Technology Adoption and Fuzzy Patent Rights

Jing-Yuan Chiou*

December 2010

Abstract

This paper considers why a patentee may have little incentives to reduce the uncertainty of patent boundary. Clearer patent rights, i.e., when patent examination results better predict subsequent court decisions, provide better guidance to technology-specific investment and encourage technology adoption. Under mild conditions, however, the patentee's post-adoption payoff decreases in clarity. The patentee prefers to maintain "fuzzy" patent rights in order to monopolize the use of the technology, or when promoting technology adoption is not a strong concern. The latter happens when the patentee, as a pure licensor, has a low (*ex ante*) quality invention.

Keywords: Fuzzy Patents, Public Notice, Technology Adoption.

JEL codes: K40, O33, O34.

*Assistant Professor, IMT Lucca. I thank Patrick Beschorner, Yassine Lefoulil, Elisabetta Ottoz, and Maria Fernanda Viecens for helpful comments. I am grateful to Michael Meurer for several helpful discussions out of which the idea of this paper grew. Feedbacks from seminar participants at CPRC, IMT Lucca, and Sabanci University, as well as several conferences are appreciated. All errors are mine. Comments are welcome and please send to: jy.chiou@imtlucca.it. Address: IMT Lucca, Piazza San Ponziano 6, Lucca 55100, Italy. Tel: +39 0583 4326 734. Fax: +39 0583 4326 565.

1 Introduction

The United States Patent No. 4,528,643, "System for Reproducing Information in Material Objects at a Point of Sale Location," was awarded to Charles Freeny Jr. in 1985, and then acquired by the E-Data Corporation in 1994 (and so was also known as the Freeny patent or E-Data patent). Aggressive enforcement during its statutory life, between 1985-2002, has created controversy among law practitioners, businessmen, and in academic circles.[1] According to the account of Meurer and Bessen (2008, ch. 9):

> '*One of the disputed claim terms was "point of sale location." The district court judge interpreted this limitation to mean that the patent did not cover transactions that occurred in private homes — that is, in the manner associated with consumer digital e-commerce... On appeal, however, the Federal Circuit interpreted this term more broadly to cover transactions that occurred within private homes. This meant that the patent could cover a wide range of e-commerce applications far beyond E-Data's original invention...*'

The reversal of court decision was an unpleasant surprise for the business community, especially during the rapid expansion of e-commerce in the early 90s.

The E-Data patent case is a typical example where an issued patent provides little information about the technology boundary of the patented invention. This paper deals with this aspect of uncertainty in the patent system, i.e., after issuance, the lingering uncertainty of the patent validity if tested in court, and the boundaries of technology territory it covers. Because of the exclusive power attached to a valid and infringed patent, uncertain boundary has non-negligible impacts. It may hinder technology diffusion or progress. Downstream technology users and future patentees along the chain of cumulative innovation process may be reluctant to use the patented invention, due to the difficulties of clearing the patent "mine field" and surviving in the "patent thicket" (Shapiro, 2001; Jaffe and Lerner, 2004). It is even asserted that under this situation patents do not deserve to be called intellectual *property rights* since there is insufficient "public notice" that any meaningful property entitlement should

[1]The invention described in the patent was a kiosk for producing music tapes or other products in retail stores using digital information. It is reported that E-Data has sent out 75,000 "amnesty" licensing packages, and sued at least 40 companies. News reports and comments are abundant on-line, see, e.g., http://www.tbtf.com/resource/freeny-timeline.html, http://www.kuesterlaw.com/edata.htm, and http://www.internetnews.com/ec-news/article.php/3390851 (last checked on October 23, 2009). See Meurer and Bessen (2008) for a general discussion.

deliver (Risch, 2007; Meurer and Bessen, 2008). Patent claims are supposed to delineate the patent coverage on the technology space, but often provide little help in the assessment of both patent validity and likelihood of infringement.

This uncertainty may come from several sources. Scientific knowledge in some fields (e.g. software) may be more inherently difficult to codify into written records than others (e.g. chemistry and pharmaceutical industry). Agency problem within the patent office may contaminate the "quality" of its decision, and so the informativeness of an issued patent.[2] In this paper, I consider private incentives, namely, a patentee's willingness, or unwillingness, to help reduce this uncertainty, and its impact on technology adoption by the other party. The patentee, either the inventor of the technology or a party closely related to the inventor, possesses relevant knowledge about the patentability issues and technological features of the invention. Furthermore, in most jurisdictions, patent examination is administered as an *ex parte* bargaining process between the patentee and patent examiner. Hence, the patentee is a natural candidate in the search for private help.

In Section 2, I introduce a model with a patentee and a developer. The developer wishes to incorporate a new technology into his investment project. After adoption, he has to exert a non-observable, technology-specific investment effort. Using the new technology is costly and will expose the developer to the risk of infringing on the patentee's patent rights. The patentee's patent boundary is resolved in a two-stage process. First, the patent office issues its opinion on whether the patent scope is broad enough to cover the new technology, then the court has the final say. The patent office's decision serves as a signal of the court's judgment. The patentee can exert some refinement effort to help the signal from the patent office fall more in line with the court judgment (Meurer and Nard, 2005). One key assumption is that when deciding whether to use the new technology, the developer observes the refinement effort chosen by the patentee. Technology adoption therefore depends on the expectation of how informative the patent office's decision will be, or the clarity of patent rights.

[2] In 1996, Gregory Aharonian, a software programmer and industrial observer, commented that '*... like many of the 40,000+ software patents to be issued in the 1990's, the Freeny patent cites no non-patent prior art, even though before the effective priority date of January 1982, there was much written about electronic commerce and/or encrypting business communications (providing grounds for an obviousness argument, if not a lack of novelty argument). Had those materials been in the hands of the examiner, I am sure a different set of claims would have issued...*' (http://www.interesting-people.org/archives/interesting-people/199606/msg00011.html, last checked on October 23, 2009.)

In Section 3, I show that the technology-specific effort, which generates hold-up concerns, will induce a preference toward clearer patent boundaries from the developer. In the presence of infringement risk, a more informative signal from the patent office better guides the developer's investment decision, and increase the developer's payoff from adoption of the new technology. Reducing uncertainty encourages technology adoption.

Increased informativeness, however, also implies that the developer's investment will be more responsive to the patent office's decision. Suppose that *ex ante* the developer believes that the court will find infringement with probability 1/2, and consider two extreme cases. If the patent office's decision is uninformative, then the developer will ignore the examination outcome and make the investment decision according to this probability; investment level is not affected by the patent office's decision. But if patent examination perfectly predicts the court ruling, then according to the patent office's decision, the developer will make an investment either as if there is no infringement risk (when the patent office issues a narrow patent indicating no infringement), or as if infringement will happen for sure (when the patent office issues a broad patent indicating infringement). This more diverse investment adjustment may not be in the patentee's interest. Even when risk neutrality is imposed, I get a fairly mild condition under which the patentee is avert to diverse investment by the developer.[3] Given adoption, to reduce the magnitude of investment adjustment, the patentee prefers less informative patent office decisions and "fuzzier" patent rights.

Opposite preferences on the precision of the patent office signal imply that the patentee's incentives to clarify the patent boundary are driven by her interests in promoting technology adoption. No private refinement efforts will be exerted when the patentee wants to monopolize the use of the new technology. She will choose the lowest possible refinement level in order to discourage technology diffusion. Even when the patentee intends to extract licensing income from the developer, she still has no incentive to engage in refinement as long as adoption is guaranteed, or will happen with sufficiently high probability. The second scenario applies to a patentee with a sufficiently low *ex ante* quality invention. That is, without information provided by patent examination, the patent is very unlikely to be found valid by the court. Hold-up, then, is less of a threat and the developer will very likely adopt the new technology in spite

[3] The condition requires that the second-order effect of hold-up (the impact of infringement probability on investment) is not too large.

of fuzzy patent rights.

Before concluding the paper in Section 6, I consider whether licensing can solve the hold-up problem and how it affects refinement incentives in Section 5.[4] It turns out that if licensing takes place early enough, more precisely, if a license is negotiated before patent examination, it perfectly substitutes for refinement efforts without jeopardizing technology adoption. In other words, if we rely on early licensing to alleviate the hold-up problem, then fuzzy patents are a side effect we have to live with.

□ **Related literature:** The probabilistic nature of patent rights has been introduced into economic analysis in the past decade. Most studies are concerned with the infringement or validity probability at the litigation stage, where patent disputes are ultimately resolved; see Lemley and Shapiro (2005) and papers cited there. Some recent works have considered a patentee's strategic choice of patent breadth or scope to influence a potential entrant's entry decision and post-entry behavior (Yiannaka and Fulton, 2006; Fulton and Yiannaka, 2008).[5] The patentee's strategic tool considered in this paper, the clarity of patent boundary, is related, but conceptually different from patent breadth. While patent breadth can be modeled as the infringement or validity probability in trial, the clarity of patent boundary refers to a higher order of uncertainty that affects how the infringement or validity assessment is formed. That is, how to interpret and extract information from a patent office's decision in order to predict a court judgment.

Similar to this paper, Farrell and Shapiro (2008) also considers the effect of clarifying the patent boundary. A beneficial effect is obtained when the patent is licensed to several downstream firms that compete against one another, but not when there is only one licensee or when multiple licensees do not compete. I show that due to hold-up concerns, reducing the boundary uncertainty also has a benefit of encouraging technology adoption when there is only one downstream user. I also stress the lack of patentee's incentives to deal with the uncertain boundary problem. Given limited participation by third parties, better patent examination may have to come from public initiatives. I then provide an argument against Lemley (2001)'s "rationally ig-

[4] Gans *et al.* (2007) empirically tests the impact of uncertainty on the timing of patent licensing. They found that the likelihood of licensing increases after the patent office's decision because of lower uncertainty. In this paper, however, I do not consider the players' optimal timing to licensing.

[5] In their seminal paper, Greena and Scotchmer (1995) also showed that less-than-full patent breadth may improve the patentee's interests in *ex ante* bargaining by weakening a second-generation patentee's threat of no entry *ex post*.

norant patent office."[6]

To the best of my knowledge, legal scholars provide most discussion about "fuzzy" patent rights and the lack of public notice. Their efforts, nevertheless, are more directed toward whether certain legal rules should be enacted or abolished to alleviate this problem.[7] In this paper, I take one step back and investigate why a patentee may lack incentives to help reduce uncertainty associated with her patent rights. Understanding one important source of the problem, in my view, is a necessary step toward finding solutions.

This paper also joins recent efforts to fill a gap in the literature, namely, the neglected role of patent office. My analysis includes patent examination as a possible way to mitigate uncertainty faced by the downstream technology user, and is complementary to recent works on patent examination *per se*, which focus on strategic interaction between patentees and the patent office (Caillaud and Duchêne, 2005; Langinier and Marcoul, 2008, 2009; Prady, 2008; Shuett, 2008).

2 Model

There are two players: a patentee and a developer. The patentee seeks patent protection for her invention, and is granted a patent with an uncertain boundary covering a technology field. The developer wishes to develop a product in order to enter the downstream market related to that field. Both players are risk neutral and protected by limited liability.

Before product development, the developer has to incur an "entry fee," or a technology adoption cost $c_f \geq 0$ to learn the fundamental knowledge of the field. The adoption cost c_f is only known to the developer, while the patentee holds a belief that c_f is distributed on $[0, \infty)$, with $F(\cdot)$ as the CDF. Assume that $F(c_f)$ is continuously differentiable and $F'(c_f) > 0$ over the relevant range.

After incurring the cost c_f and acquiring the basic knowledge, the developer exerts a technology-specific effort, or the investment effort $e \in [0,1]$, at a private cost $c_E(e) \geq 0$. To fix the idea, this effort is interpreted as the probability that the developer successfully commercializes a product in the downstream market. It may be techno-

[6]See Chiou (2008) for another argument based on the case selection issue of private litigations.

[7]Meurer and Nard (2005) and Lichtman (2005) debate the "doctrine of equivalents," on which the court relies to expand patent scope beyond what is specified in patent claims. Risch (2007) attacks the "broadest reasonable constructing rule" used by patent examiners in interpreting patent claims.

logical in nature, such as the successful development of a new functionality; or a pure marketing strategy, such as the advertisement expense; or both, such as the efforts exerted in finding a profitable new product design in a proper market niche. Assume an increasing and strictly convex investment cost, with $c_E'''(e) \geq 0$, $c_E(0) = c_E'(0) = 0$, and a sufficiently large $c_E'(1)$ that guarantees interior solutions. The investment effort is the developer's private information. To gain more insight, in several accounts I will impose quadratic investment cost, $c_E(e) = e^2/(2K)$, and uniform distribution, $F(c_f) = \nu c_f$ for $c_f \in [0, 1/\nu]$.

The developer's product may fall into the patentee's patent claims. The resolution of patent boundary consists of two steps: patent office examination a^P and court verdict a^C. There is no legal or management cost to obtain either decision. The patentee or developer can appeal the patent office's decision to the court, but the issue is fully settled once the court rules. Assume that both decisions are binary, a^P and $a^C \in \{0, 1\}$. When $a^P = 1$, the patent office issues a favorable decision supporting the patentee's claim over the new technology; and if $a^P = 0$, the patentee's claim is not approved by the patent office.[8] Similarly, when $a^C = 1$ ($a^C = 0$) the court upholds (strikes down, respectively) the patentee's rights over the technology under dispute. Denote $\alpha \in (0, 1)$ as the common *ex ante* belief that the court will side with the patentee, $\alpha = \Pr(a^C = 1)$, which measures the prior assessment of the patentee's technological contribution in terms of patent law requirement. I shall refer to it as invention quality.

The patent office's decision a^P provides some information about the final resolution of patent boundary a^C. The patentee's behavior during patent prosecution will affect the quality of patent office's decision, and so the information contained in this signal. The patentee may search and disclose prior arts to the patent examiner (Langinier and Marcoul, 2008), communicate with and explain to the examiner to help the latter better understand the invention and its difference with other inventions, and more carefully draft the patent claims and specifications in the application package (Meurer and Nard, 2005; Risch, 2007), *etc.* I assume that the patentee can exert a refinement effort r to sharpen the predictive power of the patent examination result, as captured by the following assumption.

Assumption 1. (Symmetric refinement) $\Pr(a^P = a^C) = r \in [\underline{r}, 1]$, for both $a^P = a^C \in$

[8]Thus the patent office examination outcomes have a broader interpretation than simply issuance or rejection. When $a^P = 0$, a patent can be granted, but an important claim in the original application has been trimmed by the examiner.

$\{0, 1\}$, where $\underline{r} > 1/2$ but is sufficiently close to $1/2$.

With probability r the patent office will make the same decision as the court. Contrary to Meurer and Bessen (2006), where a higher refinement effort is assumed to always improve the patentee's prospects in court, I assume symmetric impact of refinement.[9] A higher refinement effort will increase the predictive power of the patent office's decision both when $a^P = 0$ and 1. When the signal is directly observed by the (benevolent) patent examiner, symmetry implies an unbiased examiner who will not by systematically misled by the patentee in one direction or the other. Another justification can be found in the patent law. Current U.S. patent prosecution procedure does not require a patentee to conduct prior art search, but does impose "a duty of candor and good faith" (Rule 56), which obliges the disclosure of any information known to the patentee that may be material to patentability issues. Its violation may render a patent unenforceable. Hence a patentee may have questionable incentives to exert r and search prior arts, but may be even more hesitant to lie and hide information in hand. In Section 4, I keep the symmetry assumption but let the patentee observe the signal a^P. I then check her incentive to reveal the signal to the patent office and how it affects the refinement decision.

I impose a lower bound on the possible refinement effort. This minimal level $\underline{r}$ may come from the patent examiner's effort or the degree to which the court will defer to the patent office's decision.[10] Exerting an effort r entails a cost $c_R \geq 0$, with c_R and $c'_R \geq 0$, $c''_R > 0$, $c_R(\underline{r}) = c'_R(\underline{r}) = 0$, and $c'_R(1) = \infty$. I will also assume that c''_R is large enough to "force" the concavity of patentee's payoff in the refinement effort.

