

Monetary and Implicit Incentives of Patent Examiners

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July 2009

Abstract

Patent examiners, who are often accused of granting questionable patents, might lack proper incentives to carefully scrutinize applications. Furthermore, they have outside options and leave the patent office. It is thus interesting to investigate whether their granting behavior is affected by career concerns. In a simple setting, we analyze different incentive schemes that reward examiners on the basis of rejected and/or accepted patents. We then study the effect of career concerns on the granting behavior of examiners. We find that a reward based on rejection gives more incentives to search for relevant information, and career concerns increase these incentives. Besides, the information provided by the applicant has an impact on the examiner's incentive to search for information.

Keywords: Patent Examiners; Career Concerns

JEL classification: O34 (*Intellectual Property Rights*), M5 (*Personnel Economics*); J60 (*Mobility*)

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1 Introduction

Patent applications and grants have increased at an unprecedented pace over the last decades. This raise in the number of patents is associated with many criticisms concerning the functioning of patent offices and examiners are often accused of granting patents of questionable validity. Even though some wrongly patented innovations have no value, others are valuable and, therefore, are costly for society and harm competitors.¹ In the U.S., the Patent and Trademark Office (PTO) is aware of the quality concerns that have been raised and is attempting to improve the patent system with, for instance, the implementation of modernization plans. Reports on the progress of these plans are regularly published by the U.S. Government Accountability Office (GAO). One of the issues addressed in the last two reports (GAO 2005, 2007) is that the PTO has a hard time to hire and retain a skilled workforce. The reasons for which examiners leave the PTO are not clear, and the office management and patent examiners usually have divergent opinions regarding this issue. The former pretends examiners leave for personal reasons, whereas the latter claim they leave because their production goals are too high, and have not changed over the last 30 years.² It might also be the case that examiners, who gain some expertise in an area, have an outside option value and leave the PTO to work for private companies.

Because incorrectly issued patents can survive in the market, there is a need for providing new mechanisms to improve the examination process. Several possible reforms have been proposed and some are currently under careful scrutiny, and/or are implemented as pilot programs at the PTO.³ Reforms that consist in increasing the number of examiners and allowing them to spend more time on each application are ineffective if they do not account for the high proportion of valueless patents. More effective reforms involve either competitors, as it is the case of the opposition system, or applicants, with the imposition of a two-speed examination process in which patent applicants can pay more to get a better scrutiny.⁴ The proposed reforms

¹See for instance Farrell and Shapiro (2008), Gallini (2002), Hall (2006), Hall and Harhoff (2004).

²A survey has been conducted by GAO and its findings are exposed in the last report from 2007.

³As explained in Shapiro (2004), Lemley, Lichtman and Sampat (2005) and Hall (2006).

⁴The opposition system is equivalent to the European system (Hall, 2006; Lemley, Lichtman and Sampat,

acknowledge that patent applicants and competitors may have better information than the PTO about the innovation and, therefore, should be involved in the patent granting process. Even though applicants might be responsible for not providing (and possibly not searching) information useful to judge the novel content of their innovation,⁵ patent examiners might also have their share of responsibility. Hence, it is important to have a better understanding of the mechanism by which patents are granted, and of the functioning of the internal organization of the PTO. Since there are patents on obvious innovations (e.g., crustless peanut butter and jelly sandwich), it is legitimate to wonder how examiners grant patents on innovations that seem to have serious flaws. One of the explanations might be that they lack incentives to make the appropriate effort to search for information that will prove the innovation cannot be patented.

Even though the examination process is fairly standard,⁶ it is highly dependent on the examiners' skill. The process consists of regular check of legal formalities, and search of prior art—the existing set of related inventions—which is where the expertise of the examiner is the most important.⁷ Their salaries are tied to the number of applications they process: they have production quotas to meet, and earn bonuses when they exceed their quotas by at least 10%.⁸ Their production goals are based on the number of patent applications they review, their experience (position in the agency) and their field of expertise (GAO, 2007). Importantly, they are never liable in the event patents are invalidated in court and “there are no negative consequences for 2005”. The two-speed examination process, also called gold-plate patents by Lemley, Lichtman and Sampat (2005) or super patent by Lemley and Shapiro (2005) is currently implemented at the PTO.

⁵See Atal and Bar (2008), Caillaud and Duchène (2005), Langinier and Marcoul (2008) for analyses of strategic behavior of patent applicants while searching and revealing prior art information.

⁶It is documented in the Manual of Patent Examining and Procedure, see the USPTO website at <http://www.uspto.gov/web/offices/pac/mpep/>.

⁷According to Cockburn, Kortum and Stern (2003), there is a strong heterogeneity among patent examiners.

⁸They process an average of 87 applications per year and they devote about 19 hours per application spread over 3 years. According to the PTO, about 60% of eligible examiners get bonuses. What is surprising is that examiners claim that their quotas are too high, whereas more than half of them go over at least 10% of their quotas (GAO, 2007).

examiners who produce low-quality work” (GAO, 2005). Furthermore, according to Quillen et al. (2001) in the U.S. between 87% and 95% of applications are granted a patent. This suggests that they are mainly rewarded on granted patents, and do not bear the aftermath of granting questionable patents.

In a perfect patent system, examiners would never issue patents that would be later found invalid in court. They would make appropriate efforts, which would be observed by the PTO. However, this is not the case. Due to lack of resources (both in terms of examiners’ effort and PTO monitoring), it is obvious that such of a perfect system is impossible to implement. There is a moral hazard problem since the PTO does not know how much effort an examiner makes on each application. The PTO only observes the outcome which is the patent disposal (acceptance or rejection). Examiners should be responsible for granting invalid patents, and should also, to some extent, be rewarded according to the social value they create, or be punished for the social loss. Even though it might be difficult to implement such a system, at least their salaries should be set to better reflect these objectives.

Furthermore, as already mentioned, the PTO suffers from a high turnover level. Some examiners develop skills that are often sought by private companies that value not only their technical skills but also their sound knowledge of the patent system. This raises the problem of career concerns, and the problem of knowing whether patent examiners behave strategically. When they process applications, they might account for the signal they send to the private job market. Our goal is to provide answers to the following questions: How should examiners be rewarded? How much effort an examiner will make to acquire invalidating information? How will career concerns affect their incentives to search for information?

We design a simple model in which examiners are rewarded according to different incentive schemes. The PTO offers a salary scheme based on different observable outcomes. When an examiner receives a patent application he must decide how much effort to put in it. He does not know the quality of the innovation and has only prior beliefs. His search of information

allows him to find that the innovation should be patented (he cannot find any evidence against patenting), should not be patented (he finds strong evidence against patenting) or should not be patented as it stands, but can be patented with considerable narrowed claims. Therefore, by exerting some effort he is able to reject non-patentable innovations, or to narrow the patent scope of too broad applications. A patent that has been granted can later be challenged in court with a certain probability, and we make the simplifying assumption that the court systematically invalidates patents granted on non-patentable innovations, but does not invalidate patents issued on patentable innovations.

