat{c}]$. In the latter case, we select $E = (1,1)$ at $P = (1,1)$; see footnote 20.

[22] An interesting case omitted here is the impact of the defensive party's underinvestment on the offensive party's investment incentives. The latter's enforcement may backfire when $c_0^* < c_1^*$. For example, consider case 6 in Appendix C, and select the high investment profile at $P = (0,0)$ and $(1,1)$. At $P = (1,0)$, the defensive firm F_2 doesn't invest; and this in turn decreases F_1's return on investment to the point that no one invests, $E = (0,0)$. When the investment decision is interpreted as the decision to commercialize the basic technology, this captures the situation where no one enters into the commercialization stage and the technologies are put idle when only one firm patents.

[23] In empirical studies, e.g. Hall and Ziedonis (2001), patent numbers are usually treated as the dependent variable and investment as the explanatory variable. This implies a timing different from ours. Nevertheless, these two variables exhibit a positive and significant statistical relationship.

$\{0,1\}$ and $f = \frac{(1+\gamma)\Delta v}{2}$. When $P = (1,1)$, they become SC, for $\hat{c} = \Delta v - (\alpha f - L) > \underline{c}$. Firms always invest if $c \leq \underline{c}$. Table 1 applies for $c \in (\underline{c}, \hat{c}]$. ||

4.2 Patenting

We now characterize the equilibrium of the whole game with respect to the endogenized strategic relationship of patenting decisions. Again, $c > \max\{c_0^*, c_1^*\}$ is the uninteresting case where no firms apply for patents because no one invests.

□ **Strategic property of patents:** Corresponding to different ranges of investment costs, we can figure out two benefits of holding a defensive patent. Ignore the patenting cost K for a moment. By symmetry, we write down only F_1's payoffs.

Staunching: When an offensive patent extracts licensing payment, this outlay, together with the legal expense, can be avoided by holding a defensive patent. This applies when investments are not impeded by patents, $c \leq \min\{\underline{c}_0, \underline{c}_1\}$. See Table 2 for payoffs. In this scenario, different P's at most involve a zero-sum transfer between firms, plus legal expenses. So long as $L > 0$, the non-patenting party loses more than what the patent-holder gains, $\alpha f + L > \alpha f - L$. Put differently, the patent has a greater defensive value $\alpha f + L$ than the offensive value $\alpha f - L$. Patents are SC.

$p_1 \backslash p_2$	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

Proposition 2. *(Staunching) Assume costless patenting. In an industry where high investment profile is not impeded by patents, if the truce equilibrium prevails, then patenting decisions are SC.*

In this case, the value of a patent is increasing in the infringement probability α. On the other hand, a higher litigation cost L increases the defensive value, but decreases the offensive value of a patent.

Emboldening: When the rival's offensive patent is powerful enough, no firm dares invest without the aid of a defensive patent. Consider $\min\{\underline{c}_0, \underline{c}_1\} < c \leq \max\{c_0^*, c_1^*\}$

and assume that investment outcomes are as described in Table 1, with payoffs in Table 3. Note that no litigation takes place along the equilibrium path.

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

Table 3: Payoffs for intermediate c

In contrast with the previous scenario, here, firms' patenting decisions are driven by investment concerns. An offensive patent has the strategic value of deterring the other's investment, with a benefit $v_{10} - v_{11} \geq 0$; and a defensive patent safeguards firms' own investment return $v_{11} - v_{01} - c$. Comparing the two, patents are *SC* if $v_{11} - v_{01} - c > v_{10} - v_{11}$, or if $V_{11} - c > V_{10}$. The strategic property of patents is determined by whether a low ($E = (1,0)/(0,1)$) or high ($E = (1,1)$) investment profile gives rise to a greater *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 *SC* (equivalently, a sufficient condition of *SS* if this condition fails) 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 hold if patents are more powerful (α higher) or if litigations are more expensive (L higher).

Proposition 3. *(Emboldening) Assume costless patenting. Consider an industry where high investment profile is maintained under either no patent or high patent intensity, and low patent intensity causes low investment profile. In this case, higher α and L make patents more likely to be SC. To determine the strategic property of patenting decisions, there is*

- *a necessary and sufficient condition: patents are SC (SS) if and only if $V_{11} - c$ is greater (smaller, respectively) than V_{10};*
- *a sufficient condition of SS: if condition (3) fails, patents are SS.*

Remark 4. For *emboldening*, when is the condition $V_{11} - c > V_{10}$ more likely to hold? 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 3. (Multi-product competition, continued). Suppose $c \in (\underline{c}, \hat{c}]$ so that Table 3 applies. From $V_{11} - V_{10} = (1-\gamma)\Delta v > \underline{c}$, condition (3) is satisfied. Also, $\hat{c} \gtreqless (1-\gamma)\Delta v$. Both SS and SC are possible. Patents are SC if $c < (1-\gamma)\Delta v$: when the substitutability between the two new versions is small, and so the competition is not severe (γ small); or when there is great technology improvement (Δv large). ||

Remark 5. In a more general setting, e.g. with a continuous investment choice, the two benefits of a defensive patent, *staunching* and *emboldening*, may co-exist. Our insights would carry over to the mixed case: a higher enforcement cost or a greater joint profit from larger investments move patents toward SC. ||

☐ **Equilibrium:** Let us incorporate the patenting cost K and consider its relationship with the equilibrium investment outcome.

Corollary 3. *In equilibrium, when patents are SC,*[24] *the high investment profile is the unique investment outcome. The industry exhibits high patent intensity for low K, and no patent for high K.*

When patents are SS, this gives rise to different E's, yielding a non-monotonic relationship of investment with K. The equilibrium $E = (1,1)$ for either low K and high patent intensity, or high K and no patent in the industry in equilibrium. But when K is in an intermediate range, so that low patent intensity prevails in equilibrium, then only the patent-holder invests.

Merges (1997) has depicted the patenting situation in the software industry as a prisoners' dilemma game: it is a dominant strategy for each firm to pursue patents, despite their joint interests in not doing so. Our model shows this is the case when patents are SC and the patenting cost K is low. With SC and K in the intermediate range, patenting becomes a coordination game: no one has a dominant strategy, multiple equilibria exist, and they can be Pareto ranked. In this case, $P = (0,0)$ and $(1,1)$ have the same subgame perfect equilibrium in the remaining of the game. But the equilibrium $P = (1,1)$ is Pareto dominated by $P = (0,0)$ due to the expenditure in accumulating patents K. When high patent intensity prevails, firms jump on the bandwagon to engage in socially wasteful patent collection.