I assume that the effort r chosen by the patentee is observable to the developer. This is supported by the "early publication" requirement in the European and (to some extent) U.S. patent systems.[11] Under this requirement, patent applications and examination records are made public after a certain period (generally 18 months). Via

[9] One way to reconcile the two approaches is to assume that the game ends after the patent office issues the unfavorable decision $a^P = 0$. For instance, the patentee does not appeal the rejection decision by the patent office. The negative impact of refinement on patent power (when $a^P = 0$) then becomes irrelevant.

[10] Although introduced for technical reason (see footnote 16), it might be too pessimistic to say that patent examiners have no input at all and so without the patentee's effort the examination results will be totally uninformative.

[11] In Europe, all patent applications have to be published after 18 months of filing, unless they are withdrawn or rejected prior to 18 months of filing. In the U.S., early publication is exempted only if the patentee does not seek international patent protection. Adams (2003) compares early publication procedures in the U.S. and Europe, including what information is disclosed by each patent office.

these documents, third parties may be able to roughly figure out the "quality" of a given application and thus the patent office's decision. I discuss the case of unobservable refinement efforts in Section 4.

Given α and r, the probability distribution of the patent office's decision is

$$\Pr(a^P = 1|\alpha, r) \equiv q = \alpha r + (1-\alpha)(1-r), \tag{1}$$

$$\Pr(a^P = 0|\alpha, r) = 1 - q = \alpha(1-r) + (1-\alpha)r. \tag{2}$$

Knowing α and r and after observing the patent office's decision, the developer updates his beliefs about the court's decision:

$$\hat{\alpha}^1 \equiv \Pr(a^C = 1|\alpha, r, a^P = 1) = \frac{\alpha r}{q}, \tag{3}$$

$$\hat{\alpha}^0 \equiv \Pr(a^C = 1|\alpha, r, a^P = 0) = \frac{\alpha(1-r)}{1-q}. \tag{4}$$

These updated beliefs will be referred to as "patent power," for they measure the probability of infringing an issued patent. When $r = 1/2$, $\hat{\alpha}^0 = \hat{\alpha}^1 = \alpha$, the patent office's decision is totally uninformative. When $r > 1/2$, $\hat{\alpha}^0 < \alpha < \hat{\alpha}^1$, and

$$\frac{\partial \hat{\alpha}^1}{\partial r} = \frac{\alpha(1-\alpha)}{q^2} > 0 \ \text{ and } \ \frac{\partial \hat{\alpha}^0}{\partial r} = -\frac{\alpha(1-\alpha)}{(1-q)^2} < 0. \tag{5}$$

A higher refinement effort will increase (decrease) the patent power when the patent office sides with (against, respectively) the patentee.

Referring to Figure 1, the timing of the game is as follows:

- At time 1 the patentee exerts an observable refinement effort r;
- at time 1.5, after learning r but before knowing the patent office's decision, the developer learns the value of adoption cost c_f and decides whether to enter;
- at time 2, the patent office issues the decision $a^P \in \{0, 1\}$;
- at time 2.5, after adopting the new technology, the developer makes technology-specific investment effort e; and
- at time 3, the court makes a final decision $a^C \in \{0, 1\}$.

Note that the technology adoption decision is made *before* the patent office's decision. This scenario captures a common situation in high-tech, fast-moving industries where important decisions, such as which technologies to incorporate into a standard or which standard to adopt for product development, have to be made under the threat of potential patent disputes. There is not time to wait for the lengthy patent examination to reduce, but may not fully eliminate, uncertainty. By contrast, the investment effort is exerted after patent examination in order to keep the hold-up element.

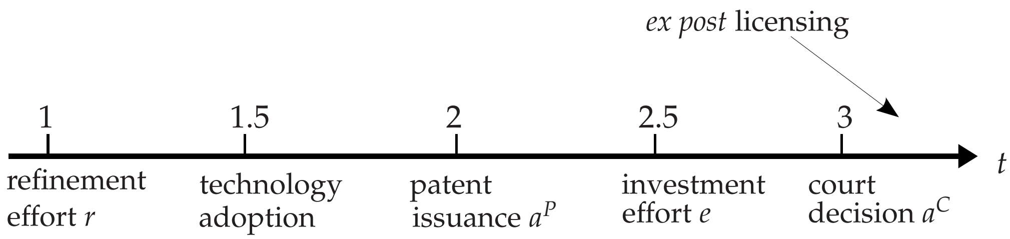


Figure 1: Timing

For my purposes, it suffices to have any adjustment by the developer according to the patent office's decision. In Section 4, I examine a "late adoption" scenario, where the adoption decision is delayed to time 2.5, after learning the patent office's decision. The main results are robust to this alternative timing with additional assumptions on the investment cost c_E and distribution function $F(c_f)$, and they are satisfied with quadratic cost c_E and uniform distribution $F(c_f)$.

Concerning payoffs, I assume that the patentee, as a pioneering patentee, needs not make any further investment. For instance, she may already operate in the downstream market. Her payoff, however, may be affected by the entry of the developer. If the developer does not adopt the technology, the patentee receives a revenue $u_{10} \geq 0$ and the developer receives zero revenue. This pair of revenues also applies when the developer spends c_f and adopts the new technology, but fails to develop a product and thus cannot enter the downstream market, an event with probability $1 - e$. With probability e the developer successfully conducts the investment project and can be present in the market. In this case, the revenues are determined by the prevailing market participation profile. Denote u_{ij} and v_{ji} as the patentee's and the developer's revenues, respectively, where $i = 1$ ($j = 1$) means that the patentee (the developer, respectively) is operating on the market; and when $i = 0$ ($j = 0$), she (he, respectively) exits the market.

Assume there is no exit cost, and for all $i, j \in \{0, 1\}$, u_{1j} and $v_{1i} \geq 0$, $u_{0j} = v_{0i} = 0$, and $v_{11} > 0$. Revenues from downstream market operation are non-negative, and exit generates zero income. Define

$$\pi \equiv \max\{u_{10}, v_{10}, u_{11} + v_{11}\} \tag{6}$$

as the maximal joint revenue from the downstream market. When $\pi \in \{u_{10}, v_{10}\}$, it is privately efficient to let one player exit the market. (The case of $\pi = u_{00} + v_{00} = 0$ is obviously uninteresting.)[12]

To close the model, notice that licensing can take place on several occasions: after the court's decision (*ex post* licensing), after patent issuance but before the developer makes technology-specific investment (*interim* licensing), and before patent issuance (*ex ante* licensing). The main analysis is conducted under *ex post* licensing only, which takes place only when the developer's investment project succeeds and the court upholds the patentee's claim, $a^C = 1$. In this case, the court grants the patentee the injunction power to shut down the developer, which serves as the threat point at bargaining. When $a^C = 0$, the developer can freely use the technology, and, absent patent rights, the antitrust authority will challenge any attempts to monopolize the market. At license negotiation, I assign the whole bargaining power to the patentee.

This setting is chosen to illustrate the main point in a simpler way. As mentioned earlier, for robustness check, variations of the basic model are examined in Section 4, including the cases of unobservable r, information revelation by the patentee, and late adoption. Section 5 analyzes other licensing opportunities.

3 Patentee's and Developer's Opposite Preferences on Refinement

This section illustrates the basic trade-offs underlying the patentee's refinement decision. Suppose that only *ex post* licensing is available, and that the developer has paid c_f and successfully built a product. In other events, the game ends and the patentee gets a revenue u_{10} and the developer gets zero.

Consider the court's decision. When $a^C = 0$, the court rejects the patentee's claim over the invention and the developer can freely use the new technology. The returns from market are u_{11} for the patentee and v_{11} for the developer, respectively. When $a^C = 1$, the court upholds the patentee's claim. With an injunction and full bargaining power, the patentee can realize the maximal return π by either shutting down the developer (when $\pi = u_{10}$) or offering a license which fully extracts the surplus and leaves zero return to the developer (as in his outside option of exiting).

[12] This payoff structure excludes any direct effect of patent rights on downstream revenues. For instance, in order to avoid infringement, the developer may want to invent or design around the patent with a lower revenue. To the extent that this (inefficient) adjustment could be captured by the specific investment, I believe there is only minor loss of generality.

At time 2.5, with the updated belief $\hat{\alpha}$, the developer's optimal investment effort $\hat{e}$ is determined by

$$\hat{e} \equiv \arg\max_{e} \ (1-\hat{\alpha})ev_{11} - c_E(e) \ \Rightarrow \ FOC: \ (1-\hat{\alpha})v_{11} \equiv c_E'(\hat{e}). \tag{7}$$

Denote the optimal investment efforts $\hat{e}^0 \equiv \hat{e}(\hat{\alpha}^0)$ and $\hat{e}^1 \equiv \hat{e}(\hat{\alpha}^1)$, corresponding to the patent office's decision, and define $\hat{v} \equiv (1-\hat{\alpha})\hat{e}v_{11} - c_E(\hat{e})$. The developer's expected payoff from technology adoption is

$$V(r;\alpha) = q\hat{v}(\hat{\alpha}^1) + (1-q)\hat{v}(\hat{\alpha}^0). \tag{8}$$

At time 1.5, the developer adopts the new technology when $V(r;\alpha) \geq c_f$.

With refinement effort r, the patentee expects technology adoption to occur with probability $F(V(r;\alpha))$. Upon adoption, given the patent power $\hat{\alpha}$, at time 2.5 the patentee's expected payoff (gross of refinement cost) is

$$\hat{u}(\hat{\alpha}) = (1-\hat{e})u_{10} + \hat{e}\left[\hat{\alpha}\pi + (1-\hat{\alpha})u_{11}\right] = u_{10} + \hat{e}\cdot D(\hat{\alpha}), \tag{9}$$

where $D(\hat{\alpha}) \equiv \hat{\alpha}(\pi - u_{11}) + u_{11} - u_{10}$. When the developer's project fails, the patentee receives u_{10}. When the developer succeeds, the patentee receives π if her patent rights are upheld in court, and u_{11} otherwise. The term $D(\hat{\alpha})$ reflects how the developer's success affects the patentee. Besides a direct impact $u_{11} - u_{10} \gtrless 0$, the patentee gets another source of revenue $\hat{\alpha}(\pi - u_{11}) \geq 0$ via her patent rights. The net impact may be positive or negative. It is negative when the two players compete fiercely on the market so that $u_{11} < u_{10}$ and the patent power $\hat{\alpha}$ is low. By contrast, if the patentee does not participate in the downstream market and only gathers licensing income, $u_{11} = u_{10} = 0$, it is always positive.

Given technology adoption, the patentee's expected payoff (gross of refinement cost) is

$$u_\tau = q\hat{u}(\hat{\alpha}^1) + (1-q)\hat{u}(\hat{\alpha}^0), \tag{10}$$

which is a convex combination between the two patent examination outcomes. When making the refinement decision at time 1, the patentee's expected payoff (net of refinement cost) is

$$U = [1-F(V)]\,u_{10} + F(V)u_\tau - c_R = u_{10} + F(V)(u_\tau - u_{10}) - c_R. \tag{11}$$

With probability $1-F(V)$, the developer does not adopt the technology and the patentee gets a revenue u_{10}. With probability $F(V)$, technology adoption occurs and the patentee's post-adoption payoff is u_τ. Assuming that c_R'' is large enough, the payoff U is then strictly concave in r. The next step is to derive players' preferences toward the refinement effort r from these payoffs.

Hold-up concerns imply that the developer's payoff $\hat{v}$ is decreasing and strictly *convex* in patent power:

$$\frac{d\hat{v}}{d\hat{\alpha}} = -\hat{e}v_{11} \leq 0, \text{ and } \frac{d^2\hat{v}}{d\hat{\alpha}^2} = -v_{11}\frac{d\hat{e}}{d\hat{\alpha}} = \frac{v_{11}^2}{c_E''(\hat{e})} > 0, \tag{12}$$

for $d\hat{e}/d\hat{\alpha} = -v_{11}/c_E'' < 0$.

For the patentee, the impact of patent power is

$$\frac{d\hat{u}}{d\hat{\alpha}} = D(\hat{\alpha})\frac{d\hat{e}}{d\hat{\alpha}} + (\pi - u_{11})\hat{e}, \text{ and } \frac{d^2\hat{u}}{d\hat{\alpha}^2} = 2(\pi - u_{11})\frac{d\hat{e}}{d\hat{\alpha}} + D(\hat{\alpha})\frac{d^2\hat{e}}{d\hat{\alpha}^2}, \tag{13}$$

where $d^2\hat{e}/d\hat{\alpha}^2 = [v_{11}/(c_E'')^2](d\hat{e}/d\hat{\alpha})c_E''' \leq 0$. Because $\pi > u_{11}$,[13] the payoff $\hat{u}$ is increasing in $\hat{\alpha}$ if $D(\hat{\alpha})$ is negative, or, when it is positive, if the absolute size of $D(\hat{\alpha})(d\hat{e}/d\hat{\alpha})$ is not too large.

More importantly, $\hat{u}$ is strictly concave in $\hat{\alpha}$ as long as the second-order effect of hold-up, $d^2\hat{e}/d\hat{\alpha}^2$, is not too large. In fact, $d^2\hat{u}/d\hat{\alpha}^2$ is *non-negative* at some $\hat{\alpha}$ only when

$$D(\hat{\alpha})\frac{v_{11}}{(c_E'')^2}c_E''' \leq -2(\pi - u_{11}) < 0, \tag{14}$$

which requires $D(\hat{\alpha})c_E''' < 0$. When $c_E''' = 0$, i.e., the investment cost c_E takes a quadratic form, $\hat{u}$ is concave in $\hat{\alpha}$.[14]

The curvatures of $\hat{v}$ and $\hat{u}$ generate players' preferences toward the clarity of patent boundary.[15] The following lemma establishes the mathematical result. (All proofs are relegated to Appendix A.)

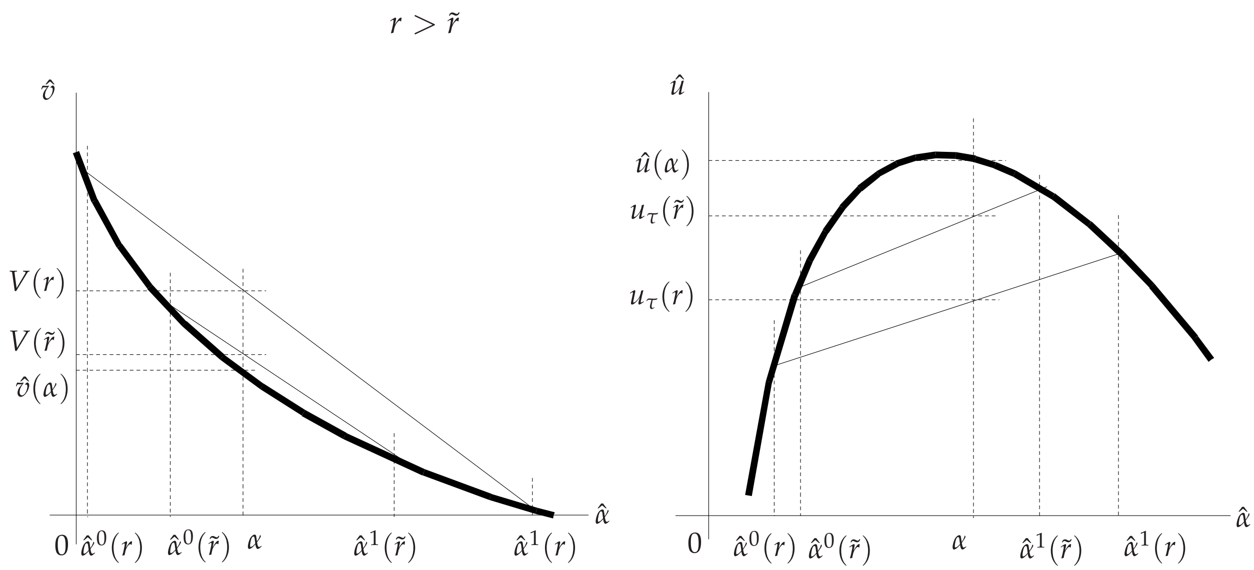
Lemma 1. *If a differentiable function $\delta(\hat{\alpha})$ is strictly convex (strictly concave) in $\hat{\alpha}$, then the convex combination $\Delta(r) = q\delta(\hat{\alpha}^1) + (1-q)\delta(\hat{\alpha}^0)$ is strictly increasing (strictly decreasing, respectively) in r.*

---

[13]If $\pi = u_{11}$, then $v_{11} = v_{01} = 0$. The developer will never use the new technology.