We propose different scenarios. In the first one, the reward is based on rejection of a patent application. In the second scenario, the reward is based on acceptance of the patent. Finally, in the third scenario the reward is based on both rejection and acceptance. We find that the reward only based on rejection induces more effort on the part of the examiner, and also makes the PTO better off. In our setting, rewarding the examiner on both rejection and acceptance is dominated as both instruments are equivalent. We then study how the existence of career concerns shapes the incentives of the patent examiner. To fully characterize the model we assume that the examiner can be skilled or not, and that his talent is unknown not only for the market but also for himself, which is standard in career concern models. The more skilled the examiner is, the higher the chances of gathering relevant information. The market does not observe the examiner's talent directly, and has prior beliefs about the examiner's ability. The market observes patents that are granted (which does not provide information about the quality of the examiner's scrutiny) but also, and most importantly, granted patents that are taken to court, and the outcome of the trial. From the observation of patents that have been challenged in court and not invalidated, the market updates its beliefs. The market offers a salary to the examiner based on the observation of patents challenged in court and not invalidated. We find that examiners with career concerns attempt to influence the market's beliefs by exerting more effort. Examiners with career concerns provide higher efforts than they would absent any

reputational concerns. Lastly, we analyze how the information reported by the applicant in the patent application will affect the effort of the examiner.

In terms of policy implication, our analysis implies that the self-interested behavior of career-conscious examiners reduces the granting of non-deserving patents and, therefore, their objectives are aligned with the PTO's objective. Our findings suggest that when ex ante the uncertainty about the patentability is high, a tough post-patent policy (a high probability that the patent will be challenged to court) and reputational pressure forces the examiner to intensify his search effort.

As a final introductory point, let us come back to some of our main assumptions. We make the simplifying assumption that rejection does not lead to any controversy. It is obviously a strong assumption, and in reality rejection can be complex. In his Internet Patent News Service, Greg Aharonian reports frequently lawyers' complaints about the fact that patents are refused on wrong ground, and that the re-examination process is time consuming, and an appeal is never a good solution.⁹ We also do not take into account the problem associated with continuation rules that are topical as the PTO in January 2006 has just proposed new changes. According to Hall (2006), continuations accounted for more than one third of all the patent applications filed in 2004. Therefore, patent examiners spend a fair amount of their time on old patents and not on new applications.

The paper is organized as follows. We briefly present the related literature in section 2. In section 3 we present the model. Section 4 is devoted to the analysis of different incentive schemes that are offered by the PTO. In section 5 we study how career concerns may affect the examiner's choice, and the incentive scheme offered by the PTO. In section 6 we investigate the effect of the optimal choice of information transmitted by the patent applicant on the effort of the examiner. Section 7 concludes.

⁹See the web site of Greg Aharonian at <http://www.bustpatents.com/>.

2 Related Literature

Even though there is an abundant patent literature, to the best of our knowledge, there exist only a few contributions that are studying the process by which patents are granted. From a theoretical viewpoint, a few papers analyze the strategic behavior of examiners. The granting of questionable patents may be due to the poor knowledge of relevant prior art – the existing set of related inventions. Langinier and Marcoul (2009) propose a model of a bilateral search of information in which both innovator and examiner provide prior art information to prove the novel content of an innovation. The main focus is on the strategic behavior of patent applicants while searching and revealing information. Caillaud and Duchêne (2005) also analyze the determinant of patent quality but they are essentially concerned with the “overload” problem that the patent office faces. Atal and Bar (2008) study the incentives of innovators to search for prior art before and after undertaking any R&D investments. As in most of the patent literature, these contributions assume that the PTO and examiners have identical objectives, and there is no strategic behavior on the part of patent examiners who have congruent incentives with the office. However, it seems realistic to consider that they are not congruent, as the PTO is a federal institution for which many examiners are working, with most likely different objectives. To the best of our knowledge, no contribution tackles the internal problems of the PTO and takes into account the fact that examiners may have career concerns. This is the objective of our analysis: first we want to investigate what should be the reward scheme of examiners, and then study the effect of career concerns.

There exist a growing number of empirical studies that have started to open the “black box” of the process by which patents are granted. First, a few surveys have been conducted in patent offices themselves, both in the U.S. and in Europe. Friebel and al. (2006) provide an analysis of the objectives of the European Office, and the nature of its internal organization. They study the way internal organization shapes the ability of the patent office to pursue these objectives. Cockburn, Kortum and Stern (2003) propose a detailed exposition of the U.S. patent

examination process, and they provide empirical evidence that there exists heterogeneity among patent examiners and in the examination process. Concerned with the overload problem facing the PTO, King (2003) provides an analysis of the effect of increasing application workloads on the recent performance of the PTO. He shows that, despite an increased workload, patent examiners do spend, on average, the same amount of time on each application, but the pendency time (time elapsed between the filing and the granting of a patent) increased. Sampat (2005), and Alcacer and Gittelman (2006) provide empirical evidence of the role played by patent applicants and examiners in revealing information regarding prior art. In nanotechnology, Sampat (2005) finds strong evidence that examiners are less informed than patent applicants and they face particular challenges in searching for information. On the other hand, Alcacer and Gittelman (2006) show that many citations (prior art information) are listed by examiners, and that firm-level effects (e.g., experience of applicants, nationality) seem to explain most of the variance of examiner citation shares (Alcacer, Gittelman and Sampat, 2009). These analyses suggest that patent applicants and examiners do not necessarily have the same information, or the same incentives to search and reveal pertinent information. Lampe (2008) finds empirical evidence that innovators conceal information about prior art that is closely related to their innovation, which validates Langinier and Marcoul (2008) theoretical findings that applicants have an incentive not to reveal the entire prior art.

Understanding mobility concerns of workers has been theoretically studied in managerial career contexts. The theoretical analysis of career concerns goes back to the seminal paper by Holmstrom (1982, 1999) in which he analyzes how an agent career concern may influence his current incentives to make decisions. He studies the effect of time on incentives, and shows that career motives can be either beneficial or detrimental to organizations depending on the context. While Fama (1980) argues that career concerns will induce efficient behavior and discipline manager's behavior, Holmstrom (1982, 1999) shows that labor market forces may induce suboptimal behavior. More precisely, a manager will, in equilibrium, make decisions in

order to manipulate labor market inference about his talent rather than to maximizing profit. A more general framework is provided by Dewatripont et al. (1999a) with multiple tasks and where the effort may affect the agent's future talent. In a companion paper, Dewatripont et al. (1999b) provide an application that studies the role of career concerns for government agencies. Our view is that, like in Holmstrom (1982, 1999), examiners are able to send signals through their patenting decisions to potential employers in order to accelerate their career track. However, it is unclear whether career motives of patent examiners will negatively impact the patenting process. We examine the conflict or complementarity between monetary incentives and career concerns or implicit incentives.

3 The Model

We consider a sequential model with two risk-neutral players: the PTO and a patent examiner. The PTO seeks to grant patents to deserving innovations and to refuse patents to non-patentable innovations.¹⁰ It offers a salary scheme to the examiner based on one or several observable outcomes. When the examiner receives a patent application, he makes a costly search effort to determine the patentability of the innovation, and to decide on the disposal of the patent case. The disposal decision is to either approve or reject a patent. At the outset, the examiner does not know the patentability of the innovation (nor does the PTO), and has only (common) prior beliefs. The innovation is patentable with probability γ or non-patentable as it stands with probability $(1 - \gamma)$. Among the latter innovations, some are not patentable at all with probability p , whereas others are partly patentable with probability $(1 - p)$. Hence, an innovation is patentable with probability γ , non-patentable with probability $(1 - \gamma)p$, and partly patentable with probability $(1 - \gamma)(1 - p)$.

We now detail the examination process, before presenting the salary schemes offered by the PTO.

¹⁰In the U.S. to be patentable an innovation must be new, non-obvious and useful.