In the case of SS, things are rather different. The investment profile is sensitive to the patenting equilibrium, and joint profit maximization may require that one firm

[24] This could happen for both staunching and emboldening; SS happens only for the emboldening scenario.

refrains from investing. To see this, note that when $K < v_{11} - v_{01} - c$, the equilibrium joint profit is $V_{11} - 2c - 2K$ since both firms patent and invest. If the patenting cost raises 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 $K' - 2K < V_{10} + c - V_{11}$, the industry-wide profit increases, albeit a higher patenting cost $K' > K$.

Remark 6. Without specifying consumer demand, we cannot provide a thorough welfare analysis. Nevertheless, a rather bold claim from Corollary 3 is that: the patent system would not be in the optimal state if it endows patents with the property of SC. 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 as when there are no patents. ||

4.3 Remarks

Remark 7. (War equilibrium) None of our results survive if the war equilibrium is selected in the subgame following $P = E = (1, 1)$. To see this, note that when the war equilibrium prevails, investment incentives remain low even when both hold a patent. The cost cutoff for F_i at $P = (1, 1)$ and $e_j = 1$ is $\underline{c}_1 < \hat{c}$, the same as when F_i has no patent. And the strategic property of investments is not affected by patents.

At the patenting stage, patents become strategically neutral when $c \leq \min\{\underline{c}_0, \underline{c}_1\}$, and Table 1 is not feasible as equilibrium outcomes when $\min\{\underline{c}_0, \underline{c}_1\} < c \leq \max\{c_0^*, c_1^*\}$. For the former case, the *staunching* effect disappears: each firm spends $2L$ in a litigation war, and by symmetry there is no licensing transfer in expectation. For the latter, the *emboldening* scenario doesn't take place since, for example, if F_2 doesn't invest at $P = (1, 0)$ due to F_1's patent threat, getting one patent and then engage in a litigation war doesn't help either. ||

Remark 8. (Alternative market conditions) Let's relax two assumptions for robustness check. First, suppose that the condition $V_{11} \geq V_{10} \geq V_{00}$ fails. For example, when the two firms compete in a single product market, and e_i is F_i's entry decision, in general we would expect monopoly profit to be higher than joint duopoly profit. Previous studies by Bessen (2003), Ménière and Parlane (2004) are conducted in this case. It would be interesting to see whether our results survive this modification.

With some qualifications, our insights carry over to the alternative environment. 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 SC more likely; and since joint profits are always higher when only one firm invests (enters), patents are more likely to be SS. In particular, when Table 1 applies, SS is guaranteed. In this sense, the single-product assumption is more restrictive (for a thorough discussion, see Appendix D.

Second, suppose Assumption 2(ii) doesn't hold. Let $v_{01} > v_{11} - (\alpha f + L)$ and $c \leq c_0^*$. Then at $P = (1, 0)$ the non-patenting firm will retreat when facing a litigation threat, and so will not invest in the first place. This is true even for c close to zero. A potential patent dispute alone deters investment. Table 3 describes the payoffs, and Proposition 3 and Corollary 3 apply directly. ||

4.4 Alternative Licensing Opportunities

We consider alternative licensing opportunities here. The *interim* licensing (licensing after investments are made but before litigation phase) illustrates the role of the enforcement cost in our model; and for *ex ante* licensing (licensing before the investment but after the patenting stage), we show that firms can exploit this opportunity to coordinate investment decisions. In this sense, patents together with *ex ante* licensing facilitate upstream collusion.

□ **Interim licensing:** In general, it is cheaper to resolve legal disputes out of court. We first consider the extreme case of costless *interim* bargaining.

At the enforcement subgame, when there is litigation, for example, when $e_2 = 1$ and only F_1 holds a patent, at the *interim* bargaining the joint profit at threat point is $V_{e_1 1} - 2L$, and the cooperative joint profit is $V_{e_1 1}$. The bargaining surplus is the litigation expense $2L$. With equal bargaining power, each firm saves its litigation cost by participating in *interim* licensing. Payoffs are the same as putting $L = 0$ in the previous discussion. On the other hand, if no litigation would ever occur, firms wouldn't bother bargaining. The truce equilibrium is robust to *interim* licensing.

For investment thresholds, $\{c_e^*\}_{e=0,1}$ are unaffected by *interim* licensing; while $\{\underline{c}_e\}_{e=0,1}$ increase to $\underline{c}_e^{in.} \equiv c_e^* - \alpha f$. The saving of L decreases the defensive party's loss from a patent attack and boosts incentives. But now the cutoff $\hat{c}$ *decreases* to $c_1^* - \alpha f = \underline{c}_1^{in.}$. Since there is no need to actually incur the enforcement expense, the "lean and hungry look" strategy becomes more attractive. This adjustment makes Table 1, and therefore the *emboldening* scenario almost impossible to attain. To see this, suppose E depends on P.[25] To have $E = (1,0)$ at $P = (1,0)$, the non-patenting player F_2 doesn't invest when $c > \underline{c}_1^{in.}$. But to have $E = (1,1)$ at $P = (1,1)$, to induce, say, $e_1 = 1$, we need $c \leq \underline{c}_1^{in.}$. Table 1 applies only when $c = \underline{c}_1^{in.}$ and firms decide whether to invest "correctly." For Proposition 2,[26] on the other hand, it is clear that under *interim* licensing, $L = 0$ and so patents become strategically neutral.

Proposition 4. *Suppose interim licensing is available at no cost. In the staunching scenario, patenting are strategically neutral. The emboldening scenario is feasible only when* $c = \underline{c}_1^{in.}$ *and firms invest if and only if they hold a patent.*

Nevertheless, all this holds true only for costless *interim* licensing. Previous results are re-gained for any strictly positive bargaining cost, since it could simply be interpreted as L. This confirms that our results are driven by the enforcement cost.

Interim bargaining costs may come from contracting costs, including the management time and efforts spent in negotiating and crafting out appropriate licensing terms, or lawyer fees up to the pre-trial settlement. Or, it may be due to some informational asymmetry at the *interim* bargaining stage, as Bebchuk (1984) (see Appendix E).

□ **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* licensing, the *ex ante* bargaining can not only resolve future patent disputes in a less expensive way, but also coordinate non-contractible investment decisions.[27] This coordination can be achieved by *not* granting a license, so that a potential infringer refrains from investing. Apparently, this is possible only in the emboldening scenario, where the investment performance depends on the patenting profile; see the following proposition.[28]

Proposition 5. *Suppose ex ante licensing is available at a cost* $l \in [0, L]$, *and* c *is in the intermediate range with payoffs in Table 3,*

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

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

[27] With a different theoretical model, Siebert and von Graevenitz (2005) finds empirical evidence that indeed firms choose different licensing timing in order to affect investment incentives.

[28] In the staunching scenario, since firms make investments whatever the patent profile, the *ex ante* licensing is used only to economize on enforcement costs when $l < L$.