[14]If $c_E''' > 0$, condition (14) fails when $D(\hat{\alpha}) \geq 0$ is greater than zero for all $\hat{\alpha}$, which is true when the patentee is a pure licensor, $u_{11} = u_{10} = 0$. In the case of $\pi = u_{10}$, it requires that $v_{11}c_E''' < 2(c_E'')^2$.

[15]In the late adoption scenario considered in Section **??**, the convexity requirement is imposed on the "penetration probability," $F(\hat{v})\hat{e}$. This is the probability that under the alternative timing, the developer will use the technology *and* successfully conduct the project and then introduce the product. Assuming convexity of $F(\hat{v})\hat{e}$, which is satisfied under uniform distribution and quadratic investment cost, both Proposition 1 and 2 hold in the late adoption case (see Proposition 5).



(a) Developer $\qquad$ (b) Inventor

Figure 2: Refinement and post-adoption payoffs

Referring to Figure 2(a), by strict convexity, the developer's return from adoption $V(r;\alpha)$ is strictly increasing in r. Notice that

$$q\hat{\alpha}^1 + (1-q)\hat{\alpha}^0 = \alpha r + \alpha(1-r) = \alpha. \tag{15}$$

This property guarantees that, regardless of r, $V(r;\alpha)$, as a convex combination between $\hat{v}(\hat{\alpha}^1)$ and $\hat{v}(\hat{\alpha}^0)$, always lies on the vertical line from α. Intuitively, more informative patent office's decisions provide better guidance about infringement risk and allow the developer to adjust investment as a response. The developer has higher incentives to adopt the new technology in the expectation of more "public notice."

When condition (14) fails so that $\hat{u}$ is globally strictly concave in $\hat{\alpha}$, for all $r > 1/2$,

$$u_\tau = q\hat{u}(\hat{\alpha}^1) + (1-q)\hat{u}(\hat{\alpha}^0) < \hat{u}(q\hat{\alpha}^1 + (1-q)\hat{\alpha}^0) = \hat{u}(\alpha). \tag{16}$$

Contrary to the developer, the patentee prefers totally uninformative patent examination ($r = 1/2$) to some clarity ($r > 1/2$). The patentee dislikes more diverse investment by the developer, as will be induced by more diverse $\hat{\alpha}^1$ and $\hat{\alpha}^0$. Her post-adoption payoff, u_τ, is strictly decreasing in r, as shown in Figure 2(b).

Proposition 1. *(Preferences conflict) Suppose that only ex post licensing is available. Due to hold-up concerns, the developer prefers more informative patent examination outcomes. More refinement increases encourages technology adoption.*

When condition (14) fails, given adoption, the patentee prefers less informative patent examination outcomes. More refinement reduces the patentee's post-adoption payoff u_τ.

This conflict in preferences establishes the basic trade-off in the patentee's refinement decision. Suppose that condition (14) doesn't hold. Post-adoption, the patentee and developer have opposite interests in refinement, $\partial V/\partial r > 0$ and $\partial u_\tau/\partial r < 0$ for all $r \in [\underline{r}, 1]$. At the refinement stage (time 1), the patentee chooses $r \in [\underline{r}, 1]$ that maximizes the payoff $U = u_{10} + F(V)(u_\tau - u_{10}) - c_R$.[16]

By $\partial u_\tau/\partial r < 0$, the patentee has no refinement incentives when $F(V) = 1$ at $r = \underline{r}$, i.e., when technology adoption concern is absent. Suppose that $0 < F(V) < 1$ and $F'(V) > 0$ for $r \in [\underline{r}, 1]$. The patentee's first-order condition is

$$\frac{\partial U}{\partial r} = F(V)\left[\frac{F'}{F}(V)\frac{\partial V}{\partial r}(u_\tau - u_{10}) + \frac{\partial u_\tau}{\partial r}\right] - c'_R. \tag{17}$$

The trade-off, if any, to pin down the optimal refinement effort lies between higher adoption probability and larger post-adoption revenue. Whether there is such a trade-off crucially depends on the patentee's business strategy in the downstream market.

Consider two market structures. When $\pi = u_{10}$, the patentee will shut down the developer when obtaining the injunction. That is, the patentee will use the patent to exclude competition in the downstream market. Technology adoption harms the patentee: $\forall \hat{\alpha} \in [0, 1)$, $D(\hat{\alpha}) < 0$ and so $\hat{u}(\hat{\alpha}) < u_{10}$. Post-adoption payoff is smaller than when there is no adoption, $u_\tau < u_{10}$. The patentee wants to discourage technology adoption. In order to do so, she will not exert any refinement effort, $r = \underline{r}$, whatever her invention quality α.

In the second scenario, I assume that $u_{11} = u_{10} = 0$, and so $\pi = v_{11}$, i.e., the patentee is a pure licensor and does not participate in downstream market. This is a special case of $\pi = u_{11} + v_{11}$, where after infringement the patentee will grant an *ex post* license and extract a licensing fee v_{11} from the developer. The patentee's post-adoption payoff is

$$u_\tau = \left[q\hat{e}^1\hat{\alpha}^1 + (1-q)\hat{e}^0\hat{\alpha}^0\right] v_{11}. \tag{18}$$

The patentee may want to exert some refinement effort in order to boost technology

[16] Below I will consider a quadratic investment cost c_E, under which both $\partial V/\partial r = \partial u_\tau/\partial r = 0$ at $r = 1/2$. If I let $\underline{r} = 0$ while maintaining $c'_R(1/2) = 0$, $r = 1/2$ will become a critical point. Together with the concavity of U, the optimal refinement is always $r = 1/2$. The assumption of $\underline{r} > 1/2$ rules out this case.

adoption and the chance that she can collect licensing payment. To gain more insight, let's consider the special case of a quadratic investment cost.

Example 1. (Quadratic investment cost) Suppose that $c_E(e) = e^2/(2K)$, with $1/K > v_{11}$ so that the optimal $\hat{e}(\hat{\alpha}) < 1$ for all $\hat{\alpha}$. Since $c_E''' = 0$, condition (14) fails. The patentee has a strictly concave preference toward patent power.

By the quadratic form, $\hat{e} = (1-\hat{\alpha})Kv_{11}$, $\hat{v} = (1-\hat{\alpha})^2 v_{11}^2 (K/2)$, and $V(r;\alpha) = \Psi(1-\alpha)^2 v_{11}^2(K/2)$, where $\Psi \equiv [(1-r)^2/q] + [r^2/(1-q)]$. When $\pi = v_{11}$ and $u_{11} = u_{10} = 0$, $u_\tau = \Lambda\alpha(1-\alpha)v_{11}K\pi$, where $\Lambda \equiv [r(1-r)]/[q(1-q)]$. The impacts of refinement effort are $\partial\Psi/\partial r > 0 > \partial\Lambda/\partial r$, for all $r > 1/2$.[17] A higher refinement effort encourages technology adoption but at the same time reduces the patentee's post-adoption payoff. (More details can be found in the appendix.)

Concerning the patentee's optimal refinement decision, the necessary and sufficient condition for the patentee to exert any refinement effort is, when evaluated at $r = \underline{r} > 1/2$,

$$\frac{F'}{F}(V)V\frac{\alpha\Lambda}{(1-\alpha)\Psi} > 1 \;\Leftrightarrow\; \frac{F'}{F}(V)V > \frac{(1-\alpha)\Psi}{\alpha\Lambda}. \tag{19}$$

The right-hand side of the condition is decreasing in α, and when $\alpha \to 0$, $\Psi/\Lambda \to 1$. Therefore, as long as $F'V/F$ is uniformly bounded,[18] this condition is less likely to hold when α is small enough. For instance, $F'V/F = 1$ under uniform distribution, and this condition becomes

$$\left[\alpha - (1-\alpha)^2\right]\underline{r}(1-\underline{r}) > \alpha(1-\alpha)\left[\underline{r}^3 + (1-\underline{r})^3\right], \tag{20}$$

which won't be true when $\alpha \leq (1-\alpha)^2$. In addition, because $\underline{r} > 1/2$, it is less likely to satisfy when $\underline{r}$ becomes larger. Higher efforts from the patent examiner will crowd out or substitute the patentee's refinement efforts. ‖

Proposition 2. *(Low private refinement). Suppose that only ex post licensing is available. The patentee will not exert any refinement effort when $F(V) = 1$ at $\underline{r}$ and so technology adoption is not a concern, or when $\pi = u_{10}$ and so the patentee prefers to monopolize the market.*

When the patentee is a pure licensor ($u_{11} = u_{10} = 0$ and so $\pi = v_{11}$), and the developer has a quadratic investment cost function, $c_E(e) = e^2/(2K)$, the patentee will exert some refinement effort $r > \underline{r}$ if and only if condition (19) holds at $r = \underline{r}$. When $F'V/F$ is uniformly bounded, this condition will not hold when α is low enough.

[17] At $r = 1/2$, both $\partial\Psi/\partial r = \partial\Lambda/\partial r = 0$.

[18] Roughly speaking, the requirement of uniformly bounded $F'V/F = (dF/dV)/(F/V)$ means that there is no sudden jump in percentage of probability density.

4 Implications and Robustness Checks

This section is devoted to robustness checks and implications of the results.

☐ **Sabotage examiner's effort:** The result of no private refinement also implies that the patentee has an incentive to sabotage the examiner's effort, i.e., to reduce $\underline{r}$. This effect has an important implication for patent system reform. If the patentee is required to conduct a thorough search and disclose prior arts (supposing this rule can be effectively enforced), then she may want to provide both relevant and irrelevant information with the intention of creating information overflow for the examiner. This strategic interaction between the patentee and examiner is an interesting topic for future research.[19]

☐ **Welfare:** With additional structure such as the R&D cost and monopoly deadweight loss, different effects of refinement identified above can be incorporated into a formal welfare analysis. It wouldn't be difficult to imagine a social trade-off between encouraging technology adoption (thus raises static efficiency) and boosting R&D incentives. The question is, even when fuzzier patent rights increase the patentee's payoffs, whether this uncertainty would be a good policy instrument to induce innovation? A thorough analysis would require a larger set of policy tools, such as patent length, patentability requirement, and infringement remedy.

☐ **IPR strategy and business model:** If the patentee has an interest in obtaining the monopoly position, $\pi = u_{10}$, but needs to make some investment in order to enter the downstream market, then the same reasoning suggests that the patentee would not want to engage in refinement at all. Again, a higher refinement effort will attract more entry and reduce the prospect of maintaining the monopoly, for the patentee will have to rely on the court's injunction to exclude competitors. This suggests a relationship between a patentee's refinement policy and business strategy. At the aggregate level, it would be interesting to investigate the prevailing market structure and the degree of uncertainty in patent rights across industries.

[19] Dewatripont and Tirole (2005) raises this issue as an potential application of their strategic communication game, but does not provide a full analysis. Langinier and Marcoul (2008) explicitly models the patentee's prior art search and revelation decision, but does not allow the possibility of information overflow. Caillaud and Duchêne (2005) consider the overload problem facing the patent office. But the problem comes from excessive volume of applications, not information contained in each application.

□ **The third case:** The case of $\pi = v_{10}$ is somewhat between the two cases $\pi = u_{10}$ and $\pi = u_{11} + v_{11}$. When $\pi = v_{10}$, post infringement, the patentee will exit the market and grant the developer a license in exchange for a payment, and $D(\hat{\alpha}) = \hat{\alpha}(v_{10} - u_{11}) + u_{11} - u_{10}$. If the developer exerts a positive effect on the patentee at the downstream market ($u_{11} \geq u_{10}$), or if $u_{11} < u_{10}$ but the magnitude of negative impact is not too large, then $u_\tau > u_{10}$ and the patentee faces the same trade-off between encouraging adoption $F(V)$ and raising post-adoption payoff u_τ as in the case of $\pi = u_{11} + v_{11}$.

However, if the competition is so fierce that $u_\tau \leq u_{10}$, as in the case of $\pi = u_{10}$, then the patentee will again not exert any refinement effort. Despite the assumption that post infringement the patentee can extract the full surplus v_{10} via licensing, this would happen because *ex post* licensing only takes place when the court upholds the patent rights.[20]

□ **Non-observable refinement:** When the refinement effort r is not observable to the developer, it is even easier to obtain the no refinement result. In this case, a rational expectation equilibrium requires that, along the equilibrium path, the developer correctly guesses the equilibrium refinement effort exerted by the patentee, and the latter won't secretly deviate from the equilibrium level.

Suppose that $\tilde{r} > \underline{r}$ is an equilibrium refinement effort, with corresponding $\tilde{q} \equiv \alpha\tilde{r} + (1-\alpha)(1-\tilde{r})$, $\tilde{\alpha}^1 \equiv (\alpha\tilde{r})/\tilde{q}$ and $\tilde{\alpha}^0 \equiv [\alpha(1-\tilde{r})]/(1-\tilde{q})$. The developer's expected payoff from technology adoption is $\tilde{V} \equiv \tilde{q}\hat{v}(\tilde{\alpha}^1) + (1-\tilde{q})\hat{v}(\tilde{\alpha}^0)$. After adoption, the developer exerts an effort $\tilde{e}^i \equiv \hat{e}(\tilde{\alpha}^i)$, according to the patent examination outcome $i = a^P \in \{0, 1\}$. When making the refinement decision, the patentee's payoff is $U = u_{10} + F(\tilde{V})(u_\tau - u_{10}) - c_R$.

Since the developer cannot detect the patentee's deviation, if the latter chooses another refinement level, $r' \neq \tilde{r}$, along the equilibrium path the developer will choose investment $(\tilde{e}^0, \tilde{e}^1)$, which leading to the same adoption probability $F(\tilde{V})$. The deviation only affects the patentee's post-adoption payoff u_τ through the distribution of

[20]With quadratic investment cost,

$$u_\tau - u_{10} = (1-\alpha)v_{11}K\left[\alpha\Lambda(v_{10} - u_{11}) + (u_{11} - u_{10})\right], \tag{21}$$

which is negative when α is small enough.

patent examination outcome $q(r')$ and patent power $\hat{\alpha}^i(r')$, $i \in \{0,1\}$, with

$$\begin{aligned} u_\tau - u_{10} &= q(r')\tilde{e}^1 D(\hat{\alpha}^1(r')) + [1-q(r')]\tilde{e}^0 D(\hat{\alpha}^0(r')) \\ &= \alpha(\pi - u_{11})\left[r'\tilde{e}^1 + (1-r')\tilde{e}^0\right] + (u_{11}-u_{10})\left[q(r')\tilde{e}^1 + [1-q(r')]\tilde{e}^0\right]. \end{aligned} \tag{22}$$

When this payoff difference is decreasing in r', the patentee has an incentive to deviate and choose a lower refinement effort than $\tilde{r}$. In this case, the only rational expectation equilibrium is no private refinement.

By $\tilde{e}^1 < \tilde{e}^0$ and

$$\frac{\partial(u_\tau - u_{10})}{\partial r'} = (\tilde{e}^1 - \tilde{e}^0)\left[\alpha(\pi - u_{10}) - (1-\alpha)(u_{11} - u_{10})\right], \tag{23}$$

in equilibrium, a necessary condition for the patentee to exert any refinement effort is thus

$$\frac{\alpha}{1-\alpha} < \frac{u_{11} - u_{10}}{\pi - u_{10}}. \tag{24}$$

This condition may hold only when $u_{11} > u_{10}$, namely, the patentee directly benefits from the developer's product at the downstream market (e.g., due to some complementarity between the two's products). It does not hold, and so the patentee does not exert any refinement effort when the patentee wants to monopolize the market ($\pi = u_{10}$), or when she is a pure licensor ($u_{10} = u_{11} = 0$).