3.1 Examination Process

The examiner receives a patent application that contains $b \geq 0$ citations (which corresponds to the prior art information) that are provided by the patent applicant.¹¹ Then, the patent examiner exerts a costly search effort $e \in (0, 1)$ to find relevant information to be able to judge the novel content of the innovation. Depending on the gathered information, the examiner decides whether to grant a patent or not. When a patent is not issued, the examiner must provide information that proves that the innovation is not patentable. When he decides to grant a patent, he includes all of the citations in the patent description.¹² Let $C(e, b)$ be the cost of search effort that also depends on the information b provided by the applicant, where $C_e(e, b) > 0$ and $C_{ee}(e, b) \geq 0$, $C(0, b) = 0$ and $C(\infty, b) = \infty$. To have a tractable model we consider the following cost function

$$C(e, b) = e^2 + eg(b), \tag{1}$$

where the function $g(b)$ is positive, whereas its derivative can be either positive or negative and, therefore, so does $C_{eb}(e, b)$. The rationale for this cost function is the following. If the examiner makes no effort, he does not find anything and incurs no cost. If he makes a positive search effort, he has to go through the entire prior art b that has been provided by the applicant. This will affect his cost of searching for information. The more information is provided by the applicant in the patent application, the more costly it is for the examiner to find information, but it might be at a decreasing or increasing rate. In other words, the marginal cost of effort can be either increasing or decreasing with the information provided by the applicant. For instance, it might be the case that when the applicant provides relatively few but relevant information, it

¹¹For the time being, we do not explicitly model the patent applicant's decision. In section 6, we analyze the applicant's incentives to provide citations.

¹²In reality, the patent granting process takes on average three years. It is not uncommon that patent applications are initially rejected. Then, the applicant provides more information, more description of the innovation, or he narrows the claims. But, what matters is that, at the end of the process, many patents are granted, some with narrowed claims. So, here we simply consider the final outcome to grant a patent or not, after all the process.

is enough to help the examiner to direct his research on the right path. On the other hand, too much information might be very costly as the examiner has to go through the entire information provided. In the analysis of the examiner's effort that follows, we keep our model as general as possible and we do not provide a more detailed specification of $g(b)$. In section 6, we consider a functional form of $g(b)$.

The effort e made by the examiner generates a probability $q(e)$ of finding the nature of the innovation where $q'(e) > 0$, $q''(e) = 0$, $q(0) \geq 0$. Hence, with probability $(1 - \gamma)pq(e)$ the examiner finds that the innovation is non-patentable and rejects it, and with probability $(1 - \gamma)(1 - p)q(e)$ he finds it is partly patentable, and issues a patent on the patentable part of the innovation. With probability $(1 - q(e))$ he does not find any information against patenting and, therefore, grants a patent. Furthermore, the probability $q(e)$ depends on the talent of the examiner, which is unknown to all of the players. The examiner can be skilled with probability θ , or less-skilled with probability $(1 - \theta)$. The intrinsic talent of the examiner will have an impact on the probability of finding information. A skilled examiner who exerts an effort e will find relevant information to reject the patent application with probability e . On the other hand, a less-skilled examiner will find the same information with a lower probability αe , where $\alpha < 1$. Therefore, the expected quality of the examiner is $\bar{\alpha} = \theta + \alpha(1 - \theta)$. The more talented the examiner, the higher the probability of invalidating the patent application. To keep our model simple we assume that the expected probability of finding the nature of the innovation is $q(e) = \bar{\alpha}e$.

Finally, when a patent has been issued, there is a probability π that it will be later on challenged in court. If the innovation is patentable, we make the simplistic assumption that it will be discovered in court, and therefore the patent will not be invalidated. However, if the innovation has been mistakenly patented, it will be invalidated in court as the court will be able to identify that the innovation should not have been granted a patent. If only part of the patent is not patentable, the court will find it. However, from a social viewpoint, an invalidated patent

provides society with a social value of zero.

The social value of a patentable innovation that is granted a patent is \overline{W} , whereas a non-patentable innovation that is wrongly issued a patent has a social value \underline{W} where $\overline{W} > 0 > \underline{W}$. Furthermore, an innovation that is non-patentable as it stands, but is partly patentable will have a social value \overline{W} if it is granted a patent on the innovative part, whereas it has a social value \overline{W}' if it is granted a patent on the entire innovation, with $\overline{W} > \overline{W}'$. It is costly for society to grant patents on innovations that are only partially novel.

Two types of errors can be made by the examiner: a patent may be refused to a patentable innovation (type I error), or a patent may be granted to a non-patentable innovation (type II error). However, because many applications are issued a patent, it seems that type II error is more likely to happen than type I error. Good innovations that are not issued a patent will obviously have an impact on society, but bad patents that are granted have a higher cost (e.g., litigation costs, reduction of competition). In our setting, we therefore consider that the PTO is concerned with preventing type II error.

3.2 PTO Salary Schemes

Let us now be more specific about what the PTO can contract upon. The PTO does not know the talent of the examiner, or the patentability of the innovation. It can observe that a patent has been refused or has been issued. In the latter case, the PTO will know whether the patent has been later on invalidated in court. Therefore, the PTO can offer a salary scheme based on the rejection of a patent application or/and on its acceptance. In fact, the PTO should be able to contract upon some characteristics of the patent, like for instance the number of citations. However, to keep our model simple we assume that when the contract is based on acceptance, it does not depend on the number of citations, and the examiner receives a fixed salary.

3.3 Timing

The timing of events goes as follows.

- In the first period, the PTO offers an employment contract entailing a salary scheme to the examiner that depends on rejection and/or on granted patent. The examiner accepts or refuses the salary.
- In the second period, if the examiner accepted the contract, he first receives a patent application. He does not know whether the innovation is patentable or not, and has only prior beliefs. Second, he makes a costly effort to judge whether it is patentable or not. With some probability he discovers that the innovation is not patentable and refuses to grant a patent. Otherwise he grants a patent.
- In the third period, the granted patent can be challenged in court and invalidated.

4 Different Incentive Schemes

We consider several incentive schemes that the PTO can offer to the examiner. First, we examine the case where the salary is based on the refusal of a patent. In order to reject an application the examiner must provide information that shows unambiguously that the innovation cannot be patented (e.g., it already existed, had already been patented). In our setting, the examiner cannot refuse a patent to a patentable innovation, as it is based on hard evidence. Therefore, the examiner should be rewarded for finding information that proves that the innovation cannot be patented. Second, we consider that the salary is based on the acceptance of a patent. The examiner makes mistakes, and can issue a patent on a non-patentable innovation. If this happens, the patent might potentially be challenged in court and invalidated. The PTO needs to account for that possibility, and reward the examiner for patents that are not invalidated in court. And third we consider that the PTO provides an incentive scheme based on both refusal and acceptance.¹³

¹³This later case could be seen as the closest to the current system in which patent examiners' salaries are (partly) based on the disposal of a patent case. It is however not clear how issued patents are weighted against rejected applications in the calculation (See GAO (2007) for a description of the salary schemes.) and, more

Whether the innovation is patentable or not, the expected probability of issuing a patent is

$$\begin{aligned}\Pr(\textit{approval}) &= \bar{\alpha}e(\gamma + (1 - \gamma)(1 - p)) + (1 - \bar{\alpha}e)(\gamma + (1 - \gamma)(1 - p) + (1 - \gamma)p) \\ &= \gamma + \bar{\alpha}e(1 - \gamma)(1 - p) + (1 - \bar{\alpha}e)(1 - \gamma).\end{aligned}$$

An examiner of average talent $\bar{\alpha}$ who makes an effort e finds that the innovation is (fully or partly) patentable with probability $\bar{\alpha}e(\gamma + (1 - \gamma)(1 - p))$ as he cannot find any invalidating information on patentable innovation or on the patentable part of an innovation. On the other hand, if he does not exert enough effort, he will not find any invalidating information because he did not search enough for it. This is represented by the second part of the probability.