(i) under low patent intensity, an ex ante license is granted only for the case where, at the patenting stage, patents are SC, and $l \leq \frac{1}{2}(V_{11} - c - V_{10})$*;*

(ii) under high patent intensity and $l > 0$*, no cross-license is observed. When patents are SC, no licenses are granted; but when patents are SS, the only possible outcome is a one-way license followed by the low investment profile. This happens when* $l \leq \frac{1}{2}[V_{10} - (V_{11} - c)]$.

5 Patent *versus* Trade Secret

Up to now, we have only considered the "downstream" phase in the R&D cycle. That is, we assume that firms already hold the basic inventions and no technology exchange is needed.[29] Since the patent system is designed to provide incentives at the "upstream" stage, i.e. to encourage innovation and its dissemination, it is desirable to examine the impact of defensive patenting on this ground.

We argue that defensive patenting may be detrimental to the very purposes of the patent system. For, as an incentive scheme, the reward of the patent system is implemented via offensive enforcement, but this is incompatible with the deterrence power of the truce equilibrium, in which no patentees earn any licensing income. To illustrate this point, consider the following scenario.

Suppose, in addition to technology A_1, F_1 owns another technology B that is valuable to F_2. The joint profit is also higher if B is used by F_2, but uncompensated revelation harms F_1. Assume trade secrecy provides perfect protection, but foregoes licensing opportunity. To induce disclosure, the patent system should serve as an effective mechanism for F_1 to share the benefit of technology flow. The incentive power of the patent system is determined by the licensing payment F_1 can extract from F_2.

Assume B is patentable with considerable strength. In the absence of a countersuit, F_1 gets enough licensing payment by patenting and disclosing it. Label the situation as a "weak" patent regime, where defensive patenting is not available to F_2. Now, imagine a policy shift to the "strong" patent regime, where F_2 can build a defensive patent based on A_2. If the truce equilibrium prevails in the strong regime, then F_1 will switch to trade secrecy protection for technology B after a regime shift. The incentive power of the patent system is lower and technology flow hampered in the strong

[29] But note that another interpretation of e_i is the second-stage innovation effort. By this token, previous analysis focuses on the effect of patents on the second-stage innovation, given the first-stage has completed.

patent regime.

The regime shift we have in mind is the U.S. patent reform in 1980s. Section 1 describes how this "pro-patent" reform facilitates the accumulation of a patent portfolio with non-negligible power, and makes it easier to implement the defensive patenting strategy. Through this example, we argue that despite the general agreement that this reform has strengthened the patent system, it may nevertheless have undermined the *incentive power* of the patent system, as a consequence of defensive patenting.

We modify the basic model as follows. For simplicity, we exclude *ex ante* or *interim* licensing, set $K = c = 0$, and assume firms always invest. Suppose that each firm at most files one infringement suit due to, e.g., a large L. This implies that each firm at most applies for one patent. If B is not patented, it is protected as a trade secret, which has no leakage risk, but enables no licensing either, due to, say, the Arrow problem. Since only technology B will be copied without permission, it is reasonable to let the probability to infringe B, α_B, be greater than the probability to infringe technologies A_1 and A_2 (which assumed a common α_A). Let $\alpha = (\alpha_A, \alpha_B)$. Under the "weak" patent regime, $\alpha = (0, \alpha_B)$ and $\alpha_B > 0$. 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 $\alpha' = \alpha + (\Delta\alpha, \Delta\alpha)$, i.e. the regime shift exhibits a uniform increase in infringement probability.

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.[30] Revenues depend on both the investment profile and technologies employed. When B is not available to F_2, nothing changes: F_i get $v_{e_ie_j}$ if $E = (e_i, e_j)$, and suppose Assumption 1 holds. When B is patented, given e_1, (i) if $e_2 = 0$, F_1 still gets v_{e_10} and F_2 gets v_{0e_1}; but (ii) if $e_2 = 1$, the access to technology B increases F_2's as well as the joint profit, while decreases F_1's revenue. Assume that F_1 gets βv_{e_11} and F_2 gets bv_{1e_1}, respectively, with $\beta \leq 1 \leq b$. By $\beta \leq 1$, the technology B is covered as a trade secret if F_1 is not properly compensated for its disclosure. The following assumption guarantees that information disclosure and full investment utilization are in line with joint interests, and no one retreats from a litigation threat.[31]

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

[31] After the modification of payoffs, at different *ex post* bargaining: (i) when F_2 infringes, the joint profit at threat points are 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 (ii) the

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

☐ **Patenting:** We first consider patenting decisions in different regimes. Under a weak regime, $\alpha = (0, \alpha_B)$, no firms patent A_i. The patent protection α_B should be high enough to induce patenting B.

Lemma 3. *Under a weak patent regime, no firm patents A_i. Given F_2 not retreats, F_1 patents B if*

$$\frac{\alpha_B}{2}\left[(b-\beta)v_{11} + (v_{10} - v_{01})\right] - L \geq (1-\beta)v_{11}. \tag{4}$$

The term $\frac{\alpha_\beta}{2}(b-\beta)v_{11}$ in condition (4) reflects the contribution of B to F_2, netting of the negative impact on F_1, and is transferred to F_1 through the licensing payment.

In the strong patent regime, $\alpha' = (\alpha'_A, \alpha'_B) > \alpha$. F_2 decides whether to get a patent; F_1 chooses between two patentable inventions with different exclusive powers.[32] If B is not patented, results at section 4 directly apply, with $e_1 = e_2 = 1$. Payoffs are the same as in Table 2, with $c = 0$ and $\alpha = \alpha'_A$. Since no patenting costs, acquiring a patent weakly dominates having no patent.[33] But if B is patented, when α'_A is high enough so that A_2 endows F_2 a creditable countersuing threat, this threat decreases F_1's enforcement payoff and reduces the incentive to engage in a litigation war. The following lemma gives the condition when there is a litigation war.[34]

Lemma 4. *Suppose B and A_2 are patented. When countersuing threats are credible and no firms retreat from a litigation war, F_1 initiates a litigation war if*

$$\begin{aligned}\frac{1}{2}\Big\{&\alpha'_B[(b-\beta)v_{11} + (v_{10} - v_{01})] - \alpha'_A\big\{\alpha'_B(v_{10} - v_{01}) \\ &+ (1-\alpha'_B)\left[(bv_{10} - \beta v_{01}) - (b-\beta)v_{11}\right]\big\}\Big\} \geq 2L.\end{aligned} \tag{5}$$

cooperation joint profits are $(\beta + b)v_{11}$ if B is patented, and V_{11} if not.

[32]The implicit assumption is that, as a true inventor, F_1 should be abler than F_2 to generate patents. And so when the latter can be granted a less valuable patent (A_2), so can F_1.

[33]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.

[34]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.