Proposition 3. *(Unobservable refinement) Suppose that the developer cannot observe the patentee's refinement effort. The patentee has any incentive to exert refinement effort only if condition (24) holds, which does not hold when the patentee wants to monopolize the market, or when the patentee is a pure licensor.*

□ **Information disclosure:** Suppose that the patentee, not the patent office (i.e., examiner), learns the signal $a^P \in \{0,1\}$, e.g., by searching for relevant prior arts. The patentee then decides whether to reveal her information during examination. To simplify the analysis, the refinement effort is still assumed to be observable by the developer, and the patent office plays a passive role and issues the patent together with the information submitted by the patentee.

The symmetric refinement assumption is maintained in the information-generating process. It implies that, when searching for prior arts and then forming a more precise assessment about the patentability of her patent, the patentee cannot systematically avoid information that would tilt her judgement in one way or the other. Whether she would reveal information is the focus here, as well as how this decision affects the refinement incentive.[21]

The developer, by observing α and r, knows that the patentee has two possible types, $\hat{\alpha}^1$ and $\hat{\alpha}^0$, with probability q and $1-q$. Whether the developer learns the true patent power depends on the extent to which the patentee transmits this information to the developer, i.e., the outcome of a signaling game. For the patentee, her available strategies are constrained by the properties of information and legal environment. That is, the extent to which she can conceal, manipulate, or even forge documents.

Consider two extreme cases. When the signal a^P is soft information, the reports that the patentee can send to the patent office are not constrained by the information she actually holds in hand. The patentee's report space is the same as her type space. In the proof of the following proposition, I show that there is no separating equilibrium, and a pooling equilibrium always exists. In a pooling equilibrium, the developer learns nothing from the patent examination outcome. His equilibrium belief remains at the *ex ante* level. The patentee cannot transmit her private information to the developer, and so won't bother to gather information in the first place. There is no private refinement.

Next, suppose that the signal a^P is hard information, i.e., the patentee can only conceal discovered information. To capture this, let's introduce another signal $\emptyset$ which means that the patentee remains silent and does not submit any information during examination. The patentee's message space, then, is type-dependent. When the patentee's true type is $\hat{\alpha}^i$, her report can only be $\hat{\alpha}^i$ or $\emptyset$.

Contrary to the soft information case, the restrictive message space guarantees the existence of a separating equilibrium. But the pooling equilibrium exists only when $\pi > u_{10} > u_{11}$ and the patentee exerts a sufficiently high refinement effort. There is only separating equilibrium, and thus previous results hold when the patentee wants to monopolize the technology use or when she is a pure licensor. Note that, even if it exists and the patentee does spend a large effort to attain the pooling equilibrium, the developer's equilibrium investment and adoption payoffs are determined according to the *ex ante* invention quality α, and patent examination is totally uninformative.

Overall, after taking into account the patentee's incentive to disclose information, either the results are the same (as in hard information and when the separating equi-

[21] Langinier and Marcoul (2008) also analyzes the patentee's decisions to collect and then reveal prior arts. In their model, however, the amount of prior arts gathered is assumed to be uninformative about the patentability of the invention.

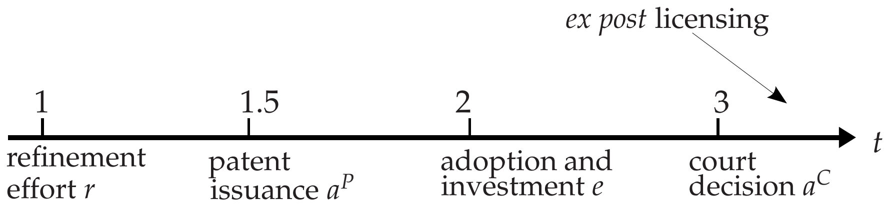


Figure 3: Timing with late adoption

librium prevails), or there is no private refinement (as in soft information).

Proposition 4. *(Information revelation) Suppose that the patentee learns the signal a^P. When this signal is soft information, there is only pooling equilibrium at the examination stage, and the patentee will not exert any refinement effort.*

When this signal is hard information, there is always a separating equilibrium. The pooling equilibrium may exist only when $\pi > u_{10} > u_{11}$ and r is large enough.

☐ **Late adoption:** Referring to Figure 3, suppose that the adoption decision is taken at time 2.5, after learning the patent office's decision. Given the patent power $\hat{\alpha}$, the developer will incur c_f when $\hat{v}(\hat{\alpha}) \geq c_f$. The developer will adopt the technology *and* successfully build the product with probability $F(\hat{v}(\hat{\alpha}))\hat{e}(\hat{\alpha})$. This probability plays a central role in this remark, and is referred to as the extent of technology penetration.

Stronger patent power, again, discourages technology penetration:

$$\frac{d}{d\hat{\alpha}}F(\hat{v})\hat{e} = F'(\hat{v})\frac{d\hat{v}}{d\hat{e}}\hat{e} + F(\hat{v})\frac{d\hat{e}}{d\hat{\alpha}} \leq 0. \tag{25}$$

A higher infringement risk reduces both the developer's adoption incentives as well as the effort he will exert post-adoption. Similar to previous analysis, refinement affects the overall technology penetration, $qF(\hat{v}(\hat{\alpha}^1))\hat{e}(\hat{\alpha}^1) + (1-q)F(\hat{v}(\hat{\alpha}^0))\hat{e}(\hat{\alpha}^0)$, through its impact on the distribution of patent examination outcome as well as patent power. The curvature of the penetration probability with respect to $\hat{\alpha}$, again, captures whether refinement enhances or reduces technology penetration. In the rest of the remark, the following assumption is maintained. It is satisfied, for instance, when $F(\cdot)$ is uniform distribution and c_E is quadratic.[22]

Assumption 2. $F(\hat{v})\hat{e}$ is strictly convex in $\hat{\alpha}$.

[22] In general it holds when the second-order effect of patent power on technology penetration is not dominated by F'' and $d^2\hat{e}/d\hat{\alpha}^2$.

The patentee's payoff, given the patent power $\hat{\alpha}$, is $\hat{u}^L(\hat{\alpha}) = u_{10} + F(\hat{v})\hat{e}D(\hat{\alpha})$. When choosing the refinement effort at time 1, the patentee's expected revenue is $U^L = q\hat{u}^L(\hat{\alpha}^1) + (1-q)\hat{u}^L(\hat{\alpha}^0)$. When c_R'' is sufficiently large, the program $\max_r U^L - c_R$ is strictly concave in r. To pin down the shape of $\hat{u}^L$ under Assumption 2, let 's consider the patentee's role at the downstream market. When the patentee prefers to monopolize the market ($\pi = u_{10}$), $\hat{u}^L$ is strictly increasing and concave in $\hat{\alpha}$. By Lemma 1, the patentee has no incentive to engage in refinement.

When the patentee is a pure licensor ($u_{11} = u_{10} = 0$), $\hat{u}^L = F(\hat{v})\hat{e}\hat{\alpha}v_{11}$. If the developer will use the technology for sure, i.e., if $F(\hat{v}) = 1$ for all $\hat{v} \geq 0$, then by $c_E''' \geq 0$, $\hat{u}^L$ is concave in $\hat{\alpha}$. The patentee will not exert refinement effort.

Suppose that technology adoption is not guaranteed, and consider uniform distribution and quadratic investment cost. Then $\hat{u}^L = \nu v_{11}^4 \hat{\alpha}(1-\hat{\alpha})^3(K/2)$, and the second-order derivative is

$$\frac{d^2\hat{u}^L}{d\hat{\alpha}^2} = 6\nu v_{11}^3 \frac{K}{2}(1-\hat{\alpha})(2\hat{\alpha}-1). \tag{26}$$

$\hat{u}^L$ is strictly concave for $\hat{\alpha} < 1/2$ and strictly convex for $\hat{\alpha} > 1/2$. The patentee will have some incentives to engage in refinement when α is at the high end, and no refinement incentives when α is low enough. To see this, suppose that at the minimal refinement $\underline{r}$, the invention quality α is so high that $\hat{\alpha}^0(\underline{r}) > 1/2$, then $\hat{u}^L$ is strictly convex and so U^L is strictly increasing in r around $\underline{r}$. The patentee will exert some refinement effort. By contrast, if the invention quality is so low that $\hat{\alpha}^1(\underline{r}) < 1/2$, then U^L is strictly decreasing in r around $\underline{r}$. By strictly concavity of $U^L - c_R$, the patentee will not exert any refinement effort.

Proposition 5. *(Late adoption) Suppose that technology adoption decisions is made after patent issuance, and Assumption 2 holds so that more refinement encourages technology penetration. The patentee has no incentives to exert any refinement effort when she wants to monopolize the technology use, or when the patentee has no downstream market capacity, but technology adoption is guaranteed for sure.*

5 Will Licensing Help?

This section considers how earlier licensing opportunities would affect the patentee's refinement incentives (see Figure 4). Assume early adoption, and that *Ex post* licensing remains as an alternative if no agreement is reached at an earlier stage. However,

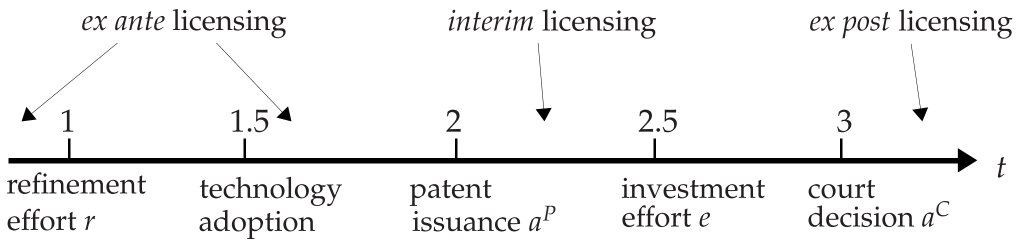


Figure 4: Licensing opportunities

to simplify the analysis, I do not allow *interim* licensing when considering *ex ante* licensing.

When $\pi = u_{10}$, the patentee prefers the developer to stay out of the market even if the latter successfully conducts the investment project. If reverse payment is allowed, then the patentee will pay the developer to exit the market or not use the technology in the first place. To avoid having to "buy out" the developer, the patentee will not engage in any refinement in order to discourage technology adoption.[23] If reverse payment is banned, then earlier licensing does not change the developer's adoption and investment behavior. The optimal license for the patentee is to mimic what would happen when only *ex post* licensing is available. The patentee, therefore, has no incentives to engage in refinement, either.

Proposition 6. *(Early licensing and monopolist) When $\pi = u_{10}$ and so the patentee wishes to discourage technology adoption, she has no incentives to exert any refinement effort even when early licensing is available.*

In the remainder of this section, the patentee is a pure licensor, $u_{10} = u_{11} = 0$. Under the assumptions that the developer is protected by limited liability and the investment effort e is not contractible, the type of license the patentee can offer is a royalty $l \in [0, 1]$ such that when the developer's project succeeds, the patentee gets a share $l \cdot v_{11}$.

□ *Interim* **licensing:** Referring to Figure 4, *interim* licensing takes place before the developer's specific investment but after the patent office issues its decision. Let l^0 and l^1 be the licensing terms offered by the patentee, given the patent office's decision

[23]When the patentee cannot verify the developer's capacity to adopt the technology and enter into the market, i.e., when the patentee cannot be sure that the developer will be a real threat to her monopoly, she may not want to engage in any licensing before the developer has "proven" himself and successfully completed the project. Earlier licensing becomes irrelevant.

$a^P = 0$ and $a^P = 1$, respectively. To induce acceptance, the royalty cannot exceed the prevailing patent power; there is a participation constraint $l^i \leq \hat{\alpha}^i$, $i \in \{0, 1\}$.

When accepting the offer l^i, the developer exerts an investment effort $\hat{e}(l^i)$, with payoff $\hat{v}(l^i)$. The patentee's expected licensing income is $\hat{u}(l^i) = \hat{e}(l^i) l^i v_{11}$. Denote l^* as the royalty that maximizes the patentee's expected licensing income in the absence of the participation constraint:

$$l^* \equiv \arg\max_l \hat{u}(l) = \hat{e}(l) l v_{11}. \tag{27}$$

Denote $\hat{u}^* \equiv \hat{u}(l^*)$ and $\hat{v}^* \equiv \hat{v}(l^*)$. The following assumption is maintained in this section.[24]

Assumption 3. $\hat{u}(l) = l\hat{e}(l)v_{11}$ is strictly concave in l and the maximizer l^* is a unique interior solution, $l^* \in (0, 1)$.

Given patent power $\hat{\alpha}$, by the strict concavity of $\hat{u}(l)$, the patentee optimally offers l^* if the participation constraint is not binding, and offers $\hat{\alpha}$ otherwise. Whether l^* is feasible, then, hinges on the refinement effort r, for it determines both $\hat{\alpha}^1$ and $\hat{\alpha}^0$. When $\hat{\alpha}^0 \geq l^*$, the patentee offers l^* for both examination outcomes. After technology adoption, the developer's payoff, $\hat{v}^*$, is not affected by the patent office's decision, and so is the patentee's licensing income $\hat{u}^*$. The patentee's payoff at the refinement stage is $F(\hat{v}^*)\hat{u}^* - c_R$. When $\hat{\alpha}^1 < l^*$, the participation constraint $l^i \leq \hat{\alpha}^i$ is binding for both $i \in \{0, 1\}$. The patentee's payoff from refinement is the same as before, $F(V)u_\tau - c_R$; *interim* licensing is irrelevant.

When $\hat{\alpha}^0 < l^* \leq \hat{\alpha}^1$, the optimal offer l^* is feasible only when the patent office issues a favorable decision $a^P = 1$, but not when $a^P = 0$. The developer's expected payoff from technology adoption is $V^{in} \equiv [q\hat{v}^* + (1-q)\hat{v}(\hat{\alpha}^0)]$. Post-adoption, the patentee's expected licensing income is $u_\tau^{in} \equiv [q\hat{u}^* + (1-q)\hat{u}(\hat{\alpha}^0)]$. The patentee's payoff from refinement is

$$F\big(q\hat{v}^* + (1-q)\hat{v}(\hat{\alpha}^0)\big)\big[q\hat{u}^* + (1-q)\hat{u}(\hat{\alpha}^0)\big] - c_R = F(V^{in})u_\tau^{in} - c_R, \tag{28}$$

which is strictly concave in r due to a sufficiently large $c_R^{''}$.

To consider how *interim* licensing modifies the patentee's refinement decision, it turns out that introducing this opportunity may eliminate the refinement effort from

[24] The first- and second-order conditions can be found in Section 3, $d\hat{u}/d\hat{\alpha}$ and $d^2\hat{u}/d\hat{\alpha}^2$, with $\hat{\alpha}$ replaced by l, and setting $\pi = v_{11}$ as well as $u_{11} = u_{10} = 0$. The first-order condition is strictly positive at $l = 0$ and strictly negative at $l = 1$ (for $\hat{e}(1) = 0$). The second-order condition is satisfied globally for quadratic c_E.

a patentee with high invention quality α, the one who is supposed to have strong refinement incentives in the previous case.

Proposition 7. (Interim licensing) Suppose that the patentee is a pure licensor and can offer an interim license.

When α is large enough so that $\hat{\alpha}^0(\underline{r}) \geq l^*$, the optimal refinement effort is either no refinement or large enough so that $\hat{\alpha}^0 < l^* < \hat{\alpha}^1$. And when

$$F'(\hat{v}^*)\hat{u}^*(1-q)\frac{\partial \hat{v}(\hat{\alpha}^0)}{\partial \hat{\alpha}^0}\bigg|_{\hat{\alpha}^0 \to l^{*-}} \frac{\partial \hat{\alpha}^0}{\partial r} < c_R', \tag{29}$$

at r such that $\hat{\alpha}^0(r) \to l^{*-}$, the patentee will not exert any refinement effort if interim licensing is available. Given $l^* = 1/2$, this condition is more likely to hold when α is higher.