The probability of rejecting a patent is

$$\Pr(\textit{rejection}) = (1 - \gamma)p\bar{\alpha}e,$$

as a rejection will only occur if an examiner of average talent $\bar{\alpha}$ makes an effort e that generates a probability $(1 - \gamma)p\bar{\alpha}e$ of finding invalidating information.

The higher the average talent of an examiner, the higher the probability of rejecting a patent application. More talented examiners tend to find invalidating information given that it does exist. Or, in other words, for a given application and a given level of effort, an examiner will approve more often a patent application if his average talent is relatively low, i.e., $\bar{\alpha} < 1/2pe$.

4.1 Incentive Scheme Only Based on Rejection

We first consider that the PTO only rewards the examiner for rejecting applications. When the examiner decides not to grant a patent he needs to provide evidence that the innovation is not patentable. In our setting, when the examiner finds evidence that allows rejecting the patent application, it is because the innovation is non-patentable. He gets a reward R when he has been able to prove that it is a non-patentable innovation, and his expected salary is

$$S_1 = (1 - \gamma)p\bar{\alpha}eR, \tag{2}$$

importantly, in the current system examiners are not liable in the case of a patent that is invalidated in court.

where $(1 - \gamma)p\bar{\alpha}e$ is the probability of discovering that the innovation is non-patentable after making an effort e for an examiner whose average talent is $\bar{\alpha}$.

The examiner chooses the effort level e that maximizes his utility function

$$\max_e U_1 = \{S_1 - C(e, b)\},$$

where $C(e)$ is given by equation (1). Consequently, for any level of reward R given by the PTO, the effort of the examiner is

$$e_1(R) = \frac{1}{2}[\bar{\alpha}(1 - \gamma)pR - g(b)], \quad (3)$$

where $e_1(R) \in (0, 1)$. The more information provided by the patent applicant, the higher (respectively, lower) the examiner's cost to process it and, therefore, the lower (respectively, higher) the scrutiny effort if $g'(b) \geq 0$ (respectively, $g'(b) < 0$). The examiner's effort and the information provided by the patent applicant are substitute (respectively, complement), which might give rise to strategic behavior on the part of the patent applicant (see section 6). When it is more likely that the innovation is patentable (higher γ), the lower the incentive of the examiner to search information to prove otherwise. Not surprisingly, the higher the reward R , the higher the probability that the innovation is non-patentable $(1 - \gamma)p$, and the higher the examiner perceives his talent $\bar{\alpha}$, the higher the scrutiny effort.

The PTO seeks to provide the optimal level of reward to the examiner by solving the following maximization program

$$\max_R G_1 = \{W - S_1\},$$

where S_1 is given by equation (2), and W is the expected social value of the innovation that is defined as follows

$$W = \gamma\bar{W} + (1 - \gamma)[\bar{\alpha}e(1 - p)\bar{W} + (1 - \bar{\alpha}e)(1 - p)(1 - \pi)\bar{W}' + (1 - \bar{\alpha}e)p(1 - \pi)\underline{W}]. \quad (4)$$

If the innovation is patentable, the examiner will never find otherwise. If the innovation is non-patentable at all, the examiner can make a mistake with probability $(1 - \bar{\alpha}e)$ and grant a patent to a non-patentable innovation, which will not be invalidated in court with probability

$(1 - \pi)$. On the other hand, if the innovation is partly patentable, the examiner can issue a patent on the patentable part of it with probability $\bar{\alpha}e(1 - p)$. In the later case, the social value of a patent granted to the patentable part of the innovation is equivalent to the social value of a patent granted to a patentable innovation. The examiner can also make a mistake and issue a patent on the entire innovation that will not be later on invalidated in court with probability $(1 - \bar{\alpha}e)(1 - p)(1 - \pi)$. Anytime a patent is invalidated in court, its social value is null.

By a backward induction argument, we plug equation (3) into the maximization program of the PTO, and we determine the optimal level of reward R that should be given to the examiner

$$R_1^* = \frac{1}{2(1-\gamma)^p} \left[\frac{g(b)}{\bar{\alpha}} + \omega \right], \quad (5)$$

where $\omega = (1 - \gamma) [(1 - p)(\bar{W} - (1 - \pi)\bar{W}') - p(1 - \pi)\underline{W}] > 0$ represents the expected gain from avoiding to wrongly grant a patent to a non-patentable (or partly patentable) innovation. The higher the gain from avoiding making a type II error, the higher the reward. Note that the expected talent of the examiner decreases the reward that the PTO has to offer. The optimal reward is also increasing (respectively, decreasing) with the information given by the applicant b and with the social value of a patented patentable innovation if $g'(b) \geq 0$ (respectively, $g'(b) < 0$). It is decreasing with the value of a patented non-patentable innovation. In other words, the lower the social loss associated to a type II error, the lower the examiner's reward. It is also decreasing with the probability of finding evidence against patenting and with the probability of going to court.

Evaluated at the optimal level of reward R_1^* given by equation (5), the examiner makes an optimal effort

$$e_1^* = \frac{1}{4} [\bar{\alpha}\omega - g(b)]. \quad (6)$$

We assume that the parameters are such that $g(b) \in [\omega\bar{\alpha} - 4, \omega\bar{\alpha}]$. The optimal effort of the examiner depends on the probability that the patent will be challenged in court, through the reward R . Indeed, there is only an indirect effect as the examiner does not directly gain from having the patent he granted going to court. However, he derives indirect benefits (or losses)

through the expected social value he creates. The effort of the examiner increases with π for small values of the probability of finding a non patentable innovation conditional on not being patentable as it stands, that is, $p \leq p_1 \equiv \bar{W}' / (\bar{W}' - \underline{W})$. The social value from granting a patent to a deserving innovation will push the PTO to increase R which, in turn, pushes the examiner to increase his effort. On the other hand, if p is relatively high, that is, $p > p_1$, it goes the other way around. As π increases, the marginal expected social value of the innovation is negatively affected and, therefore, the reward is reduced, which induces less effort from the examiner.

As the probability that the innovation is non-patentable increases, the effort of the examiner increases or decreases depending on the value of π . For a given R , the examiner always intensifies his search as $(1 - \gamma)p$ increases. However, as it becomes more likely that the innovation is not patentable, the PTO does not need to increase R to provide incentives for the examiner to search for invalidating information, and therefore R decreases. Overall, an increase in $(1 - \gamma)p$ induces an increase in the optimal effort if the probability to be challenged in court is relatively low that is, $\pi \leq \pi_1$. If π is relatively small, very few wrongly granted patents will be challenged in court, and therefore the marginal social value of effort increases as well. More effort from the examiner will allow to compensate for a low π , and to avoid granting patents to non-patentable innovation. On the other hand, if π is relatively large, that is, $\pi > \pi_1$, many wrongly patents will be challenged, and invalidated in court. Therefore, in this case, the marginal social benefit of effort decreases with $(1 - \gamma)p$, as more wrongly patents will be challenged in court.¹⁴

The optimal salary of the examiner is

$$S_1^* = \frac{1}{8}[(\bar{\alpha}\omega)^2 - g(b)^2]. \quad (7)$$

The information provided by the applicant allows shaping the salary scheme of the examiner. As $sign(\partial S_1^* / \partial b) = -sign(g'(b))$, the more information transmitted by the applicant, the higher

¹⁴Notice that instead of taking the derivative with respect to $(1-\gamma)p$ – the probability that the innovation is non-patentable – we could take the derivative with respect to p – the probability that the innovation is non-patentable conditional on not being patentable as it stands. The results would be similar.