☐ **Policy shift and technology flow:** Suppose F_1 patents B under a weak regime, and patenting A_i dominates no patent strategy under a strong regime. After the regime shift, F_1 switches to patent A_1 and technology flow is terminated if: (i) the truce equilibrium prevails and so F_1 is not compensated for disclosing B; or (ii) F_1 still gets positive profit from a litigation war, but the gain is smaller than the loss of technology disclosure $(1-\beta)v_{11}$. The following numerical example covers both cases.

Example 4. Assume a uniform regime shift, $\alpha'_B = \alpha_B + \Delta\alpha$ and $\alpha'_A = \Delta\alpha$. And consider the following set of parameters: $\alpha_B = \frac{1}{3}$, $\beta = .99, b = 1.2, v_{11} = 100, v_{10} = 120, v_{00} = v_{01} = 0$, and $L = 13$. With these values, B is patented at the weak regime and no firm would suspend its investment when facing a litigation war.

Figure 2 summarizes F_1's patenting decision over $\Delta\alpha \in [0, \frac{2}{3}]$.[35] Patenting A_1 secures a payoff 100 for F_1; and the thick line represents its payoff when patenting B. Comparing the two, the optimal decision is non-monotonic in $\Delta\alpha$: F_1 patents B when $\Delta\alpha \in [0, .21)$ or $[.35, \frac{2}{3}]$, but for $\Delta\alpha \in [.21, .35)$, it switches to A_1.

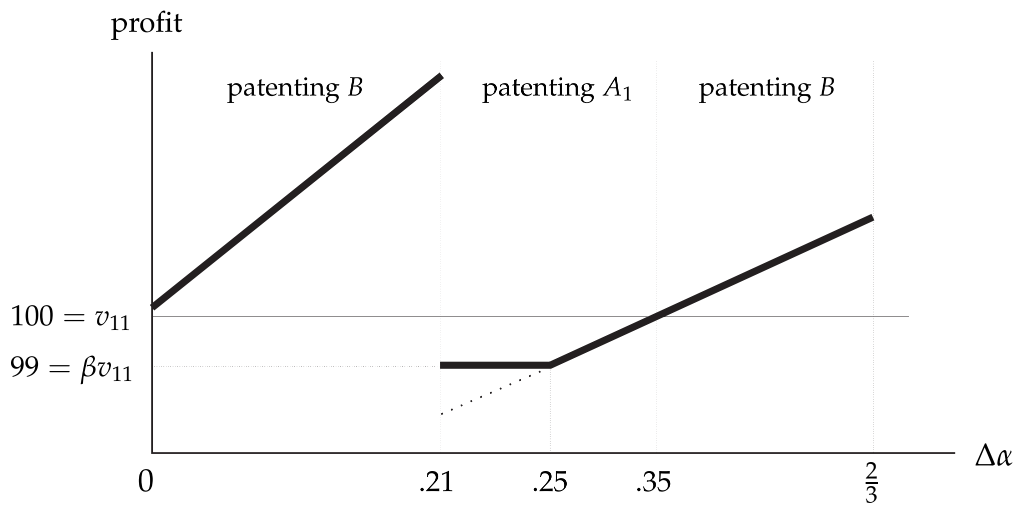

Figure 2: Patent Power and Patenting Decision

In this example, defensive patenting is not available until $\Delta\alpha$ exceeds .21. Before that level, only F_1 benefits from a general strengthening of patent rights and gets more licensing payment from F_2. When $\Delta\alpha \geq .21$, a patent on A_2 is powerful enough and any enforcement leads to a litigation war. For $\Delta\alpha$ not large enough,[36] either the

[35] With these parameter values, F_1 has no incentives to bring two suits, and so won't patent both.

[36] If F_1 still patents B, from the left-hand side of inequality (5), the expected gain from a war (the expected licensing fee) is increasing in $\Delta\alpha$ with chosen values.

truce equilibrium prevails (for $\Delta\alpha \in [.21, .25)$); or the positive gain from a war cannot compensate for the loss of disclosing B (for $\Delta\alpha \in [.25, .35)$). F_1 switches to patent A_1 and protects B as a trade secret. Only when $\Delta\alpha \geq .35$ will F_1 patent B again.[37] ‖

Proposition 6. *When 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 high or low values of $\Delta\alpha$, and are eliminated for intermediate values of $\Delta\alpha$.

6 Concluding Remarks

In a sense, we have revealed the "dark side" of defensive patenting in this paper, in spite of the general appraisal of safeguarding firms' freedom of operation. In particular, we have confirmed the worry that firms jump on the bandwagon to engage in socially wasteful patent accumulation (Corollary 3); and that an increase of patent power may weaken the incentive power of the patent system, as a consequence of defensive patenting (Proposition 6).

Since the premise of defensive patenting is the ability to build a patent portfolio with non-negligible infringement probability, our results support the argument that the "flooding" of a large amount of low-quality yet powerful patents should be partly responsible for, in Jaffe and Lerner's words, a "broken" U.S. patent system. And, two ingredients of the U.S. patent reform play critical roles: the USPTO's issuing more patents with arguably lower quality, and the CAFC's greater willingness to uphold issued patents.

In an influential paper, Lemley (2001) argues that, instead of spending more resources on each application at the patent office, it would be more efficient to let private parties select which patents are worth detailed examination through expensive litigation since, from empirical experience, most granted patents are not economically important for they are never licensed or enforced. And so the author asserts that, despite critiques, the current quality control within USPTO may be optimal.

[37] The threshold .21 is determined by the condition such that F_2 has a credible countersuing threat; .25 by condition (5) binding; and .35 by the profit from a litigation war equals one ($(1-\beta)v_{11} = 1$).

One problem with this reasoning is its very starting point. The example in section 5 shows that a valuable 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. Therefore, if the CAFC maintains its position of high presumed validity, the calculation should tilt toward weeding out bad patents within the patent office.

For future research, an interesting topic is to integrate the concerns raised in this paper into the optimal patent design, for instance, the optimal scope under defensive patenting. Previous literature on cumulative innovation (e.g. Green and Scotchmer (1995), Chang (1995)) has ignored the second-generation inventor's ability to build a defensive patent portfolio against the enforcement from first-generation. In that way, it propounds the view that increasing the patent power unambiguously benefits the latter. If the first-generation inventor is also a technology user, this might no longer be true. It would be desirable to see whether established results in the literature are robust to the introduction of defensive patenting.

Finally, if we stick to costless enforcement, the fact that there may be no high investment under high patent intensity (Proposition 4, for c in the intermediate range) begs the question: whether patents create too strong incentives for playing the "lean and hungry look" strategy. Alternatively, whether the patent system induces the optimal vertical disintegration, e.g. the entry of design-specialized firms in the semiconductor industry, who have no manufacturing capacity and presumably less vulnerable to patent threats. We need an ownership model to discuss these issues, and leave for future research.