When α is small enough so that $\hat{\alpha}^1(\underline{r}) < l^*$, then interim licensing will not have significant negative impact on the refinement effort. That is, it is impossible to have the case where under interim licensing the optimal refinement is low enough so that $\hat{\alpha}^1 < l^*$, but without interim licensing the refinement effort is high enough so that $\hat{\alpha}^0 < l^* < \hat{\alpha}^1$.

The analysis suggests that *interim* licensing may not improve the clarity of patent rights for a high quality invention (high α). Nevertheless, by alleviating the hold-up problem it can substitute for the patentee's refinement activity. To see this, let's turn to quadratic investment cost. In this case, given adoption, the average probability that the developer will successfully conduct the investment project is $q\hat{e}^1 + (1-q)\hat{e}^0 = (1-\alpha)Kv_{11}$, independent of refinement level. Fixing α and the distribution function $F(\cdot)$, the degree of technology adoption is thus determined by the developer's expected payoff from using the new invention, $V(r;\alpha) = (1-\alpha)^2\Psi v_{11}^2 K/2$. By $\partial\Psi/\partial r > 0$, the upper bound of this payoff is thus $(1-\alpha)v_{11}^2K/2$, when $r = 1$.

Suppose that α is so large that $\hat{\alpha}^0(\underline{r}) \geq l^*$ and condition (29) holds, the patentee gives up any refinement activity under *interim* licensing. This is the case only if $\alpha > l^* = 1/2$. The optimal royalty $l^* = 1/2$ thus determines the developer's payoff, $\hat{v}^* = v_{11}^2K/8$. Given adoption, the expected successful probability under *interim* licensing is higher than without it, $\hat{e}(l^*) = Kv_{11}/2 > (1-\alpha)Kv_{11}$, for $\alpha > 1/2$. And the developer's payoff will also be greater if α is large enough: $v_{11}^2K/8 \geq (1-\alpha)v_{11}^2K/2$ whenever $\alpha \geq 3/4$. In other words, for α large enough, *interim* licensing may eliminate refinement without hampering technology diffusion. Note that this comparison is made by using the highest refinement $r = 1$ when there is no *interim* licensing. Any lower r will only strengthen the result.

Remark. An interesting result shown in the proof of this proposition is how *interim* licensing may change the adoption *v.s.* revenue trade-off when $\alpha > 1/2$ and $\hat{\alpha}^0(\underline{r}) < l^* < \hat{\alpha}^1(\underline{r})$. When α falls in the middle range such that $\hat{\alpha}^0(\underline{r}) < l^* < \hat{\alpha}^1(\underline{r})$, the developer's and patentee's post-adoption payoffs are always V^{in} and u_τ^{in}, respectively. And when $\alpha > 1/2$, I show that $\partial V^{in}/\partial r > \partial V/\partial r$ and $\partial u_\tau^{in}/\partial r > \partial u_\tau/\partial r$, that is, *interim* licensing will increase the responsiveness of adoption to refinement while reducing the negative impact of refinement on the patentee's post-adoption payoff. Furthermore, with quadratic investment cost and so $l^* = 1/2$, I show that the latter effect may be so strong that u_τ^{in} may be *increasing* in r for r close to 1/2. In other words, there may be no more adoption *v.s.* revenue trade-off. ‖

□ *Ex ante* **licensing:** Referring to Figure 4, there are two opportunities to offer an *ex ante* license, before or after the patentee incurs the refinement efforts. To focus on the change these licensing opportunities would bring, I do not allow *interim* licensing here.

Suppose that *ex ante* licensing takes place after the patentee chooses the refinement level. Because the adoption cost c_f is assumed to be the developer's private information, it doesn't matter to the patentee whether the license is offered before or after the technology adoption decision is made. Lacking other means of screening this information, at most one license will be accepted along the equilibrium path.[25] In addition, I assume that even if the developer has taken the license, he can still walk away at no cost. That is, the patentee cannot impose any fine if the developer decides not to adopt the patentee's technology and remains inactive. This is consistent with the assumptions of limited liability and zero revenue if the developer remains idle.

Let l^{**} be the optimal value of the following program:

$$l^{**} \equiv \arg\max_l F\big(\hat{v}(l)\big)\hat{u}(l) \quad \Rightarrow \quad FOC: \; F'\hat{u}\frac{\partial \hat{v}}{\partial l} + F\frac{\partial \hat{u}}{\partial l} = 0. \tag{30}$$

That is, l^{**} is the optimal licensing term that maximizes the patentee's expected licensing income when there is only a technology adoption constraint. (If the optimizers are not unique, choose the smallest one.)[26] Because $F' > 0$ and $\partial\hat{v}/\partial l < 0$, the *ex ante* optimal royalty $l^{**} < l^*$. Bringing in the technology adoption concern will reduce the

[25] If two licenses give different adoption payoffs, the developer will surely choose the one with higher payoff. If two licenses lead to the same adoption payoff for the developer, and thus the same adoption probability, but different post-adoption revenue for the patentee, the patentee will again choose the one with higher revenue.

[26] For simplicity, I assume that the patentee cannot do better by offering random contracts, i.e., $(l^s)_{s=1,\ldots,S}$

optimal royalty relative to the case where the developer has already employed the patentee's invention.

When offering an *ex ante* license, the patentee faces a participation constraint that the developer's payoff from taking the *ex ante* license cannot be lower than $V(r;\alpha)$, what he would expect by rejecting the license and proceeding alone. By $\partial V(r;\alpha)/\partial r > 0$, the payoff $V(r;\alpha)$ attains its minimal value at $r = \underline{r}$. Therefore, when α is high enough such that $\hat{\alpha}^0(\underline{r}) \geq l^{**}$, the optimal royalty l^{**} is implementable in the absence of *any* refinement effort, $\hat{v}(l^{**}) \geq \hat{v}(\hat{\alpha}^0(\underline{r})) > V(\alpha, \underline{r})$. The patentee will not exert any refinement effort. This is true as long as $\hat{v}(l^{**}) \geq V(\alpha, \underline{r})$.

Suppose that $\hat{v}(l^{**}) < V(\alpha, \underline{r})$, and so for all $r \in [\underline{r}, 1]$, $V(r;\alpha) > \hat{v}(l^{**})$, the developer will not accept the royalty l^{**}. Intuitively, the patentee will not exert any refinement effort because more refinement will only increase the developer's reservation value $V(r;\alpha)$ and reduce the feasible royalty terms.

To show this result, note that the patentee's *ex ante* license offering may contain two royalties, l^0 and l^1, contingent on the patent office's decision $a^P \in \{0, 1\}$. Given the refinement decision, the patentee can offer $(l^0, l^1) = (\hat{\alpha}^0, \hat{\alpha}^1)$ that fully replicates the outcome of no *ex ante* licensing. There is no loss of generality in assuming that once the developer has decided to use the patentee's invention, he will also take the *ex ante* license. The following lemma nevertheless shows that when Assumption 3 holds and $c_E''' \geq 0$, then it is optimal for the patentee to offer a fixed royalty $l^0 = l^1$.

Lemma 2. *(Optimal ex ante license) Suppose that Assumption 3 holds and $c_E''' \geq 0$. The optimal contract (l^0, l^1) that solves the program: $\forall q$,*

$$\begin{aligned} &\max_{(l^0,l^1)} \; q\hat{u}(l^1) + (1-q)\hat{u}(l^0) \\ &s.t. \; q\hat{v}(l^1) + (1-q)\hat{v}(l^0) = \bar{v}, \end{aligned} \tag{31}$$

has the property that $l^0 = l^1$.

By this lemma, the patentee will optimally construct the *ex ante* license in such a way that the royalty is invariant in the patent office's decision, $l^0 = l^1$. Let $\tilde{l}$ be the optimal licensing offer, which must satisfy $\hat{v}(\tilde{l}) \geq V(r;\alpha)$, where r is the refinement effort chosen by the patentee at time 1. The patentee's expected payoff, when making

such that the royalty l^s is realized with probability $q^s \in (0,1)$, with $\sum_{s=1}^{S} q^s = 1$. By the same reasoning, this can be guaranteed by the same conditions as in Lemma 2 below.

the refinement decision, is

$$F\big(\hat{v}(\tilde{l})\big)\hat{u}(\tilde{l}) - c_R, \;\; s.t. \;\; \hat{v}(\tilde{l}) \geq V(r;\alpha). \tag{32}$$

Suppose that the refinement effort r and the subsequent *ex ante* license are both chosen at the optimal level. When the patentee exerts some refinement effort, $r > \underline{r}$, the developer's participation constraint must be binding, $\hat{v}(\tilde{l}) = V(r;\alpha)$. If not, $\hat{v}(\tilde{l}) > V(r;\alpha)$, then the patentee can marginally reduce the refinement effort, saving the refinement cost without jeopardizing her ability to offer the same $\tilde{l}$ and receive the same expected licensing income $F(\hat{v}(\tilde{l}))\hat{u}(\tilde{l})$.

Obviously, as long as the developer prefers clearer patent rights, $\partial V/\partial r > 0$, the patentee will optimally choose *not* to exert any refinement effort. A higher r requires a larger cost c_R and will raise the developer's reservation value at the contracting stage, and thus reduce the feasible set of *ex ante* contracts. The patentee does not gain from patent refinement.

Lastly, consider an *ex ante* license offered before the patentee makes the refinement effort. If at the contracting stage the patentee can commit to the refinement effort she will exert later, then previous analysis applies. A higher refinement effort will raise the developer's reservation value $V(r;\alpha)$ at the contracting stage. The patentee will not engage in refinement.

Suppose that the patentee cannot commit to a refinement effort at the bargaining stage. If the developer refuses the patentee's licensing offer, then the game continues as if there is only *ex post* licensing. Denote $\hat{r}$ as the patentee's optimal refinement effort in that case. The developer is willing to accept an *ex ante* license when his payoff is higher than $V(\alpha, \hat{r})$. An *ex ante* license that can fully mimic the outcome without *ex ante* licensing, and thus will be accepted by the developer is: a royalty $l^0 = \hat{\alpha}^0$ ($l^1 = \hat{\alpha}^1$) is imposed when the patent office issues a decision $a^P = 0$ ($a^P = 1$, respectively). (And by Lemma 2, to keep the developer's adoption payoff at $V(\alpha, \hat{r})$, the patentee can do strictly better by offering a constant royalty.) It follows that *ex post* licensing will become an off-path event, and the patentee and developer will agree on an *ex ante* license. After the agreement, the patentee will no longer exert any refinement effort.

Similar to the case where *interim* licensing is available, no refinement effort by the patentee doesn't mean that the overall technology adoption rate will suffer. Indeed, in the case where the *ex ante* licensing takes place before the refinement decision,[27] the

[27] When *ex ante* licensing takes place after the refinement decision, the optimal royalty is either l^{**} (when

fact that the optimal *ex ante* license $\tilde{l}$ has to satisfy the participation constraint $\hat{v}(\tilde{l}) \geq V(\alpha, \hat{r})$ implies that the technology adoption probability will not be damaged by this earlier bargaining opportunity. Furthermore, in the case of quadratic investment cost, without *ex ante* licensing the probability that the developer will successfully conduct the investment project is $(1-\alpha)Kv_{11}$. And by the participation constraint: $\forall r > 1/2$,

$$\hat{v}(\tilde{l}) = (1-\tilde{l})^2 v_{11}^2 \frac{K}{2} \geq V(\alpha, \hat{r}) = (1-\alpha)^2 \Psi v_{11}^2 \frac{K}{2} \tag{33}$$

$$\Rightarrow \; (1-\tilde{l})^2 \geq (1-\alpha)^2 \Psi > (1-\alpha)^2, \tag{34}$$

for $\partial\Psi/\partial r > 0$ whenever $r > 1/2$ and $\Psi = 1$ at $r = 1/2$. The successful probability, $\hat{e}(\tilde{l}) = (1-\tilde{l})v_{11}K$, thus, is strictly larger than without *ex ante* licensing.

Proposition 8. *(Ex ante licensing) Suppose that the patentee has no downstream capacity and offers a license before patent examination. When Assumption 3 holds and the elasticity ξ is strictly monotonic in l for $l \leq l^*$, regardless of the exact timing of the ex ante licensing the patentee has no incentive to exert any refinement effort.*

When ex ante licensing takes place before the refinement decision, the overall probability that the developer will successfully conduct the downstream investment with the new invention is higher than that without ex ante licensing.

6 Concluding Remarks

In this paper, I investigated a patentee's incentives to reduce the uncertainty surrounding her patent rights. I showed that, under some mild conditions, the patentee's refinement effort is motivated by technology diffusion concerns. But even when the patentee has no other income than licensing payment, I found that private refinement effort may vanish when the invention quality α is sufficiently low. This result corresponds to the general perception in the software or e-business industry, where patents are claimed to be issued to technologies already in the public domain and patent examination fails to clear the enforceability of these patents in court. I also show that earlier licensing, in particular at the *ex ante* stage, could alleviate the hold-up problem and fully substitute the patentee's refinement effort without jeopardizing technology

$\hat{v}(l^{**}) \geq V(\alpha, \underline{r})$) or $\tilde{l}$ such that $\hat{v}(\tilde{l}) = V(\alpha, \underline{r})$ (when $\hat{v}(l^{**}) < V(\alpha, \underline{r})$). However, the optimal refinement without *ex ante* licensing, $\hat{r}$, maybe lead to $\hat{v}(l^{**}) < V(\alpha, \hat{r})$. I need further information about $\hat{r}$ to compare the effect on technology adoption.

diffusion. This implies that if I rely on early licensing to mitigate hold-up, then fuzzy patent rights are something I have to live with.

For future research, the strong assumptions imposed in our model provide quite a few natural extensions. First, I may expand the model to consider multiple patentees or multiple developers, or both.[28] When there are several patentees, besides deriving the strategic relationship of refinement decisions, it would be important to let patent-holders offer *interim* or even *ex ante* licenses, jointly or separately. Allowing licensing would contribute to the literature of standard-setting organization and patent pools and enhance our understanding of how these collective rights organizations, or IPR clearinghouses, would affect the overall performance of the patent system. For instance, adding refinement decisions before the formation of a patent pool might help clarify whether the demand or competition margin will bind, and thus whether a patent pool is pro-competitive (Lerner and Tirole, 2004).

Second, despite the positive results obtained in Section 5, it might be too optimistic to assume that early (*ex ante*) licensing is always available.[29] It may well be that not all potential developers have the same access to *ex ante* licensing. When it is not available, our results suggest a policy response to let public decision-makers (the patent office or court) be the primary source of providing certainty in the patent system.

To introduce the patent office examiner into the model, I may also want to relax the assumption that the patentee's refinement effort has an unbiased effect, $r = \Pr(a^P = a^C)$ for both $a^C \in \{0, 1\}$. It would be interesting to consider a patentee's biased incentives to improve the patent power $\hat{\alpha}^1$ without jeopardizing $\hat{\alpha}^0$, when the patent office issues an unfavorable decision (Meurer and Bessen, 2006). If this is true, and if the patent examination remains an *ex parte* procedure, then patent examiners should be provided with adequate incentives to counter this bias and raise the informativeness of issued patents in the other side. That is, I might consider introducing some "ad-

[28]In an earlier version of the paper, I attempted a preliminary analysis with two patent-holders, and showed that when the two inventions are perfect complements and perfect substitutes, as well as under the special cases of quadratic investment cost and uniform distribution for the adoption cost, the two patent-holders' refinement decisions are strategic complements.

[29]For instance, in the U.S. early publication is not mandatory as long as there are (or will be) no foreign equivalent applications filed in countries where early publication will take place. In this case, a potential developer will have difficulty searching for relevant patent applications and seeking a license before patents are granted. Even under the early publication requirement (e.g. European Union and Japan), it typically happens eighteen months after the patentee files the patent application. Because the twenty-year patent term begins with the filing date, a patentee may not want to wait until after publication to start the examination process.

vocacy" elements into patent examination, with the patentee and examiner searching for information to support opposite causes (Dewatripont and Tirole, 1999).