(respectively, lower) the optimal expected salary of the examiner if $g'(b) < 0$ (respectively, $g'(b) > 0$). In fact, two effects work in opposite direction. As the applicant provides more information, the effort of the examiner increases when both the examiner's effort and the information transmitted by the applicant are complement (i.e., $g'(b) < 0$). However, the PTO reduces the reward R given to the examiner as it does not have to provide more incentive to intensify the search. Overall, the optimal expected salary increases as by searching more the examiner increasing his chances of finding more invalidating information. The salary decreases with the probability of having a non-patentable innovation if the benefit from avoiding a mistake if the innovation is non-patentable is larger than the benefit from avoiding a mistake if it is partly patentable.

We summarize these findings in the following lemma.

Lemma 1 *If the incentive scheme is based on rejection,*

1. *the more talented the examiner, the higher his search effort, the lower his reward and the higher his expected salary,*
2. *the higher the probability of a good innovation, the lower his search effort, the higher his reward and the lower his expected salary,*
3. *the higher the probability to go to court, the higher (respectively, lower) his search effort, his reward and his expected salary if $p \leq p_1$ (respectively, $p > p_1$),*
4. *the higher the probability of having a non-patentable innovation, the higher (lower) his search effort if $\pi \leq \pi_1$ ($\pi > \pi_1$), the lower his reward and his expected salary,*
5. *the more information transmitted by the patent applicant, the lower (respectively, higher) his search effort, the higher (respectively, lower) his reward and the lower his expected salary if $g'(b) \geq 0$ (respectively, $g'(b) < 0$).*

Proof. All the proofs are relegated in the appendix. ■

Even in a setting in which the salary of the examiner does not depend on a potential trial outcome, the probability of having the granted patent challenged in court affects the search effort of the examiner. Because the expected social value he creates is impacted by a trial outcome, so does his effort.

We can also characterize the optimal utility of the examiner

$$U_1^* = (e_1^*)^2, \quad (8)$$

where the more effort provided by the examiner, the higher his utility. The equilibrium benefit of the PTO is

$$G_1^* = (1 - (1 - \gamma)p)\overline{W} - \omega + 2(e_1^*)^2. \quad (9)$$

The PTO benefits from more scrutiny on the part of the examiner. As the probability of having a patentable innovation increases, so does the gross expected social value of the innovation. However, the effort of the examiner decreases, and the total impact of an increase of γ on the optimal expected benefit of the PTO is not clear. It increases the gross benefit, but it also increases the associated cost as the PTO must increase the reward to give more incentive to the examiner to perform a higher effort. The effect of an increase of the probability of having the patent invalidated in court is also unclear.

4.2 Incentive Scheme Only Based on Approval

We now consider another incentive scheme in which the examiner is only rewarded on the basis of granted patent that is not invalidated in court later on. He gets a reward A for granting a patent that will not be invalidated in court. With probability π the patent is challenged in court, and only a non-patentable innovation will be invalidated in court. With probability $(1 - \pi)$ the patent is not challenged in court. The expected salary of the examiner is now

$$S_2 = [\gamma + (1 - \gamma)(1 - p)\overline{\alpha}e + (1 - \gamma)(1 - \overline{\alpha}e)(1 - \pi)]A, \quad (10)$$

where the last part of the salary represents a non-patentable innovation that is patented because of lack of evidence against it, and has not been challenged in court. The second part of the salary

represents an innovation that was non-patentable as it stands, but was granted a patent on its patentable part.

The examiner solves the following maximization program

$$\max_e U_2 = \{S_2 - C(e, b)\},$$

which yields, for any given A , the following optimal effort

$$e_2(A) = \frac{1}{2}[\bar{\alpha}(1 - \gamma)(\pi - p)A - g(b)] \text{ if } \pi > p. \quad (11)$$

The effort is null if $\pi \leq (p + g(b))/\bar{\alpha}(1 - \gamma)A$. As long as the probability of going to court is small, the examiner has no incentive to make any effort. However, if $\pi > (p + g(b))/\bar{\alpha}(1 - \gamma)A$, the examiner chooses to make a positive effort. Notice that the court acts as random auditor for the PTO. In our setting, in absence of possible court intervention, the patent examiner would have no incentives to search for invalidating information. The court will rectify the lack of incentives. In our modeling framework, we could think about a random monitoring (or an internal quality check done by the PTO) instead of the possibility of having the patent invalidated in court. However, the introduction of monitoring would not qualitatively change our findings. That is why we only consider that the patent might be challenged in court, which can rectify some of the incentives.

The maximization program of the PTO is

$$\max_A G_2 = \{W - S_2\},$$

where W and S_2 are given by equations (4) and (10), respectively. The resolution of the program yields

$$A_2^* = \frac{1}{2(1-\gamma)(\pi-p)} \left[\frac{1}{\bar{\alpha}}(g(b) - 2\Phi) + \omega \right], \quad (12)$$

where $\Phi = [\gamma + (1 - \gamma)(1 - \pi)]/[(1 - \gamma)(\pi - p)\bar{\alpha}] \geq 0$. When π is relatively small ($\pi \leq p$), the objective function of the examiner is strictly decreasing with the effort. Indeed, by exerting an effort the examiner reduces his chances of being rewarded for making a mistake of granting a

patent on a non-patentable innovation. Therefore, he has no incentive to make a costly effort. The PTO does not offer any reward and $A = 0$.

However, for higher values of π , the examiner exerts an optimal effort

$$e_2^* = \frac{1}{4}[\bar{\alpha}\omega - g(b) - 2\Phi],$$

and his salary is

$$S_2^* = \frac{1}{8}[(\bar{\alpha}\omega)^2 - (g(b) - 2\Phi)^2]. \quad (13)$$

Before comparing the levels of effort depending on the regime (rejection or approval regimes), we perform some comparative statics on the optimal effort and salary.

The more talented to examiner, the higher his effort for a given level of A . For low values of $\bar{\alpha}$, the PTO will increase A as $\bar{\alpha}$ increases, and therefore the salary will increase as well. Effort and reward go in the same direction as $\bar{\alpha}$ increases for low values of the average talent. For higher values of $\bar{\alpha}$, this is no longer the case, as the reward A decreases with $\bar{\alpha}$. It is not clear how this will affect the salary. The information transmitted by the patent applicant will have the same impact than in the case of an incentive scheme based on rejection. As the applicant brings more information, the examiner increases (respectively, reduces) his effort and the PTO decreases (respectively, increases) the reward if $g'(b) \geq 0$ (respectively, $g'(b) < 0$). An increase in the probability of having a patentable innovation reduces the effort of the examiner, and increases the level of reward. However, the effect on the expected salary is unclear. Finally, an increase in p has only a clear effect on both the effort and the reward if $\pi \leq \pi_1$. If the benefit from avoiding an error for a non-patentable innovation is higher than the benefit of avoiding an error for the partially patentable innovation, then both the effort of the examiner and the reward are increased after an increase of p .

We summarize these findings in the following lemma.