Appendix

A Proofs

□ Lemma 1

Proof. By Assumption 1, $\hat{v}_{e_1 0} \geq \hat{v}_{e_1 1}$, F_1 credibly exercises its injunctive power absent a license. At the threat point, revenue stream is $\hat{v}_{e_1 0}$ for F_1 and $\hat{v}_{0 e_1}$ for F_2. There is bargaining surplus for cooperative joint revenue stream is $\hat{v}_{e_1 1} + \hat{v}_{1 e_1}$. The two parties agree to exploit F_2's investment, and the investment outcome is $E = (e_1, 1)$. Note that e_1 affects the magnitude of the bargaining surplus, but not the licensing fee: by splitting equally the bargaining surplus, F_1 gets

$$\int_{T_1}^{\infty}\left[\hat{v}_{e_10}+\frac{\hat{v}_{e_11}+\hat{v}_{1e_1}-\hat{v}_{e_10}-\hat{v}_{0e_1}}{2}\right]e^{-rt}dt=\left(v_{e_11}+\frac{v_{e_10}+v_{1e_1}-v_{e_11}-v_{0e_1}}{2}\right)e^{-rT_1}. \quad (6)$$

Let $f\equiv\frac{1}{2}(v_{e_10}+v_{1e_1}-v_{e_11}-v_{0e_1})=\frac{1}{2}(v_{10}-v_{01})$, the same for both $e_1=0,1$. *Q.E.D.*

□ **Lemma 2**

Proof. Partition the enforcement stage into intervals with equal length $\Delta>0$, and suppose F_1 can bring a suit at $2n\Delta$ and F_2 at $(2n+1)\Delta$, with $n=0,1,2,\ldots$. Let F_1 bring the first suit at time $T_1=N_1\Delta, N_1\in\{0,2,4,\ldots\}$. F_2's enforcement date is $T_2=N_2\Delta$, $N_2\in\{1,3,5,\ldots\}$, with $N_2\geq N_1+1$.[38] Consider possible events at T_1.

◇ With probability $1-\alpha$, the court finds F_1's patent not infringed and no bargaining takes place. During $[T_1,T_2)$ the prevailing investment profile is $E=(1,1)$ and each firm gets $\hat{v}_{11}$. At time T_2, F_2 executes its patent attack against F_1. By Lemma 1, expected payoffs are:

$$\begin{aligned}\pi_1^{1-\alpha}&=\int_{T_1}^{T_2}\hat{v}_{11}e^{-rt}dt+\alpha\int_{T_2}^{\infty}(\hat{v}_{11}-\hat{f})e^{-rt}dt+(1-\alpha)\int_{T_2}^{\infty}\hat{v}_{11}e^{-rt}dt-L(e^{-rT_1}+e^{-rT_2})\\&=(v_{11}-L)e^{-rT_1}-(\alpha f+L)e^{-rT_2}, \qquad (7)\\ \pi_2^{1-\alpha}&=(v_{11}-L)e^{-rT_1}+(\alpha f-L)e^{-rT_2}, \qquad (8)\end{aligned}$$

where $\hat{f}=\frac{1}{2}(\hat{v}_{10}-\hat{v}_{01})$. By Assumption 2, the optimal $T_2=T_1+\Delta$.

◇ With probability α, F_2 infringes F_1's paten and the two bargain. For the threat point payoffs, absent 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 countersues. Again, with probability $1-\alpha$ the court finds no infringement, $E=(1,0)$ prevails forever; with probability α, F_2's patent is infringed, the two firms meet and bargain again.

If the bargain fails again, F_2 exerts its injunctive power and there is mutual blocking, $E=(0,0)$. In an agreement, the two firms may be able to restore *ex post* efficiency, $E=(1,1)$; or previous bargaining failure persists and only $E=(1,0)$ is feasible. The

[38] T_2 could be chosen contingent on whether F_2 infringes F_1's patent. But for both events countersuing reduces to a unilateral enforcement. The optimal suing dates are the same.

results are the same in either case,[39] and we proceed with the former, i.e. the two firms reach a cross-license at T_2. By symmetry, no balance payment is made, and each firm gets a stream value of $\hat{v}_{11}$. Summing up, the threat point joint payoff at T_1's bargaining is $(V_{10} - 2L)e^{-rT_1} + [\alpha(V_{11} - V_{10}) - 2L]e^{-rT_2}$ for each gets

$$
\begin{aligned}
\pi_1^{th.} &= \int_{T_1}^{T_2} \hat{v}_{10} e^{-rt} dt + \alpha \int_{T_2}^{\infty} \hat{v}_{11} e^{-rt} dt + (1-\alpha) \int_{T_2}^{\infty} \hat{v}_{10} e^{-rt} dt - L(e^{-rT_1} + e^{-rT_2}) \\
&= (v_{10} - L)e^{-rT_1} + [\alpha(v_{11} - v_{10}) - L]e^{-rT_2}, \qquad (9) \\
\pi_2^{th.} &= (v_{01} - L)e^{-rT_1} + [\alpha(v_{11} - v_{01}) - L]e^{-rT_2}. \qquad (10)
\end{aligned}
$$

Next, consider the cooperative profit at T_1. By assumption a license covers only F_1's patent. At T_2 a suit is brought by F_2 against F_1, but a license is secured following the infringement judgement. $E = (1,1)$ is maintained over the whole period $[T_1, \infty)$, with joint profit $V_{11}e^{-rT_1} - 2L(e^{-rT_1} + e^{-rT_2})$. The bargaining surplus at T_1, then, is

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

A license is granted, and the expected payoffs when F_1 prevails at T_1 are:

$$
\begin{aligned}
\pi_1^{\alpha} &= (v_{10} - L)e^{-rT_1} + [\alpha(v_{11} - v_{10}) - L]e^{-rT_2} + \frac{1}{2}\left[(V_{11} - V_{10})e^{-rT_1} - \alpha(V_{11} - V_{10})e^{-rT_2} \right] \\
&= (v_{11} + f - L)e^{-rT_1} - (\alpha f + L)e^{-rT_2}, \qquad (12) \\
\pi_2^{\alpha} &= (v_{11} - f - L)e^{-rT_1} + (\alpha f - L)e^{-rT_2}. \qquad (13)
\end{aligned}
$$

Again the optimal $T_2 = T_1 + \Delta$. It is then straightforward to derive firms' expected payoffs. *Q.E.D.*

□ **Proposition 1**

Proof. Given $\Delta > 0$. Lemma 2(i) guarantees the optimality of counter-suing. Consider F_1's decision at time T_1 for filing the first suit, conditional on F_2's strategy.