Concerning the role of the court, a similar extension could be introduced at the litigation stage. That is, I could consider a situation where both a^P and a^C are signals about a "true" patent boundary, which has a true value 1 (i.e., the patentee should get the exclusive power of the technology) with probability α. The probability distribution of a^P is affected by the patentee's as well as the examiner's efforts, while that of a^C is affected by the litigation inputs of the patentee and potential infringer or patent challenger in court. I can then use this framework to re-examine the "rational ignorance" hypothesis and consider the optimal division of labor between the patent office and private challengers to improve the performance of the patent system (Lemley, 2001; Chiou, 2008).

Appendix

A Proofs

□ Lemma 1

Proof. Fix $\alpha \in (0,1)$ and suppose that $\delta(\hat{\alpha})$ is strictly convex in $\hat{\alpha}$. By strictly convexity, for any $r > 1/2$, $\Delta(r) > \Delta(1/2)$. Consider any r and $\tilde{r}$ such that $1 \geq r > \tilde{r} > 1/2$. Denote $q \equiv \alpha r + (1-\alpha)(1-r)$, $\hat{\alpha}^1 \equiv \alpha r/q$, and $\hat{\alpha}^0 \equiv \alpha(1-r)/(1-q)$. Similarly, denote $\tilde{q} \equiv \alpha\tilde{r} + (1-\alpha)(1-\tilde{r})$, $\tilde{\alpha}^1 \equiv \hat{\alpha}^1(\tilde{r}) = \alpha\tilde{r}/\tilde{q}$, and $\tilde{\alpha}^0 \equiv \hat{\alpha}^0(\tilde{r}) = \alpha(1-\tilde{r})/(1-\tilde{q})$. Because $r > \tilde{r}$, $\hat{\alpha}^1 > \tilde{\alpha}^1 > \tilde{\alpha}^0 > \hat{\alpha}^0$.

To show that $\Delta(r) = q\delta(\hat{\alpha}^1) + (1-q)\delta(\hat{\alpha}^0) > \Delta(\tilde{r}) = \tilde{q}\delta(\tilde{\alpha}^1) + (1-\tilde{q})\delta(\tilde{\alpha}^0)$, define

$$\tilde{\delta}(\hat{\alpha}) = \begin{cases} \delta(\hat{\alpha}) & \text{if} \quad \hat{\alpha} \in [0, \tilde{\alpha}^0) \cup (\tilde{\alpha}^1, 1], \\ \frac{\hat{\alpha}-\tilde{\alpha}^0}{\tilde{\alpha}^1-\tilde{\alpha}^0}\delta(\tilde{\alpha}^1) + \frac{\tilde{\alpha}^1-\hat{\alpha}}{\tilde{\alpha}^1-\tilde{\alpha}^0}\delta(\tilde{\alpha}^0) & \text{if} \quad \hat{\alpha} \in [\tilde{\alpha}^0, \tilde{\alpha}^1]. \end{cases} \tag{A.1}$$

That is, on the space of $(\hat{\alpha}, \delta(\hat{\alpha}))$, $\tilde{\delta}$ is constructed by replacing δ with the convex combination of $(\tilde{\alpha}^1, \delta(\tilde{\alpha}^1))$ and $(\tilde{\alpha}^0, \delta(\tilde{\alpha}^0))$ for $\hat{\alpha} \in [\tilde{\alpha}^0, \tilde{\alpha}^1]$; and keep $\tilde{\delta} = \delta$ otherwise. By the way it is constructed, $\tilde{\delta}$ is convex, though not strictly convex due to the linear part of $\hat{\alpha} \in [\tilde{\alpha}^0, \tilde{\alpha}^1]$. By convexity,

$$\Delta(r) = q\delta(\hat{\alpha}^1) + (1-q)\delta(\hat{\alpha}^0) = q\tilde{\delta}(\hat{\alpha}^1) + (1-q)\tilde{\delta}(\hat{\alpha}^0) \geq \tilde{\delta}(q\hat{\alpha}^1 + (1-q)\hat{\alpha}^0) = \tilde{\delta}(\alpha); \tag{A.2}$$

and by convex combination,

$$\Delta(\tilde{r}) = \tilde{q}\delta(\tilde{\alpha}^1) + (1-\tilde{q})\delta(\tilde{\alpha}^0) = \tilde{q}\tilde{\delta}(\tilde{\alpha}^1) + (1-\tilde{q})\tilde{\delta}(\tilde{\alpha}^0) = \tilde{\delta}(\tilde{q}\tilde{\alpha}^1 + (1-\tilde{q})\tilde{\alpha}^0) = \tilde{\delta}(\alpha). \tag{A.3}$$

Thus $\Delta(r) \geq \Delta(\tilde{r})$. To show strict inequality, because δ is strictly convex in $\hat{\alpha}$,

$$\delta(\tilde{\alpha}^1) > \delta(\tilde{\alpha}^0) + \frac{d\delta}{d\hat{\alpha}}\big|_{\tilde{\alpha}^0} \cdot (\tilde{\alpha}^1 - \tilde{\alpha}^0) \text{ and } \delta(\tilde{\alpha}^0) > \delta(\tilde{\alpha}^1) + \frac{d\delta}{d\hat{\alpha}}\big|_{\tilde{\alpha}^1} \cdot (\tilde{\alpha}^0 - \tilde{\alpha}^1), \tag{A.4}$$

or, equivalently,

$$\frac{d\delta}{d\hat{\alpha}}\big|_{\tilde{\alpha}^0} < \gamma \equiv \frac{\delta(\tilde{\alpha}^1) - \delta(\tilde{\alpha}^0)}{\tilde{\alpha}^1 - \tilde{\alpha}^0} < \frac{d\delta}{d\hat{\alpha}}\big|_{\tilde{\alpha}^1}. \tag{A.5}$$

The slope of the line connecting $(\tilde{\alpha}^0, \delta(\tilde{\alpha}^0))$ and $(\tilde{\alpha}^1, \delta(\tilde{\alpha}^1))$, γ, lies between the slope of δ when evaluated at $\tilde{\alpha}^0$ and $\tilde{\alpha}^1$. Extend the line to the interval $[\hat{\alpha}^0, \hat{\alpha}^1]$, that is, let $\tilde{\delta}(\hat{\alpha}^1) = \delta(\tilde{\alpha}^1) + \gamma(\hat{\alpha}^1 - \tilde{\alpha}^1)$ and $\tilde{\delta}(\hat{\alpha}^0) = \delta(\tilde{\alpha}^0) - \gamma(\tilde{\alpha}^0 - \hat{\alpha}^0)$. By condition (A.5) and the strict convexity of δ,

$$\tilde{\delta}(\hat{\alpha}^1) < \delta(\tilde{\alpha}^1) + \frac{d\delta}{d\hat{\alpha}}\big|_{\tilde{\alpha}^1} \cdot (\hat{\alpha}^1 - \tilde{\alpha}^1) < \delta(\hat{\alpha}^1), \tag{A.6}$$

and

$$\tilde{\delta}(\hat{\alpha}^0) < \delta(\tilde{\alpha}^0) - \frac{d\delta}{d\hat{\alpha}}\big|_{\tilde{\alpha}^0} \cdot (\tilde{\alpha}^0 - \hat{\alpha}^0) < \delta(\hat{\alpha}^0). \tag{A.7}$$

Therefore,

$$\Delta(r) = q\delta(\hat{\alpha}^1) + (1-q)\delta(\hat{\alpha}^0) > q\tilde{\delta}(\hat{\alpha}^1) + (1-q)\tilde{\delta}(\hat{\alpha}^0) > \tilde{\delta}(q\hat{\alpha}^1 + (1-q)\hat{\alpha}^0) = \tilde{\delta}(\alpha) = \Delta(\tilde{r}). \tag{A.8}$$

By the same reasoning, when δ is strictly concave in $\hat{\alpha}$, then Δ is strictly decreasing in r *Q.E.D.*

☐ Example 1:

Proof. Given quadratic investment cost, it is straightforward to derive $\hat{\alpha}$ and $\hat{v}$, and so

$$\begin{aligned} V(r;\alpha) &= \left\{ q\left[\frac{(1-\alpha)(1-r)}{q}\right]^2 + (1-q)\left[\frac{(1-\alpha)r}{1-q}\right]^2 \right\} v_{11}^2 \frac{K}{2} \\ &= \left[\frac{(1-r)^2}{q} + \frac{r^2}{1-q}\right](1-\alpha)^2 v_{11}^2 \frac{K}{2} = \Psi(1-\alpha)^2 v_{11}^2 \frac{K}{2}. \end{aligned} \tag{A.9}$$

For all $r > 1/2$ and $\alpha \in (0,1)$,

$$\frac{\partial \Psi}{\partial r} = \frac{rq - (1-r)(1-q)}{q^2(1-q)^2} \left\{ 2q(1-q) + [rq + (1-r)(1-q)] \frac{\partial q}{\partial r} \right\} = \frac{\alpha^2[r - (1-r)]}{q^2(1-q)^2} > 0. \tag{A.10}$$

A higher refinement effort encourages technology adoption.

It is also straightforward to get the patentee's post adoption payoff. Similarly, for all $r > 1/2$ and $\alpha \in (0,1)$,

$$\begin{aligned} \frac{\partial \Lambda}{\partial r} &= \frac{1}{q^2(1-q)^2} \left[(1-r-r)q(1-q) - r(1-r)(1-q-q) \frac{\partial q}{\partial r} \right] \\ &= -(1-\alpha) \frac{\alpha[r-(1-r)]}{q^2(1-q)^2} < 0, \end{aligned} \tag{A.11}$$

a higher refinement effort reduces the patentee's post-adoption payoff. The first-older condition to determine the optimal r is

$$\begin{aligned} \frac{\partial U}{\partial r} &= \alpha(1-\alpha)v_{11}^2 KF(V) \left\{ \frac{F'}{F}(V) \frac{V}{\Psi} \Lambda \frac{\partial \Psi}{\partial r} + \frac{\partial \Lambda}{\partial r} \right\} - c_R' \\ &= \alpha^2(1-\alpha)^2 v_{11}^2 KF(V) \frac{[r-(1-r)]}{q^2(1-q)^2} \left\{ \frac{F'}{F}(V) V \frac{\alpha \Lambda}{(1-\alpha)\Psi} - 1 \right\} - c_R'. \end{aligned} \tag{A.12}$$

The necessary and sufficient condition for the patentee to exert $r > \underline{r}$ is

$$\frac{F'}{F}(V) V \frac{\alpha \Lambda}{(1-\alpha)\Psi} > 1 \quad \Rightarrow \quad \frac{F'}{F}(V) V > \frac{(1-\alpha)\Psi}{\alpha \Lambda}, \tag{A.13}$$

when evaluating $r = \underline{r}$. To show that the right-hand side of the condition is decreasing in α:

$$\frac{(1-\alpha)\Psi}{\alpha \Lambda} = \frac{(1-\alpha)[(1-r)^2(1-q) + r^2 q]}{\alpha r(1-r)}, \tag{A.14}$$

and so

$$\begin{aligned} \frac{\partial}{\partial \alpha} \left(\frac{(1-\alpha)\Psi}{\alpha \Lambda} \right) = & \frac{-1}{\alpha^2 r(1-r)} \Big\{ \alpha \big[(1-r)^2(1-q) + r^2 q + (1-\alpha)(1-r)^2(2r-1) \\ & - (1-\alpha) r^2 (2r-1) \big] + (1-\alpha) \left[(1-r)^2(1-q) + r^2 q \right] \Big\}. \end{aligned} \tag{A.15}$$

The numerator, by the definitions of q and $1-q$ and by expressing

$$\alpha r^3 = \alpha^2 r^3 + \alpha(1-\alpha) r^3 \;\text{ and }\; \alpha(1-r)^3 = \alpha^2(1-r)^3 + \alpha(1-\alpha)(1-r)^3, \tag{A.16}$$

is:

$$
\begin{aligned}
&\alpha(1-\alpha)r^2(1-r)+\alpha(1-\alpha)r(1-r)^2-\alpha^2(1-r)^3-(1-\alpha)r(1-r)^2-\alpha^2 r^3 \\
&-(1-\alpha)r^2(1-r)-2\alpha(1-\alpha)r(1-r) \\
=&-\alpha(1-\alpha)r(1-r)-(1-\alpha)r(1-r)-\alpha^2[r^3+(1-r)^3]<0.
\end{aligned}
\tag{A.17}
$$

Q.E.D.

□ Proposition 4

Proof. Consider soft information. When the patentee has type $\hat{\alpha}^i$, $i \in \{0,1\}$, and the developer believes that her type is $\tilde{\alpha}$, given developer's investment, the patentee's payoff is $\hat{u}(\hat{e}(\tilde{\alpha});\hat{\alpha}^i) = u_{10} + \hat{e}(\tilde{\alpha})D(\hat{\alpha}^i)$. By $\hat{\alpha}^1 > \hat{\alpha}^0$ and $\pi > u_{11}$, $D(\hat{\alpha}^1) > D(\hat{\alpha}^0)$, but $D(\hat{\alpha}^i) \gtreqless 0$, $i \in \{0,1\}$. In a separating equilibrium, different types of patentee send different reports and the developer learns the true type. Since there is no restriction on the message space, one type of the patentee can perfectly mimic the other type. The incentive constraints are

$$
\hat{u}(\hat{e}(\hat{\alpha}^1);\hat{\alpha}^1) \geq \hat{u}(\hat{e}(\hat{\alpha}^0);\hat{\alpha}^1) \quad \Rightarrow \quad \left[\hat{e}(\hat{\alpha}^1)-\hat{e}(\hat{\alpha}^0)\right] D(\hat{\alpha}^1) \geq 0, \tag{A.18}
$$

and

$$
\hat{u}(\hat{e}(\hat{\alpha}^0);\hat{\alpha}^0) \geq \hat{u}(\hat{e}(\hat{\alpha}^1);\hat{\alpha}^0) \quad \Rightarrow \quad \left[\hat{e}(\hat{\alpha}^0)-\hat{e}(\hat{\alpha}^1)\right] D(\hat{\alpha}^0) \geq 0. \tag{A.19}
$$

The two conditions require that $\left[\hat{e}(\hat{\alpha}^1)-\hat{e}(\hat{\alpha}^0)\right] \cdot \left[D(\hat{\alpha}^1)-D(\hat{\alpha}^0)\right] \geq 0$. But this is impossible by $D(\hat{\alpha}^1) > D(\hat{\alpha}^0)$ and $\hat{e}(\hat{\alpha}^1) < \hat{e}(\hat{\alpha}^0)$. There is no separating equilibrium.

In a pooling equilibrium, along the equilibrium path both types of patentee send the same report; the developer's belief remains at the *ex ante* level, $\alpha = q\hat{\alpha}^1 + (-q)\hat{\alpha}^0$, and exerts investment $\hat{e}(\alpha) \in (\hat{e}(\hat{\alpha}^1), \hat{e}(\hat{\alpha}^0))$. Suppose that the developer holds belief $\tilde{\alpha}$ when observing the off-path report, i.e., the report that should not be sent in equilibrium. The patentee's incentive constraint is $[\hat{e}(\alpha)-\hat{e}(\tilde{\alpha})]D(\hat{\alpha}^i)$, $i \in \{0,1\}$. The incentive constraint holds when the developer holds "passive" belief, i.e., he thinks that both types of patentee have the same incentive to deviate, and so $\tilde{\alpha} = \alpha$. Alternatively, if $D(\hat{\alpha}^i) < 0$ for both $i \in \{0,1\}$ (as in the case of $\pi = u_{10}$), then the incentive constraint holds with $\tilde{\alpha} = \hat{\alpha}^0$; and if $D(\hat{\alpha}^i) > 0$ for both $i \in \{0,1\}$ (as in the case of $u_{10} = u_{11} = 0$), then it holds with $\tilde{\alpha} = \hat{\alpha}^1$. When the pooling equilibrium prevails for all r, given adoption, the patentee's expected payoff is $q\hat{u}(\hat{e}(\alpha);\hat{\alpha}^1) + (1-q)\hat{u}(\hat{e}(\alpha);\hat{\alpha}^0) = \hat{u}(\hat{e}(\alpha);\alpha)$.