Lemma 2 *If the incentive scheme is based on approval,*

1. *the more talented the examiner, the higher his search effort,*

2. *the more information is transmitted by the patent applicant, the lower (higher) his search effort, the higher (lower) his reward and the lower (higher) his expected salary if $g'(b) \geq 0$ ($g'(b) < 0$),*
3. *the higher the probability of a patentable innovation, the lower his search effort, the higher his reward,*
4. *the higher the probability of having a non-patentable innovation, the higher the effort, the lower his reward if $\pi \leq \pi_1$.*

It is also of interest to compare how the efforts under the two regimes (rejection and approval) are affected differently after changes in different parameters. We find the following results.

Lemma 3 *The examiner's search effort under an approval regime*

1. *increases at a higher rate than in a rejection regime when the average talent of the examiner increases,*
2. *decreases at a higher rate than in a rejection regime when the probability of having a patentable innovation increases,*
3. *is affected in the same way by an increase in the prior art information provided by the applicant.*

When the examiner becomes more talented on average, he intensifies his search more if his reward is based on approved patents rather than rejected patents. Yet, his effort is lower under the approval regime. If it is more likely that the innovation is patentable, the examiner has less incentive to perform invalidating search in the approval regime. Lastly the information provided by the patent applicant affects the efforts in the manner because it does affect their costs in the same manner.

The utility of the examiner is

$$U_2^* = (\gamma + (1 - \gamma)(1 - \pi))A_2^* + (e_2^*)^2,$$

and the benefit of the PTO is

$$G_2^* = (1 - p(1 - \gamma))\overline{W} - \omega + 2(e_2^*)^2 - \Phi \frac{g(b)}{2}. \quad (14)$$

The benefit function of the PTO and the utility function are both increasing with the effort of the examiner.

It is straightforward to compare the two levels of effort in both scenarios. The examiner exerts less effort when his salary depends on granted patents rather than on the refusal of patents ($e_2^* < e_1^*$), even though his salary is smaller under the first regime ($S_2^* > S_1^*$), and so does his utility ($U_2^* > U_1^*$) when $\pi > p$. In a regime based on rejection, the examiner intensifies his effort compared to a regime based on approval. If he had the choice between the two regimes, the examiner would rather prefer to be rewarded on the patents he grants if the probability to be challenged in court is relatively high. On the other hand, if the probability to be challenged in court is relatively small, his utility and expected salary are null as he does not make any effort if his reward is based on approval. Furthermore, the benefit of the PTO is smaller under an acceptance regime compared to a refusal regime ($G_1^* > G_2^*$).

Proposition 1 *The examiner exerts less effort when his salary depends on granted patents rather than on refused patents ($e_2^* < e_1^*$). The benefit of the PTO is smaller under an acceptance regime compared to a refusal regime ($G_1^* > G_2^*$).*

Therefore, the PTO should be more inclined to offer a salary (bonus) that rewards refusal rather than acceptance. Examiners should get rewarded on what is actually observed at the time the patent is processed, which is the invalidating information that is contained in the patent application. Furthermore, this reward does not directly depend on the observation of a trial that will happen later on. Therefore, bonuses should be based on the mere observation of rejected

patents that are well-documented. This will induce patent applicants to intensify their search effort. However, examiners would rather be rewarded based on the patents they grant if the probability to be challenged in court is relatively high (i.e., $\pi > p$). They need to make more effort in the case of a salary based on rejection, but overall they get a smaller utility out of it.

4.3 Incentive Scheme Based on Both Rejection and Approval

Lastly, we consider an incentive scheme in which the examiner gets rewarded based on both rejection and acceptance, such as his expected salary is

$$S_3 = [\gamma + (1 - \gamma)(1 - \bar{\alpha}e)(1 - \pi) + (1 - \gamma)\bar{\alpha}e(1 - p)]A + (1 - \gamma)\bar{\alpha}epR.$$

The maximization program is therefore

$$\max_e \{S_3 - C(e, b)\},$$

which gives an optimal level of effort

$$e_3(R, A) = \frac{1}{2}[(1 - \gamma)\bar{\alpha}(pR + (\pi - p)A) - g(b)].$$

This effort depends on the reward from granting patents A and from rejecting patents R . It is no longer necessary that $\pi \leq p$ to have a positive effort, given A and R . Here again, the effort is decreasing in b . For given values of A and R , we can compare the different levels of effort of the examiner. If $g(b) > 0$ and $\pi \leq p$, $e_2(A) < e_3(R, A) \leq e_1(R)$, whereas if $\pi > p$, $e_3(R, A) > e_1(R)$ and $e_3(R, A) > e_2(A)$. Furthermore, at the optimal values R_1^* and A_2^* from proposition 1, $e_1^* > e_2^*$. The PTO needs to choose R and A that maximize its objective function, that is

$$\max_{R, A} \{W - S_3\}.$$

There exist no R and A solutions of this maximization program and therefore the PTO offers the following contract

$$A_3^* = 0, \text{ and } R_3^* = R_1^*,$$

which is nothing but the first incentive scheme that only depends on the refusal. In fact, the two instruments are equivalent and rewarding the examiner on both refusal and acceptance does not give him more incentive. Therefore,

$$e_3^* = e_1^*.$$

Between offering a contract based on refusal, refusal and acceptance and only acceptance, the PTO prefers to offer a salary only based on refusal. By doing so it does not reward the examiner for making mistakes, and gives him incentive to put on more effort to search for information that permits to refuse a patent.

Proposition 2 *A salary based on disposal (rejection and acceptance) does not provide more incentive than a salary only based on refusal.*

5 Career Concerns of Patent Examiners

As mentioned in the introduction, the PTO has a hard time to retain a skilled workforce and skilled examiners tend to leave the PTO to work for private companies (GAO, 2005, 2007). Therefore, we wonder how these problems of career concerns affect the effort made by examiners. To analyze that, we need to modify our setting in the following way. The timing is now as follows. In the first period (identical to our previous setting), the PTO offers an incentive scheme to the examiner based on rejection. The examiner receives a patent application, chooses a level of effort to find information that proves that the innovation is not patentable. Then he decides to grant a patent or not. In the second period, the private market observes whether a patent has been invalidated in court or not, and updates its beliefs about the ability of the examiner. The private market then makes an offer to an examiner who is believed to be a good examiner.

Let us first consider the second period. Using Bayes' rule, the private market updated beliefs concerning the ability of the examiner are

$$\hat{\theta} = \frac{\theta\gamma + (1 - \gamma)\theta e(1 - p)}{\gamma + (1 - \gamma)\bar{\alpha}e(1 - p)}. \quad (15)$$

Recall that θ represents the probability that an examiner is skilled, which is unknown to all players. After making an effort e , a skilled examiner finds invalidated information with probability e , whereas a less-skilled examiner will find it only with probability αe where $\alpha < 1$. The average talent of an examiner is $\bar{\alpha} = \theta + \alpha(1 - \theta)$. By exerting more effort, the examiner attempts to manipulate the market's beliefs as $\partial\hat{\theta}/\partial e > 0$.

We assume that the salary offered by the private market is based on its updated beliefs about the ability of the examiner. The market offers a salary $\hat{\theta}$ to examiners whose patents have not been invalidated in court. For examiners whose patents have been successfully challenged, or have not been challenged, the private market does not make any offer.