◇ 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, by suing first at T_1, F_1 gets π_1^s according to Lemma 2; if F_1 deviates and not sues, since the equilibrium

[39] 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.

strategy requires F_2 to sue at time $T_1+\Delta$, whatever F_1 does, this deviation only delays a litigation war. F_1 loses its first-mover advantage and gets a payoff

$$\begin{aligned}\pi_1' &= \int_{T_1}^{T_1+\Delta} \hat{v}_{11} e^{-rt} dt + \left[v_{11} - \alpha f(1-e^{-r\Delta}) - L(1+e^{-r\Delta})\right] e^{-r(T_1+\Delta)} \\ &= \left\{v_{11} - \left[\alpha f(1-e^{-r\Delta}) + L(1+e^{-r\Delta})\right] e^{-r\Delta}\right\} e^{-rT_1}\end{aligned} \tag{14}$$

$$\Rightarrow \pi_1^s - \pi_1' = (\alpha f - L)(1+e^{-r\Delta})(1-e^{-r\Delta})e^{-rT_1} > 0, \quad \forall\, \Delta > 0. \tag{15}$$

F_1 has no incentives to deviate. In equilibrium, patent disputes take place at time 0 and Δ. As $\Delta \to 0$, the equilibrium payoff approaches to $\pi^w = v_{11} - 2L$ for both firms.

$\diamond$ Truce equilibrium: Sticking to the equilibrium strategy of 'tit-for-tat,' F_2 will not sue later if F_1 not sue now. F_1 gets $v_{11}e^{-rT_1}$ by following the equilibrium strategy. If F_1 deviates and sues, the expected payoff is π_1^s. Since $v_{11}e^{-rT_1} - \pi_1^s = -\left[\alpha f(1-e^{-r\Delta}) - L(1+e^{-r\Delta})\right] e^{-rT_1}$ and $e^{-r\Delta} \to 1$ as $\Delta \to 0$, F_1 has no incentives to deviate for Δ small enough. No litigation occurs along the equilibrium path and both firms get $\pi^t = v_{11}$. *Q.E.D.*

□ Corollary 3

Proof. Referring to Table 2 and 3, the equilibrium at the patenting stage can be characterized in terms of the strategic property of patents. Consider emboldening (Table 3). When patents are SC, $v_{11} - v_{01} - c > v_{10} - v_{11} \geq 0$, patenting gives nonnegative benefits. The patenting equilibrium is: (i) if $K < v_{10} - v_{11}$, then patenting is a dominant strategy. $P = (1,1)$ 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 $P = (0,0)$ is the unique equilibrium. Whether $P = (0,0)$ or $(1,1)$, the equilibrium investment profile is $E = (1,1)$.

When patents are SS, $v_{11} - v_{01} - c < v_{10} - v_{11}$. To have $E = (1,1)$ at $P = (1,1)$, it must be $c \leq \hat{c} = v_{11} - v_{01} - (\alpha f - L)$, and so $v_{11} - v_{01} - c \geq \alpha f - L \geq 0$. Patenting is profitable. Similar to SC, the equilibrium $E = (1,1)$ for either $K > v_{10} - v_{11}$ or $K < v_{11} - v_{01} - c$. When $K \in [v_{11} - v_{01} - c, v_{10} - v_{11}]$, strategic substitutability generates two asymmetric equilibria $P = (1,0)$ and $(0,1)$, where only the patent-holder invests in equilibrium. E and K follows a non-monotonic relationship.

The same argument applies for staunching, where only SC is possible. *Q.E.D.*

□ Proposition 5

Proof. An *ex ante* license commits the patent-holder not to enforce her patent rights. Under low patent intensity, joint payoffs with and without a license are $V_{11} - 2c$ and $V_{10} - c$, respectively. The condition to reach a license coincides with that of strategic complementarity of patents.

When $P = (1,1)$, by truce equilibrium $E = (1,1)$ can be attained without bargaining; no cross-licensing is needed. The only way to increase joint profit with costly *ex ante* bargaining is to change the investment outcome to $E = (1,0)/(0,1)$. This is done with one-way license so that hold-up is in force. The condition leading to the joint choice of $E = (1,1)$ ($E = (1,0)/(0,1)$) coincides with the condition of SC (SS, respectively) for patents. *Q.E.D.*

□ Lemma 3

Proof. Suppose F_2 not retreats. If F_1 patents B and sues F_2 for infringement, with probability $1 - \alpha_B$ it gets only βv_{11}. With probability α_B, there is an infringement and a license negotiation follows. The bargaining surplus is $(\beta + b)v_{11} - V_{10} \geq 0$, by Assumption 2 and 3. Patenting B leaves F_1 a profit of

$$\alpha_B \left(v_{10} + \frac{1}{2}[(\beta + b)v_{11} - V_{10}] \right) + (1 - \alpha_B)\beta v_{11} - L; \tag{16}$$

it is profitable if condition (4) holds. When B is patented, with F_2's payoff $bv_{11} - \frac{\alpha_B}{2}[(b - \beta)v_{11} + (v_{10} - v_{01})] - L$, it is easy to find F_2's no retreat condition. *Q.E.D.*

□ Lemma 4

Proof. Suppose the reaction lag Δ approaches to zero, and ignore for a moment the enforcement cost $2L$. When F_1 initiates a litigation war, possible outcomes are

◇ 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. From Lemma 3 and $\alpha_B = 1$, F_1 gets $\beta v_{11} + \frac{1}{2}[(b - \beta)v_{11} + (v_{10} - v_{01})]$, and F_2 gets $bv_{11} - \frac{1}{2}[(b - \beta)v_{11} + (v_{10} - v_{01})]$.

◇ With probability $\alpha'_A(1 - \alpha'_B)$, only F_1 infringes. To negotiate a license, the threat point profits are βv_{01} for F_1 and bv_{10} for F_2 (e_1 is shut down). The cooperative joint profit is $(\beta + b)v_{11}$. Assumption 3 guarantees 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 $bv_{11} + \frac{1}{2}[(bv_{10} - \beta v_{01}) - (b - \beta)v_{11}]$. Licensing fee paid by F_1 is $\frac{1}{2}[(bv_{10} - \beta v_{01}) - (b - \beta)v_{11}] \geq 0$.

◇ With probability $\alpha'_A\alpha'_B$, a cross-license is negotiated to solve mutual blocking. The threat point payoff is v_{00} for both firms. The bargaining surplus is $(\beta+b)v_{11} - V_{00}$. Each gets $\frac{1}{2}(\beta+b)v_{11} = bv_{11} - \frac{1}{2}(b-\beta)v_{11}$, with a balance payment $\frac{1}{2}(b-\beta)v_{11}$ from F_2 to F_1.