Since refinement affects neither the post-adoption payoff nor the developer's incentive to adopt, the ruler will not exert any refinement effort.

To show that there is always a separating equilibrium under hard information, suppose that one type of patentee, say, $\hat{\alpha}^1$, reveals her information. Since the other type $\hat{\alpha}^0$ cannot mimic by submitting the same information, and since the developer knows that the patentee always knows something, i.e., there is no type $\emptyset$ such that the patentee's own assessment about the patent power remains at the *ex ante* level, whichever the message the type $\hat{\alpha}^0$ sends, the developer can perfectly figure out her true type. There is no feasible deviation from the truth-telling equilibrium.

In a pooling equilibrium, the two types of patentee must send the same message $\emptyset$, and the developer's equilibrium belief remains at the *ex ante* level α. Since the only feasible deviation fully reveals the patentee's type, the incentive constraints are, for both $i \in \{0, 1\}$,

$$\hat{u}(\hat{e}(\alpha); \hat{\alpha}^i) \geq \hat{u}(\hat{e}(\hat{\alpha}^i); \hat{\alpha}^i) \quad \Rightarrow \quad \left[\hat{e}(\alpha) - \hat{e}(\hat{\alpha}^i)\right] D(\hat{\alpha}^i) \geq 0. \tag{A.20}$$

By $\hat{e}(\hat{\alpha}^0) > \hat{e}(\alpha) > \hat{e}(\hat{\alpha}^1)$, the two constraints require that $D(\hat{\alpha}^1) \geq 0 \geq D(\hat{\alpha}^0)$. Without entirely eliminating the uncertainty, i.e., when $r < 1$ and so $\hat{\alpha}^1 < 1$ as well as $\hat{\alpha}^0 > 0$, this is not possible when the patentee either wants to monopolize the technology use or is a pure licensor. In the former case, $\pi = u_{10}$, $D^(\hat{\alpha}^i) < 0$ for both $i \in \{0, 1\}$; and in the latter case, $\pi = v_{11}$ and $u_{11} = u_{10} = 0$, $D(\hat{\alpha}^i) > 0$ for both $i \in \{0, 1\}$.

To have a pooling equilibrium, it is necessary to have $\pi > u_{10} > u_{11}$ and a sufficiently high refinement effort r such that $\hat{\alpha}^1$ is large while $\hat{\alpha}^0$ is small enough. In a pooling equilibrium, the developer fixes his investment level at $\hat{e}(\alpha)$, according to the *ex ante* belief α, and so his adoption probability is $F(V(\alpha, r = 1/2))$, despite the patentee's high effort. The patentee's post-adoption payoff becomes $\hat{u}(\alpha)$. When $\hat{u}(\alpha)$ is strictly concave in α, this payoff is higher than the expected payoff under the separating equilibrium, $q\hat{u}(\hat{\alpha}^1) + (1 - q)\hat{u}(\hat{\alpha}^0)$. Suppose that the pooling equilibrium prevails when it exists. The patentee's refinement decision then is shaped by two regimes. When r is small enough such that there is only the separating equilibrium, previous analysis holds. And once r is large enough such to reach the pooling equilibrium, the patentee has no incentive to further raise refinement effort. The patentee's optimal refinement level then is determined by comparing the highest payoff in the two regimes. Note that, when deciding whether to reach the pooling equilibrium, the patentee faces the same trade-off, but the impact of r goes in the *opposite* direction as before. A sufficiently high refinement effort that induces pooling equilibrium will *reduce* the developer's adoption incentives, but *raise* the patentee's post-adoption payoff. *Q.E.D.*

□ Proposition 5

Proof. For the second-order effect of patent power on technology penetration,

$$\frac{d^2}{d\hat{\alpha}^2}F(\hat{v})\hat{e} = F''(\hat{v})\hat{e}\left(\frac{d\hat{v}}{d\hat{\alpha}}\right)^2 + 2F'(\hat{v})\frac{d\hat{e}}{d\hat{\alpha}}\frac{d\hat{v}}{d\hat{\alpha}} + F'(\hat{v})\hat{e}\frac{d^2\hat{v}}{d\hat{\alpha}^2} + F(\hat{v})\frac{d^2\hat{e}}{d\hat{\alpha}^2}. \tag{A.21}$$

Because $d\hat{e}/d\hat{\alpha}$ and $d\hat{v}/d\hat{\alpha}$ have the same sign, the penetration probability is convex in $\hat{\alpha}$ if the sign of $d^2F(\hat{v})\hat{e}/d\hat{\alpha}^2$ is not dominated by F'' and $d^2\hat{e}/d\hat{\alpha}^2$. It is satisfied under uniform distribution and quadratic investment cost, where $F'' = d^2\hat{e}/d\hat{\alpha}^2 = 0$.

For the patentee, when $\pi = u_{10}$,

$$\frac{d\hat{u}^L}{d\hat{\alpha}} = (u_{10} - u_{11})\left[F(\hat{v})\hat{e} - (1-\hat{\alpha})\frac{d}{d\hat{\alpha}}F(\hat{v})\hat{e}\right] > 0, \text{ and} \tag{A.22}$$

$$\frac{d^2\hat{u}^L}{d\hat{\alpha}^2} = (u_{10} - u_{11})\left[2\frac{d}{d\hat{\alpha}}F(\hat{v})\hat{e} - (1-\hat{\alpha})\frac{d^2}{d\hat{\alpha}^2}F(\hat{v})\hat{e}\right] < 0. \tag{A.23}$$

When $u_{11} = u_{10} = 0$, $\hat{u}^L = F(\hat{v})\hat{e}\hat{\alpha}v_{11}$, and

$$\frac{d\hat{u}^L}{d\hat{\alpha}} = v_{11}\left[F(\hat{v})\hat{e} + \hat{\alpha}\frac{d}{d\hat{\alpha}}F(\hat{v})\hat{e}\right] \text{ and } \frac{d^2\hat{u}^L}{d\hat{\alpha}^2} = v_{11}\left[2\frac{d}{d\hat{\alpha}}F(\hat{v})\hat{e} + \hat{\alpha}\frac{d^2}{d\hat{\alpha}^2}F(\hat{v})\hat{e}\right]. \tag{A.24}$$

If $F(\hat{v}) = 1$ for all $\hat{v} \geq 0$, then

$$\frac{d^2\hat{u}^L}{d\hat{\alpha}^2} = v_{11}\left(2\frac{d\hat{e}}{d\hat{\alpha}} + \hat{\alpha}\frac{d^2\hat{e}}{d\hat{\alpha}^2}\right) = v_{11}\left[2\frac{d\hat{e}}{d\hat{\alpha}} + \hat{\alpha}\frac{v_{11}c_E'''}{(c_E'')^2}\frac{d\hat{e}}{d\hat{\alpha}}\right]. \tag{A.25}$$

By $c_E''' \geq 0$, $\hat{u}^L$ is globally concave. Suppose that technology adoption is not guaranteed, and consider uniform distribution and quadratic investment cost. Given these forms, the optimal $\hat{e} = (1-\hat{\alpha})Kv_{11}$ and $\hat{v} = (1-\hat{\alpha})^2 v_{11}^2(K/2)$, and so $\hat{u}^L = vv_{11}^4\hat{\alpha}(1-\hat{\alpha})^3(K/2)$. *Q.E.D.*

□ Proposition 6

Proof. Suppose that reverse payment is feasible. When the patentee offers an *interim* license, given the patent power $\hat{\alpha}$, the developer has an outside option value $\hat{v}(\hat{\alpha})$. An *interim* license has to leave the developer at least an expected payoff $\hat{v}(\hat{\alpha})$. Since $\pi = u_{10} \geq u_{11} + v_{11}$, the upper bound of the patentee's payoff is $\pi - \hat{v}(\hat{\alpha}) = u_{10} - \hat{v}(\hat{\alpha})$.

This payoff can be achieved by paying the developer his outside option value and ask him not to make any investment.

Another way to see this is to consider the most general license (x, f^0, f^1, f^2), where x is the probability that the developer enters the market, given that his project succeeds, and f^0 is the payment from the patentee to the developer when the latter's project fails, f^1 the payment when the project succeeds but the patentee asks the developer not to enter, and f^2 the payment when the project succeeds and the developer enters. By limited liability constraint for both parties, f^0 and $f^1 \in [0, u_{10}]$ while $f^2 \in [-v_{11}, u_{11}]$.

The patentee's optimization problem is

$$\begin{aligned}
&\max \quad (1-\hat{e}x)u_{10} + \hat{e}xu_{11} - [(1-\hat{e})f^0 + \hat{e}xf^2 + \hat{e}(1-x)f^1] \\
&\quad s.t. \;\; (IC): \;\; \hat{e} = \arg\max_{e} \;\; (1-e)f^0 + e[x(v_{11}+f^2) + (1-x)f^1] - c_E(e) \qquad \text{(A.26)} \\
&\qquad\quad (IR): \;\; (1-\hat{e})f^0 + \hat{e}[x(v_{11}+f^2) + (1-x)f^1] - c_E(\hat{e}) \geq \hat{v}(\hat{\alpha}).
\end{aligned}$$

It is straightforward to show that the developer's participation constraint must be binding. This in turn implies that the optimal investment induced by the optimal *interim* license is $\hat{e} = 0$, for $u_{10} \geq u_{11} + v_{11}$ and a higher $\hat{e}$ and thus $c_E(\hat{e})$ makes the (IR) constraint more stringent. In other words, the patentee should just pay the developer $f^0 = \hat{v}(\hat{\alpha})$ so that no investment will be made.

At the refinement stage, the patentee's expected payoff is thus $[1 - F(V)]u_{10} + F(V)(u_{10} - V) - c_R = u_{10} - F(V)V - c_R$, for, given adoption, the expected payment to the developer is $q\hat{v}(\hat{\alpha}^1) + (1-q)\hat{v}(\hat{\alpha}^0) = V$. Since a higher refinement will increase the payment V and the adoption probability $F(V)$, the patentee will optimally choose no refinement and leave $r = \underline{r}$.

When the patentee offers an *ex ante* license, by similar logic the patentee will want to pay the developer not to enter the market. If the license is offered after the refinement decision, then the patentee will choose the minimal possible refinement level, $r = \underline{r}$, in order to minimize the expected licensing payment $F(V)V$. And if the license is offered before the refinement decision, then again the developer's outside option value is $F(V)V$. After paying the developer for a promise not to adopt the technology, the patentee does not have any incentive to make any refinement. If the patentee cannot commit to the refinement effort she will incur later, then the *ex ante* payment to the developer is negotiated with the belief that the patentee will exert $r = \underline{r}$ later. But even if the patentee can commit to r, she will want to commit to the smallest possible level in order to lower $F(V)V$.

Suppose that reverse payment is not feasible. Either the patentee will not make any licensing offer, or, in case where a license is offered, the developer pays the patentee when his project succeeds and he enters the market. In the previous construction, when the patentee can offer an *interim* license, forbidding reverse payment requires that $f^0 = f^1 = 0$ and $f^2 \in [-v_{11}, 0]$. Redefine $f^2 = -lv_{11}$, with $l \in [0,1]$, i.e., f^2 is the royalty rate paid by the developer. Then the developer's (IR) constraint becomes $x(1-l) \geq (1-\hat{\alpha})$, which should be binding at optimum. The patentee's expected payoff, given a biding participation constraint, is $u_{10} - \hat{e}x(u_{10} - u_{11} - v_{11}) - \hat{e}(1-\hat{\alpha})v_{11}$, where $\hat{e}$ depends only on $1-\hat{\alpha}$ (but not on x and l). The optimal contract is $x^* = 1-\hat{\alpha}$ and $l^* = 0$. That is, even when successful the developer is allowed to enter only with probability $1-\hat{\alpha}$ and no royalty is paid. The optimal *interim* license fully mimics the outcome of the case where no such licensing opportunity is available. In other words, the patentee may just forgo *interim* licensing. The no refinement result then follows previous discussion.

Similarly, the patentee will just forgo *ex ante* licensing, and thus the no refinement result is not affected by this licensing opportunity. *Q.E.D.*

□ **Proposition 7**

Proof. Let us consider three cases according to the level of α. When $\hat{\alpha}^0(\underline{r}) \geq l^*$, i.e., the invention quality α is high enough so that at $r = \underline{r}$, the patent power is strong enough to support the optimal royalty l^* even when the patent office issues an unfavorable decision $a^P = 0$. (A necessary condition is $\alpha \geq l^*$.) The patentee's expected payoff from refinement is[30]

$$U^{in} = \begin{cases} F(\hat{v}^*)\hat{u}^* - c_R, & \text{if } \quad l^* \leq \hat{\alpha}^0 < \hat{\alpha}^1, \\ F(V^{in})u^{in}_{\tau} - c_R, & \text{if } \quad \hat{\alpha}^0 < l^* < \hat{\alpha}^1. \end{cases} \tag{A.27}$$

When the refinement effort is so low that $l^* \leq \hat{\alpha}^0 \leq \hat{\alpha}^0(\underline{r})$, the patentee can charge l^* regardless of the patent office's decision. And if the patentee chooses r large enough such that $\hat{\alpha}^0 < l^* < \hat{\alpha}^1$, then l^* is feasible only when the patent office issues a favorable decision to the patentee, $a^P = 1$.

To find the optimal r, first notice that when $l^* \leq \hat{\alpha}^0$, the revenue is not affected by

[30]Because at $\underline{r} > 1/2$, $\hat{\alpha}^1(\underline{r}) > \hat{\alpha}^0(\underline{r}) \geq l^*$, further increase r will cause $\hat{\alpha}^1 > l^*$.

r, and so the optimal $r = \underline{r}$ over this range. It follows that if $\partial U^{in\cdot}/\partial r \leq 0$ as $\hat{\alpha}^0 \to l^{*-}$:

$$\begin{aligned}
\left.\frac{\partial U^{in}}{\partial r}\right|_{\hat{\alpha}^0 \to l^{*-}} =& F'\left[q\hat{u}^* + (1-q)\hat{u}(\hat{\alpha}^0)\right]\left[(\hat{v}^* - \hat{v}(\hat{\alpha}^0))\frac{\partial q}{\partial r} + (1-q)\frac{\partial \hat{v}(\hat{\alpha}^0)}{\partial \hat{\alpha}^0}\frac{\partial \hat{\alpha}^0}{\partial r}\right] \\
&+ F\left[(\hat{u}^* - \hat{u}(\hat{\alpha}^0))\frac{\partial q}{\partial r} + (1-q)\frac{\partial \hat{u}(\hat{\alpha}^0)}{\partial \hat{\alpha}^0}\frac{\partial \hat{\alpha}^0}{\partial r}\right] - c_R' \qquad \text{(A.28)} \\
=& F'(\hat{v}^*)\hat{u}^*(1-q)\left.\frac{\partial \hat{v}(\hat{\alpha}^0)}{\partial \hat{\alpha}^0}\right|_{\hat{\alpha}^0 \to l^{*-}}\frac{\partial \hat{\alpha}^0}{\partial r} - c_R' \leq 0,
\end{aligned}$$

then under *interim* licensing the patentee will not exert any refinement effort, the optimal $r = \underline{r}$.

Condition (29) is a sufficient, but not necessary, condition to reach no refinement from the patentee. If it fails, I need to compare

$$F(\hat{v}^*)\hat{u}^* \gtrless \max_r F(V^{in})u_\tau^{in} - c_R \qquad \text{(A.29)}$$

to determine the optimal r. The optimal r then exhibits a "bang-bang" property: It is either $\underline{r}$ or "jumps" to some level large enough such that $\hat{\alpha}^0 < l^* < \hat{\alpha}^1$.