We now turn to the first period choice of effort of the examiner in presence of career concerns. It is solution of

$$\max_e \{(1 - \gamma)p\bar{\alpha}eR + \delta[\gamma\pi + (1 - \gamma)(1 - p)\bar{\alpha}e\pi]\hat{\theta}(e) - C(e, b)\},$$

where $\gamma\pi$ represents the probability that a patentable innovation will be challenged in court and not invalidated, whereas $(1 - \gamma)(1 - p)\bar{\alpha}e\pi$ represents the probability that a patented innovation that was partly patentable will be challenged and not invalidated in court. Therefore, an examiner whose patent has been challenged but not invalidated receives a salary $\hat{\theta}$ whereas an examiner whose patent has been challenged and invalidated does not receive any offer from the market. The parameter δ represents the discount factor.

For a given level R , the examiner's effort is

$$e_{cc}(R) = \frac{1}{2}[\bar{\alpha}(1 - \gamma)pR + (1 - \gamma)(1 - p)\delta\pi\theta - g(b)]. \quad (16)$$

In presence of career concerns, for a given level of R , the examiner intensifies his search effort ($e_{cc}(R) > e_1(R)$).

The optimal level of reward given by the PTO is reduced to

$$R_{cc}^* = \frac{1}{2p(1-\gamma)}\left[\frac{g(b)}{\bar{\alpha}} + \omega - \delta\pi\frac{\theta(1-p)(1-\gamma)}{\bar{\alpha}}\right].$$

The optimal reward can be decomposed into two terms: the first term is related to monetary incentive whereas the second one is related to career concerns (non-monetary incentives). Interestingly, if career concerns have an important impact, the optimal reward is reduced. The PTO does not need to reward the examiner as much as before, as the market will give him extra incentives to search for information. Up to some point, it becomes unnecessary to provide the examiner with monetary incentives.

Therefore, the optimal level of effort of the patent examiner in the presence of career concerns is

$$e_{cc}^* = \frac{1}{4}[\bar{\alpha}\omega - g(b) + (1-p)(1-\gamma)\pi\delta\theta]. \quad (17)$$

By comparing equations (6) and (17) we find that $e_{cc}^* > e_1^*$, that is, an examiner with career concerns always exerts more effort than without career concerns.

Proposition 3 *Monetary and implicit incentives make the patent examiner intensify his search of information.*

By doing so he gets more immediate reward from non-patentable innovations that are refused, and also he increases his chances of being discovered as a skilled examiner on the job market. The existence of outside option value makes examiners more efficient.

We now perform some comparative statics and analyze how changes in different parameters affect the efforts of the examiner with and without career concerns. Some effects are magnified by career concerns. Not surprisingly, as the average talent of the examiner increases, so does his effort, but at a higher rate when he has career concerns. As his average talent increases, an examiner wants to signal it to the market. As the probability of having a patentable innovation increases, both efforts decrease, at a more rapid path in the presence of career concerns. As it becomes more likely that the innovation is patentable, the examiner does not have to search for invalidating information.

We consider how the effort will be affected by a change in the probability to be challenged in court π , for different values of the probability of having a non-patentable innovation, p .

For very low values of p , that is, $p \in (0, p_1)$, it is more likely that the innovation is (partly) patentable, and the examiner intensifies his search as π increases, at a higher rate in the presence of career concerns. Indeed, the examiner has more to win when the patent goes to court and is not invalidated. For intermediate values of p , that is, $p \in (p_1, p_{cc})$, it is less likely that the innovation is patentable, and therefore an examiner without career concerns reduces his search effort as the probability to be invalidated in court increases. On the other hand, in the presence of career concerns, the prospect of sending a signal to the market is still high enough for the examiner to intensify his search. So, in this case, career concerns boost incentives to search even though the likelihood to be challenged in court increases. However, when it becomes very likely that the innovation is non patentable, both efforts decrease with π , as the patent has more chances to be invalidated in court.

We now consider that π is given, and we let $p(1 - \gamma)$ increase. For low values of π , that is, $\pi \in (0, \pi_{cc})$, both efforts increase with p . As the probability of having a non-patentable innovation increases, so do the efforts when the chances of being challenged in court are very low. When π reaches intermediate values, that is, $\pi \in (\pi_{cc}, \pi_1)$, even though in absence of career concerns the examiner would still intensify his search, he does not do it anymore in the presence of career concerns as the chances of sending a bad signal to the market are too high. Lastly, for high values of π , both efforts decrease with p . We summarize these findings in the following lemma.

Lemma 4 *The optimal effort of an examiner with career concerns*

1. *increases with his talent at a higher rate than without career concerns ($\partial e_{cc}^*/\partial \bar{\alpha} > \partial e_1^*/\partial \bar{\alpha} > 0$),*
2. *decreases with the probability of having a patentable innovation at a higher rate than without career concerns ($\partial e_{cc}^*/\partial \gamma < \partial e_1^*/\partial \gamma < 0$),*
3. *increases with the probability of the patent being challenged in court, while the effort without*

career concerns decreases, for intermediate values of p , that is, $p \in (p_1, p_{cc})$,

4. *decreases with the probability that the innovation is not patentable, while the effort without career concerns increases, for intermediate values of π , that is, $\pi \in (\pi_{cc}, \pi_1)$.*

These findings suggest that when the uncertainty about the patentability of an innovation is rather high (intermediate values of p), a tough post-patent policy (a high probability of having the patent challenged in court) and reputational pressure will push the examiner to better scrutinize the patent application.

6 Applicant Incentives

In the previous sections, the prior art information provided by the applicant was exogenously given. We now consider that, at the outset of the game, the patent applicant chooses the information that will be included in the patent application, and we derive the applicant's optimal choice b^* . Then, we investigate how the examiner effort and the prior art information provided by the applicant are related.

6.1 Revelation of prior art by the applicant

First, we need to be more specific about the private value of the patented innovation. We denote \bar{V} the private value of a patented patentable innovation, \underline{V} the private value of a patented non-patentable innovation and v the private value of a partly patented innovation, with $\bar{V} > \underline{V} > v > 0$. The applicant would prefer to obtain a patent on its entire innovation even though it is not entirely new, rather than having a patent only on the patentable part of it, as he gets a larger monopoly power when he is granted a broader patent. Furthermore, the acquisition of information for the innovator is also costly. We assume that the cost to search and provide the prior art information b is $c(b)$ where $c'(b) > 0$ and $c''(b) \leq 0$. The shape of the cost function is related to the ease with which the applicant finds prior art information. The usual convex

cost function ($c''(b) < 0$) could represent an innovation for which there is relatively few prior art information and, therefore, it becomes more costly for the applicant to find more prior art information. On the other hand, a linear cost function ($c''(b) = 0$) could represent an innovation for which there is abundant prior art information, and the marginal cost of finding prior art is constant.

If we consider that the PTO rewards the examiner based on rejection,¹⁵ the applicant chooses b that solves the following program¹⁶

$$\max_b \Pi(b) = \{V(e_1^*(b)) - c(b)\},$$

where the expected value of the patented innovation is

$$V(e) = \gamma \bar{V} + (1 - \gamma)[\bar{\alpha}e(1 - p)v + (1 - \bar{\alpha}e)(1 - \pi)\underline{V}]. \quad (18)$$

With probability γ the innovation is patentable, and the applicant obtains \bar{V} . On the other hand, with probability $(1 - \gamma)$ the innovation is either partly patentable and discovered as such, or is not patentable at all, but this is not discovered by the patent examiner. Therefore the applicant can get a patent on a patentable part of the innovation, or can be wrongly granted a patent on a non-patentable innovation, that does not go to court and is never invalidated in court. If it exists, a positive optimal choice b^* is solution of¹⁷

$$\frac{\partial V(e)}{\partial e} \frac{\partial e_1^*}{\partial b} - \frac{dc(b)}{db} = 0. \quad (19)$$

With the specified optimal level of effort (6), and by using equation (18), we obtain the following first order condition

$$\frac{\bar{\alpha}}{4} \Delta g'(b) - c'(b) = 0, \quad (20)$$

¹⁵The optimal level of effort is however identical if the reward is based on acceptance. Only the expected benefit and the reward will be different. We consider the reward based on rejection as this is the most efficient policy.