Adding up the four events, the expected payoffs from a litigation war are: for F_1,

$$\begin{aligned} &\beta v_{11} + \frac{\alpha'_B}{2}[(b-\beta)v_{11} + (v_{10} - v_{01})] \\ &\qquad - \frac{\alpha'_A}{2}\Big\{\alpha'_B(v_{10} - v_{01}) + (1-\alpha'_B)\left[(bv_{10} - \beta v_{01}) - (b-\beta)v_{11}\right]\Big\} - 2L, \end{aligned} \tag{17}$$

and for F_2,

$$\begin{aligned} &bv_{11} - \frac{\alpha'_B}{2}[(b-\beta)v_{11} + (v_{10} - v_{01})] \\ &\qquad + \frac{\alpha'_A}{2}\Big\{\alpha'_B(v_{10} - v_{01}) + (1-\alpha'_B)\left[(bv_{10} - \beta v_{01}) - (b-\beta)v_{11}\right]\Big\} - 2L. \end{aligned} \tag{18}$$

The optimality of counter-suing requires

$$\text{for } F_1\text{:} \quad \frac{\alpha'_B}{2}\left[(1-\alpha'_A)(b-\beta)v_{11} + (1-\alpha'_A)(v_{10} - v_{01}) + \alpha'_A(bv_{10} - \beta v_{01})\right] \geq L, \tag{19}$$

$$\text{for } F_2\text{:} \quad \frac{\alpha'_A}{2}\left[\alpha'_B(v_{10} - v_{01}) + (1-\alpha'_B)(bv_{10} - \beta v_{01}) - (1-\alpha'_B)(b-\beta)v_{11}\right] \geq L. \tag{20}$$

Assuming both inequalities hold, and assume only F_1 has a positive expected licensing income, then a litigation war arises if condition (5) holds.

For no retreating, suppose F_2 not retreats. If F_1 switches off its investment and eliminates the infringement risk, by suing F_2, with probability $1-\alpha'_B$, F_1 gets βv_{01}. With probability α'_B, there is an infringement: the threat point profit is v_{00} for both; and the cooperative joint profit is $\beta v_{01} + bv_{10} \geq 2v_{00}$, by Assumption 3. Dividing the surplus equally, F_1 gets $\frac{1}{2}(\beta v_{01} + bv_{10})$. F_1's expected payoff of suing F_2 is

$$\frac{\alpha'_B}{2}(\beta v_{01} + bv_{10}) + (1-\alpha'_B)\beta v_{01} - L = \beta v_{01} + \frac{\alpha'_B}{2}(bv_{10} - \beta v_{01}) - L. \tag{21}$$

F_1 won't shut down its investment if this term is smaller than the payoff from a litigation war. 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 then get F_2's no retreat condition. *Q.E.D.*

B Eliminating the war equilibrium

In this appendix, we introduce asymmetric information about firms' litigation cost as a simple way to eliminate the Pareto dominated war equilibrium. Assume a firm is the 'normal type' with probability $1-\epsilon$, where payoffs are as specified in the basic 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 countersuit.

To justify this behavior, we assume litigation exhibits scale economy for the pure-defensive type: the second lawsuit costs less than the first one.[40] As an extreme case, suppose there is only a fixed cost $\bar{L}$ for engaging in patent disputes. Assume $\alpha f < \bar{L}$ so that it never worths the purely defensive firm to initiate the first lawsuit. But once it has fought in the court, the marginal cost for the second suit is zero, and so a countersuit is brought with the least delay.

Assume each firm can be one of the two types 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. Fix $\Delta > 0$ and consider the normal type F_1's enforcement decision at time T_1. F_1 gets π_1^s by suing since a countersuit is guaranteed whatever the type of F_2. 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 regardless of F_1's wish for peace. We show that as long as ϵ is large enough, a normal type F_1 doesn't attack even if its rival of the normal type sticks to the war strategy.

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

$$\epsilon v_{11} e^{-rT_1} + (1-\epsilon)\left\{ v_{11}[e^{-rT_1} - e^{-r(T_1+\Delta)}] + \left[v_{11} - \alpha f(1-e^{-r\Delta}) - L(1+e^{-r\Delta}) \right] e^{-r(T_1+\Delta)} \right\}, \quad (22)$$

for it loses the first-mover advantage at time $T_1+\Delta$ with probability $1-\epsilon$. The difference with π_1^s is (ignoring the discount factor e^{-rT_1}):

$$\epsilon e^{-r\Delta} \left[\alpha f(1-e^{-r\Delta}) + L(1+e^{-r\Delta}) \right] - (1-e^{-r\Delta})(1+e^{-r\Delta})(\alpha f - L). \quad (23)$$

When ϵ is large enough, this difference is strictly positive, with the precise condition

$$\epsilon > \frac{1-e^{-r\Delta}}{e^{-r\Delta}} \cdot \frac{(1+e^{-r\Delta})(\alpha f - L)}{\alpha f(1-e^{-r\Delta}) + L(1+e^{-r\Delta})} \equiv \epsilon_\Delta. \quad (24)$$

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

[40] The scale economy of litigation may come from the 'learning effect.' See Lerner (1995) and papers cited there. 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. A countersuit entails no such damage.

C Full Characterization of Investment Outcomes

In this appendix we write down all the possibilities of investment outcomes corresponding to patent profiles, for $c \in (\min\{\underline{c}_0, \underline{c}_1\}, \max\{c_0^*, c_1^*\}]$. There are ten scenarios. Note that when there are multiple investment equilibria for a given patent profile, we list them all in the same cell. For example, in case 3, at $P = (1,1)$, both $E = (1,1)$ and $(0,0)$ are possible outcomes.

$\diamond$ Case 1 applies when $\underline{c}_1 < c < \hat{c} < c_1^* < \underline{c}_0 < c_0^*$, or $\underline{c}_1 < c < \hat{c} < \underline{c}_0 < c_1^* < c_0^*$, or $\underline{c}_1 < c < \underline{c}_0 < \hat{c} < c_1^* < c_0^*$.

$\diamond$ Case 2 applies when $\underline{c}_0 = \underline{c}_1 < \hat{c} < c < c_0^* = c_1^*$, or $\underline{c}_0 < \underline{c}_1 < \hat{c} < c < c_0^* < c_1^*$, or $\underline{c}_1 < \hat{c} < \underline{c}_0 < c < c_1^* < c_0^*$, or $\underline{c}_1 < \underline{c}_0 < \hat{c} < c < c_1^* < c_0^*$.

$\diamond$ Case 3 applies when $\underline{c}_0 = \underline{c}_1 < c < \hat{c} < c_0^* = c_1^*$, or $\underline{c}_0 < \underline{c}_1 < c < c_0^* < \hat{c} < c_1^*$, or $\underline{c}_0 < \underline{c}_1 < c < \hat{c} < c_0^* < c_1^*$, or $\underline{c}_1 < \underline{c}_0 < c < \hat{c} < c_1^* < c_0^*$.

$\diamond$ Case 4 applies when $\underline{c}_1 < \hat{c} < c < c_1^* < \underline{c}_0 < c_0^*$, or $\underline{c}_1 < \hat{c} < c < \underline{c}_0 < c_1^* < c_0^*$.