Consider when condition (29) is more likely to hold. A higher α will require a larger r to reach the same level of $\hat{\alpha}^0$, i.e.,

$$\frac{\partial \hat{\alpha}^0}{\partial \alpha}d\alpha + \frac{\partial \hat{\alpha}^0}{\partial r}dr = 0 \;\Rightarrow\; \frac{dr}{d\alpha} = -\frac{\partial \hat{\alpha}^0/\partial \alpha}{\partial \hat{\alpha}^0/\partial r} = \frac{r(1-r)}{\alpha(1-\alpha)} > 0. \qquad \text{(A.30)}$$

On the revenue side, when evaluating at $\hat{\alpha}^0 = l^*$,

$$-(1-q)\frac{\partial \hat{\alpha}^0}{\partial r} = \frac{\alpha(1-\alpha)}{1-q} = \hat{\alpha}^0\frac{1-\alpha}{1-r} = l^*\frac{1-\alpha}{1-r}, \qquad \text{(A.31)}$$

thus to keep $\hat{\alpha}^0 = l^*$,

$$\frac{\partial}{\partial \alpha}(\frac{1-\alpha}{1-r})d\alpha + \frac{\partial}{\partial r}(\frac{1-\alpha}{1-r})dr = \frac{-1}{1-r}\left(1 + \frac{1-\alpha}{1-r}\frac{\partial \hat{\alpha}^0/\partial \alpha}{\partial \hat{\alpha}^0/\partial r}\right)d\alpha = \frac{-d\alpha}{1-r}\left(1 - \frac{r}{\alpha}\right). \qquad \text{(A.32)}$$

And from $\hat{\alpha}^0 = l^*$, I can find $\alpha = rl^*/[rl^* + (1-r)(1-l^*)]$, and therefore $\alpha \geq r$ if and only if $l^* \geq 1/2$ (with quadratic investment cost, $l^* = 1/2$). I can conclude that when $l^* \geq 1/2$, condition (29) is more likely to hold for high values of α.

Next, when α is in an intermediate range such that $\hat{\alpha}^0(\underline{r}) < l^* \leq \hat{\alpha}^1(\underline{r})$, then for all $r \geq \underline{r}$, the patentee's payoff is

$$U^{in} = F(V^{in})u_\tau^{in} - c_R, \qquad \text{(A.33)}$$

for a higher r will still cause l^* to stay in the open interval $(\hat{\alpha}^0, \hat{\alpha}^1)$. The first-order conditio to determine the optimal refinement effort is

$$\begin{aligned}\frac{\partial U^{in}}{\partial r} =& F' \cdot \left[q\hat{u}^* + (1-q)\hat{u}(\hat{\alpha}^0)\right] \left[(\hat{v}^* - \hat{v}(\hat{\alpha}^0))\frac{\partial q}{\partial r} + (1-q)\frac{\partial \hat{v}(\hat{\alpha}^0)}{\partial \hat{\alpha}^0}\frac{\partial \hat{\alpha}^0}{\partial r}\right] \\ &+ F \cdot \left[(\hat{u}^* - \hat{u}(\hat{\alpha}^0))\frac{\partial q}{\partial r} + (1-q)\frac{\partial \hat{u}(\hat{\alpha}^0)}{\partial \hat{\alpha}^0}\frac{\partial \hat{\alpha}^0}{\partial r}\right] - c_R'.\end{aligned} \tag{A.34}$$

Comparing with the case where only *ex post* licensing is allowed, the opportunity of *interim* licensing raises both the developer's and patentee's expected payoffs upon adoption. It also changes how these payoffs will respond to the refinement effort,

$$\frac{\partial V^{in}}{\partial r} - \frac{\partial V}{\partial r} = \left[\hat{v}^* - \hat{v}(\hat{\alpha}^1)\right]\frac{\partial q}{\partial r} - q\frac{\partial \hat{v}(\hat{\alpha}^1)}{\partial \hat{\alpha}^1}\frac{\partial \hat{\alpha}^1}{\partial r}, \tag{A.35}$$

$$\frac{\partial u_\tau^{in}}{\partial r} - \frac{\partial u_\tau}{\partial r} = \left[\hat{u}^* - \hat{u}(\hat{\alpha}^1)\right]\frac{\partial q}{\partial r} - q\frac{\partial \hat{u}(\hat{\alpha}^1)}{\partial \hat{\alpha}^1}\frac{\partial \hat{\alpha}^1}{\partial r}. \tag{A.36}$$

When $\alpha \geq 1/2$ and so $\partial q/\partial r \geq 0$, *interim* licensing will make the developer's payoff more responsive to the refinement effort, $\partial V^{in}/\partial r > \partial V/\partial r$, and reduce the negative impact of refinement effort on the patentee's licensing income, $\partial u_\tau^{in}/\partial r > \partial u_\tau/\partial r$. In fact, it may even happen that the refinement effort will *increase* licensing income, $\partial u_\tau^{in}/\partial r > 0$. To see this, consider the case of quadratic investment cost, under which the optimal royalty is $l^* = 1/2$ and so $\hat{u} = Kv_{11}^2/4$. The expected licensing payment is

$$u_\tau^{in} = \left[\frac{q}{4} + (1-q)\hat{\alpha}^0(1-\hat{\alpha}^0)\right]Kv_{11}^2 = \left[\frac{q}{4} + \alpha(1-\alpha)\frac{r(1-r)}{1-q}\right]Kv_{11}^2. \tag{A.37}$$

The impact of r on u_τ^{in} is proportional to

$$\frac{\partial}{\partial r}\left[\frac{q}{4} + \alpha(1-\alpha)\frac{r(1-r)}{1-q}\right] = \frac{\alpha-(1-\alpha)}{4} + \frac{\alpha(1-\alpha)}{(1-q)^2}[(1-r-r)(1-q) + r(1-r)(\alpha-(1-\alpha))], \tag{A.38}$$

which is positive when $\alpha > 1/2$ and $r \to 1/2$ (assuming $\underline{r}$ is sufficiently close to 1/2). In this case, the adoption *v.s.* revenue tradeoff will disappear, and the patentee will have higher incentives to engage in refinement.

Lastly, when α is small enough so that $\hat{\alpha}^1(\underline{r}) < l^*$, the patentee's expected payoff from refinement is

$$U^{in.} = \begin{cases} F(V)u_\tau - c_R, & \text{if} \quad l^* > \hat{\alpha}^1 > \hat{\alpha}^0, \\ F(V^{in})u_\tau^{in} - c_R, & \text{if} \quad \hat{\alpha}^0 < l^* \leq \hat{\alpha}^1. \end{cases} \tag{A.39}$$

With low refinement *interim* licensing is irrelevant regardless of the patent office's decision. And only r is large enough so that $\hat{\alpha}^0 < l^* \leq \hat{\alpha}^1$ could the patentee offer l^* after a decision $a^P = 1$.

The same as in the high α case, I can check the first-order condition at the boundary between the two regimes to gain some information about the optimal refinement effort. Here it should be evaluated at $\hat{\alpha}^1 \to l^{*+}$:

$$\begin{aligned}\left.\frac{\partial U^{in}}{\partial r}\right|_{\hat{\alpha}^1 \to l^{*+}} =& F' \cdot \left[q\hat{u}^* + (1-q)\hat{u}(\hat{\alpha}^0)\right]\left[(\hat{v}^* - \hat{v}(\hat{\alpha}^0))\frac{\partial q}{\partial r} + (1-q)\frac{\partial \hat{v}(\hat{\alpha}^0)}{\partial \hat{\alpha}^0}\frac{\partial \hat{\alpha}^0}{\partial r}\right] \\ &+ F \cdot \left[(\hat{u}^* - \hat{u}(\hat{\alpha}^0))\frac{\partial q}{\partial r} + (1-q)\frac{\partial \hat{u}(\hat{\alpha}^0)}{\partial \hat{\alpha}^0}\frac{\partial \hat{\alpha}^0}{\partial r}\right] - c_R'.\end{aligned} \tag{A.40}$$

If this term is (weakly) negative, then the optimal refinement effort falls into the lower end. Furthermore, comparing the first-order conditions with and without *interim* licensing at $\hat{\alpha}^1 \to l^{*+}$ shows that

$$\left.\frac{\partial U^{in}}{\partial r}\right|_{\hat{\alpha} \to l^{*+}} - \left.\frac{\partial U}{\partial r}\right|_{\hat{\alpha} = l^*} = -F' \cdot \left[q\hat{u}^* + (1-q)\hat{u}(\hat{\alpha}^0)\right] q \left.\frac{\partial \hat{v}(\hat{\alpha}^1)}{\partial \hat{\alpha}^1}\right|_{\hat{\alpha} = l^*} \frac{\partial \hat{\alpha}^1}{\partial r} > 0. \tag{A.41}$$

The first-order condition jumps upward at the point $\hat{\alpha}^1 = l^*$. I can conclude that in this case *interim* licensing will not discourage too much the refinement effort, if ever. That is, if without *interim* licensing the optimal $\hat{r}$ is large enough so that $\hat{\alpha}^0 < l^* < \hat{\alpha}^1$, then *interim* licensing will maintain a refinement effort such that the relation $\hat{\alpha}^0 < l^* < \hat{\alpha}^1$ still holds. Conversely, when expression (A.40) is (weakly) negative so that the optimal refinement effort under *interim* licensing falls into the low range such that $l^* > \hat{\alpha}^1 > \hat{\alpha}^0$, then it would already be the case without *interim* licensing. *Q.E.D.*

□ Lemma 2

Proof. By the concavity of $\hat{u}$ in l (Assumption 3), the optimal $l^i \leq l^*, i \in \{0, 1\}$. If some $l^i > l^*$, then $\partial \hat{u}/\partial l^i < 0$ and a small reduction in l^i will increase both the patentee's and developer's payoffs.

Suppose that $l^0 \neq l^1$. Consider a small change of royalties, (dl^0, dl^1), that keeps the constraint satisfied:

$$q\frac{\partial \hat{v}}{\partial l^1}dl^1 + (1-q)\frac{\partial \hat{v}}{\partial l^0}dl^0 = 0 \;\Rightarrow\; dl^0 = -\frac{q(\partial \hat{v}/\partial l^1)}{(1-q)(\partial \hat{v}/\partial l^0)}dl^1. \tag{A.42}$$

This will change the objective function by

$$q\frac{\partial \hat{u}}{\partial l^1}dl^1 + (1-q)\frac{\partial \hat{u}}{\partial l^0}dl^0 = qdl^1\frac{\partial \hat{u}}{\partial l^0}\left(\frac{\partial \hat{u}/\partial l^1}{\partial \hat{u}/\partial l^0} - \frac{\partial \hat{v}/\partial l^1}{\partial \hat{v}/\partial l^0}\right), \tag{A.43}$$

where $\partial\hat{u}/\partial l = [\hat{e} + l(\partial\hat{e}/\partial l)]v$ and $\partial\hat{v}/\partial l = -\hat{e}v$. When both l^0 and l^1 are in the interval $(0, l^*] \subset (0,1)$ but $l^0 \neq l^1$, say, $l^0 < l^1$, then

$$\begin{aligned} &\frac{\partial\hat{u}(l^1)/\partial l^1}{\partial\hat{u}(l^0)/\partial l^0} - \frac{\partial\hat{v}(l^1)/\partial l^1}{\partial\hat{v}(l^0)/\partial l^0} = \frac{\hat{e}(l^1) + l^1\frac{\partial\hat{e}(l^1)}{\partial l^1}}{\hat{e}(l^0) + l^0\frac{\partial\hat{e}(l^0)}{\partial l^0}} - \frac{\hat{e}(l^1)}{\hat{e}(l^0)} \\ =&\frac{1}{\hat{e}(l^0)(\partial\hat{u}/\partial l^0)}\left[\hat{e}(l^0)l^1\frac{\partial\hat{e}(l^1)}{\partial l^1} - \hat{e}(l^1)l^0\frac{\partial\hat{e}(l^0)}{\partial l^0}\right] = \frac{\hat{e}(l^1)}{\partial\hat{u}/\partial l^0}[\xi(l^1) - \xi(l^0)], \end{aligned} \tag{A.44}$$

where $\xi \equiv (l/\hat{e})(\partial\hat{e}/\partial l) = -(l/\hat{e})[v/c_E''(\hat{e})]$ is the elasticity of investment effort $\hat{e}$ with respect to the royalty l. By

$$\frac{\partial\xi}{\partial l} = -\frac{v}{\hat{e}(c_E'')^2}\left[\hat{e}c_E'' - l\frac{\partial\hat{e}}{\partial l}(c_E'' + \hat{e}c_E''')\right], \tag{A.45}$$

when $c_E''' \geq 0$, the elasticity is strictly monotonic in l for $l \leq l^*$. In this case, whenever $l^0 \neq l^1$, there is a pair of feasible changes (dl^0, dl^1) that can increase the value of the objective function. It can't be optimal.

If some element, say, l^0 hits the boundary point 0, i.e., $l^0 = 0 < l^1 \leq l^*$, then

$$\hat{e}(l^0)l^1\frac{\partial\hat{e}(l^1)}{\partial l^1} - \hat{e}(l^1)l^0\frac{\partial\hat{e}(l^0)}{\partial l^0} = \hat{e}(l^0)l^1\frac{\partial\hat{e}(l^1)}{\partial l^1} < 0. \tag{A.46}$$

A feasible pair of changes that will increase the patentee's payoff is $dl^1 < 0$ and $dl^0 = 0$ such that the constraint still holds. *Q.E.D.*

References

Adams, S. (2003). "A Comparison of Early Publication Practices in the Unites States and Europe," *World Patent Information*, Vol. 25: 117-22.

Ayres, I. and P. Klemperer (1999), "Limiting Patentees' Market Power without Reducing Innovation Incentives: The Perverse Benefits of Uncertainty and Non-Injunctive Remedies," *Michigan Law Review*, Vol. 97: 985-1033.

Caillaud, B. and A. Duchêne, (2005), "Patent Office in Innovation Policy: Nobody's Perfect," working paper.

Chiou, J.-Y., (2008), "The Patent Quality Control Process: Can I Afford An (Rationally) Ignorant Patent Office?" working paper.

Dewatripont, M. and J. Tirole, (1999), "Advocates," *Journal of Political Economy*, Vol. 107: 1-39.

Dewatripont, M. and J. Tirole, (2005), "Modes of Communication," *Journal of Political Economy*, Vol. 113: 1217-38.

Farrell, J. and C. Shapiro, (2008), "How Strong Are Weak Patents?" *American Economic Review*, Vol. 98: 1347-69.

Fulton, M. and A. Yiannaka, (2008), "Strategic Licensing of Product Innovations," working paper.

Gans, J., D. Hsu, and S. Stern, (2007), "The Impact of Uncertain Intellectual Property Rights on the Market for Ideas: Evidence from Patent Grant Delays," working paper.

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

Langinier, C. and P. Marcoul (2008), "Search of Prior Art and Revelation of Information by Patent Applicants," working paper.

Langinier, C. and P. Marcoul (2009), "Monetary and Implicit Incentives of Patent Examiners," working paper.

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

Lemley, M. and C. Shapiro, (2005), "Probabilistic Patents," *Journal of Economic Perspectives*, vol. 19: 75-98.

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

Lerner, J. and J. Tirole, (2004), "Efficient Patent Pools," *American Economic Review*, Vol. 94: 691-711.

Lichtman, D., (2005), "Substitutes for the Doctrine of Equivalents: A Response to Meurer and Nard," working paper.

Meurer, M. and J. Bessen, (2006), "Patent Litigation with Endogenous Disputes," *American Economic Review: Papers and Proceedings*, 96: 77-81.

Meurer, M. and J. Bessen, (2008), *Patent Failure: How Judges, Bureaucrats, and Lawyers Put Innovators at Risk*, Princeton: Princeton University Press.

Meurer. M and C. Nard, (2005), "Invention, Refinement, and Patent Claim Scope: A New Perspective on the Doctrine of Equivalents,' '*Georgetown Law Journal*,

Prady, D. (2008), " "Is That a Gun in Your Pocket...?" Applications for Patents and Costly Verification," working paper.

Risch, M., (2007), "The Failure of Public Notice in Patent Prosecution," *Harvard Journal of Law and Technology*, Vol. 21: 180-232.

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

Shuett, F. (2008), "Inventors and Impostors: An Economic Analysis of Patent Examination," working paper.

Yiannaka, A. and M. Fulton, (2006), "Strategic Patent Breadth and Entry Deterrence with Drastic Product Innovations," *International Journal of Industrial Organization*, Vol. 24: 177-202.