$\diamond$ Case 5 applies when $\underline{c}_1 < \hat{c} < c_1^* < \underline{c}_0 < c < c_0^*$, or $\underline{c}_1 < \hat{c} < \underline{c}_0 < c_1^* < c < c_0^*$, or $\underline{c}_1 < \underline{c}_0 < \hat{c} < c_1^* < c < c_0^*$.

$\diamond$ Case 6 applies when $\underline{c}_0 < c_0^* < \underline{c}_1 < c < \hat{c} < c_1^*$, or $\underline{c}_0 < \underline{c}_1 < c_0^* < c < \hat{c} < c_1^*$.

$\diamond$ In case 7, the unique $E = (1,1)$ prevails in all $P \neq (1,1)$; and at $P = (1,1)$, there are two equilibria $E = (1,1)$ and $(0,0)$. This scenario applies when $\underline{c}_0 < c < c_0^* < \underline{c}_1 < \hat{c} < c_1^*$, or $\underline{c}_0 < c < \underline{c}_1 < c_0^* < \hat{c} < c_1^*$, or $\underline{c}_0 < c < \underline{c}_1 < \hat{c} < c_0^* < c_1^*$.

$\diamond$ In case 8, the unique $E = (0,0)$ prevails in all $P \neq (0,0)$; and at $P = (0,0)$, there are two equilibria $E = (0,0)$ and $(1,1)$. This applies when $\underline{c}_0 < c_0^* < \underline{c}_1 < \hat{c} < c < c_1^*$, or $\underline{c}_0 < \underline{c}_1 < c_0^* < \hat{c} < c < c_1^*$, or $\underline{c}_0 < \underline{c}_1 < \hat{c} < c_0^* < c < c_1^*$.

$\diamond$ In case 9, there are two equilibria $E = (0,0)$ and $(1,1)$ for all P. This applies when $\underline{c}_0 < c_0^* < c < \underline{c}_1 < \hat{c} < c_1^*$.

$\diamond$ In case 10, there are two equilibria $E = (1,0)$ and $(0,1)$ for all P. This applies when

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

case 1

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

case 2

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

case 3

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

case 4

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

case 5

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

case 6

$\underline{c}_1 < \hat{c} < c_1^* < c < \underline{c}_0 < c_0^*$.

D Alternative Industrial Structure

In this appendix we consider an alternative market environment. For simplicity, assume: $v_{10} \geq 2v_{11} \geq 2v_0 \geq 0$, where $v_0 = v_{0e}$ 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), Ménière and Parlane (2004). If, say, only F_2 infringes F_1's patent, it has to exit the market. F_1 enjoys the monopoly profit v_{10}, and F_2 gets v_0. A second consequence of this modification is that, when firms split the monopoly profit in case of mutual blocking, then, ignoring the enforcement cost, the outcome of a litigation war is no more a zero-sum transfer between the two. Higher joint payoff $(v_{10} + v_0)$ can only be realized through litigation, and this increases the return from a war. The truce equilibrium exists only when enforcement is sufficiently costly to offset this gain. To see how other results are affected, suppose the truce equilibrium exists.

□ Small c: When firms always invest, expected payoffs are summarized in Table 4.

The offensive and defensive values of a patent are $\alpha(v_{10} - v_{11}) - L$ and $\alpha(v_{11} - v_0) + L$, respectively. Since $v_{10} - v_{11} \geq v_{11} - v_0$, we don't necessarily have strategic

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

Table 4: Payoff of small c

complementarity as in Proposition 2. But the comparative statics with respect to L holds: patents are more likely to be SC for larger L.

☐ Intermediate c: When firms invest only if protected by patent-holding, payoffs are summarized in Table 5.

The offensive value ($v_{10} - v_{11}$) is strictly higher than the defensive value ($v_{11} - v_0 - c$). Patents are SS. Note that this result is consistent with Proposition 3: joint profit concern determines patents' strategic property. In a sense, the single product environment leads to a narrower set of results since it allows only strategic substitutability.

E Asymmetric Information in *Interim* Licensing

Here we show that our results are qualitatively robust to *interim* licensing costs introduced in the way of Bebchuk (1984), i.e. settlement bargaining under asymmetric information. After the investment stage, suppose each patent-holder F_i receives some private information regarding the power of its patent, α_i: e.g., F_i is aware of some prior arts about the validity of its patent; or after reverse engineering efforts it has a more precise assessment of the extent to which its patent reads on F_2's investment.

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 $\rho \in (0,1)$, and denote the expected value as α^e. Assumption 2 holds 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, we let the uninformed party (the defendant) makes a take-it-or-leave-it settlement offer.

We look for this case: (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 F_1's type by litigating with type-$\bar{\alpha}$. Bargaining fails with probability ρ; and (ii) when $P = E = (1,1)$, the truce

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

Table 5: Payoff of Intermediate c

equilibrium exists, and so no need to engage in *interim* licensing.

☐ One effective patent: Consider F_1 threats to sue F_2, and the latter makes a take-it-or-leave-it settlement payment s. The type-α_1 F_1 accepts if the offer is high enough: $s \geq \alpha_1 f - L$. There are three cases: (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 offer $s = \underline{\alpha} f - L$, F_2 is expected to pay $(1-\rho)(\underline{\alpha} f - L) + \rho(\bar{\alpha} f + L)$; and (iii) if $s \geq \bar{\alpha} f - L$, F_2 settles with both types by the minimum licensing payment $s = \bar{\alpha} f - L$. F_2 screens F_1 if and only if:

$$(1-\rho)(\underline{\alpha} f - L) + \rho(\bar{\alpha} f + L) < \bar{\alpha} f - L \Rightarrow 2\rho L < (1-\rho)(\bar{\alpha} - \underline{\alpha}) f, \quad (25)$$

$$\text{and} \qquad (1-\rho)(\underline{\alpha} f - L) + \rho(\bar{\alpha} f + L) < \alpha^e + L \Rightarrow \underline{\alpha} f - L < \underline{\alpha} f + L. \quad (26)$$

☐ 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. Depending on one's own type, the profits from a war are $\pi(\underline{\alpha}) = \underline{\alpha} f - \alpha^e f - 2L = -\rho \Delta\alpha f - 2L < 0$ and $\pi(\bar{\alpha}) = \bar{\alpha} f - \alpha^e f - 2L = (1-\rho)\Delta\alpha f - 2L$.

For our purpose, if inequality (25) holds and $\pi(\bar{\alpha}) < 0$, litigation takes place with a positive probability only when there is one effective patent. The expected gain from holding a patent is $\alpha^e f - L$ for the patent-holder, and the expected loss is $\rho(\bar{\alpha} f + L) + (1-\rho)(\underline{\alpha} f - L)$ for the non-patenting firm. With two relevant patents, the truce equilibrium guarantees firms a peaceful life. It is straightforward to show that all our results with *ex post* licensing go through, with accompanying modifications.

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