¹⁶We abstract from patenting costs that would be a fixed cost.

¹⁷The second order condition is satisfied if $g''(b) \leq 0$ and $c''(b) > 0$ or $g''(b) < 0$ and $c''(b) \geq 0$ as long as $\Delta > 0$. If $\Delta < 0$, then $g''(b) = 0$ and $c''(b) > 0$ must be satisfied.

where $\Delta = (1 - \gamma)[(1 - \pi)\underline{V} - (1 - p)v] > 0$ if $\pi < 1 - (1 - p)v/\underline{V}$. As long as $\text{sign}(\Delta) = \text{sign}(g'(b))$ there exists a positive solution b^* . On the other hand, if $\text{sign}(\Delta) \neq \text{sign}(g'(b))$ the applicant does not provide any prior art information, $b^* = 0$. The sign of $g'(b)$ has an impact on the optimal level of effort e_1^* of the examiner as seen in equation (6). When $g'(b) > 0$, the more prior art information provided by the applicant, the lower the optimal effort of the examiner. In some sense, the effort of the applicant to provide prior art information and the examiner's effort are substitute. In the same vein, when $g'(b) < 0$, they are complement as the more information provided by the applicant, the higher the effort of the examiner to search for invalidating information. In fact, because the applicant provides b before the examiner chooses his effort, $e_1^*(b)$ is a best response function to any choice b made by the applicant. For any level b , the best response function will be affected differently by changes in the parameters of the model. Furthermore, the sign of Δ will impact differently $\partial V(e)/\partial e$. If $\Delta > 0$ (respectively, $\Delta < 0$), an increase in the effort of the examiner negatively (respectively, positively) impact the expected payoff of the applicant. Hence, the applicant will have different incentives to provide prior art information depending on whether his transmission of information will increase or decrease his expected payoff.

Provided that a positive solution exists, we perform some comparative static analysis on b^* by taking the total differentiation of equation (20). An increase in the probability of having a patentable innovation γ always induces the applicant to provide less prior art information b^* , even though it does affect differently the applicant's payoff depending on whether Δ is positive or negative. In the former case, the probability to be challenged in court is relatively small ($\Delta > 0$) and both efforts to provide information for the applicant and to search for invalidating information for the examiner are substitute ($g'(b) > 0$). An increase in γ has a direct and an indirect effect on $\Pi(b^*)$. Indeed, by using the envelop theorem, the total differentiation of $\Pi(b^*)$ with respect to γ is reduced to

$$\frac{\partial \Pi(b^*)}{\partial \gamma} = \frac{\partial V(e)}{\partial e} \frac{\partial e_1^*}{\partial \gamma} + \frac{dV}{d\gamma}.$$

Therefore, an increase in γ has a positive direct effect on the expected private value of the innovation ($dV/d\gamma > 0$). As the innovation is more likely to be patentable, it increases its expected private value. On the other hand, an increase in γ triggers a decrease in the best response function $e_1^*(b)$, which means that, for any value of b , the examiner will exert less effort. This reduction in the examiner's effort has a positive indirect effect on the expected private value. As the examiner makes less effort, the chances that the applicant is granted a patent on a non-patentable innovation increases, and so does the expected private value. Overall, in this case, an increase in γ always makes the applicant better off. In the later case, the probability of being challenged in court is relatively high ($\Delta < 0$) and the efforts of both the applicant and the examiner are complement ($g'(b) < 0$). The direct effect on the expected private value can be positive or negative (depending on the value of Δ). In fact, as the innovation is more likely to be patentable it still increases the expected value of the innovation. However, because π is now relatively high, it is less likely that the applicant will be wrongly granted a patent. Furthermore, the indirect effect through the effort of the examiner is always negative. Overall, it is not clear whether the expected payoff will be reduced or not as γ increases.

As the average talent of the examiner increases, so does the information provided by the applicant. When $\bar{\alpha}$ increases, for any given b the best response function $e_1^*(b)$ increases as well. When $\Delta > 0$, an increase in $\bar{\alpha}$ has a negative direct impact on the expected private value of the innovation as well as a negative indirect impact through $e_1^*(b)$. Overall, the more talented the examiner on average, the lower the expected benefit of the applicant. Therefore, by increasing b the applicant forces the examiner to reduce his effort, which increase the expected private value. On the other hand, when $\Delta < 0$, both the direct effect and the indirect effect have a positive impact on the expected private value. Hence, the applicant benefit from a more talented examiner, The applicant increases b which also increases the expected private value.

As the probability of having a non-patentable innovation conditional on not being entirely patentable, p , increases, so does the prior art information transmitted by the applicant if $g'(b) >$

0. On the other hand, if $g'(b) < 0$, the applicant reduces the prior art information transmitted. In terms of the expected benefit, with arguments similar to those presented above, the applicant's payoff decreases with p , if $\pi \leq \pi_1$ and $\Delta > 0$, or if $\pi > \pi_1$ and $\Delta < 0$. The applicant does not benefit from an increase in p . For all other configurations of parameters, we cannot conclude. As the probability that the patent will be challenged in court increases, the applicant transmits less (more) information if $g'(b) > 0$ ($g'(b) < 0$). In terms of payoff, as long as $p > p_1$ and $\Delta > 0$, or $p \leq p_1$ and $\Delta < 0$, an increase in π has a negative impact on the expected value of the innovation. For all others configuration, we cannot conclude.

We summarize these findings in the following lemma.

Lemma 5 *Provided that $\text{sign}(\Delta) = \text{sign}(g'(b))$,*

1. *the higher the probability of a patentable innovation, the less prior art information is provided by the applicant,*
2. *the more talented the examiner, the more prior art information is provided by the applicant,*
3. *the higher the probability of having a non-patentable innovation, the more (respectively, less) prior art information transmitted if $g'(b) > 0$ (respectively, $g'(b) < 0$),*
4. *the higher the probability of the patent being challenged in court, the less (respectively, more) prior art information transmitted if $g'(b) > 0$ (respectively, $g'(b) < 0$).*

6.2 Examiner's optimal effort

As we know how the optimal prior art information transmitted by the applicant varies with different parameters of the model, we can now determine the impact of these changes on the optimal effort of the examiner, evaluated at the optimal value b^* . We thus identify a direct effect –for a given b , how the effort will vary after a change in one parameter– and an indirect effect –through the variation of b . We obtain the following results.

Lemma 6 *Whenever $g'(b) < 0$,*

1. *the higher the probability of a patentable innovation, the lower the optimal search effort of the examiner,*
2. *the more talented the examiner, the higher his optimal search effort.*

If $g'(b) < 0$, and $\Delta < 0$, there exists a positive b^* and both indirect and direct effects reinforce each other. However, if $g'(b) < 0$, and $\Delta > 0$ or if $g'(b) > 0$, and $\Delta < 0$, we find that $b^* = 0$, and only the direct effect matters. On the other hand, if $g'(b) > 0$, and $\Delta > 0$ we cannot conclude as both effects work in opposite direction.

Lemma 7 *Whenever $g'(b) < 0$ or $g'(b) > 0$,*

1. *the higher the probability of having a non-patentable innovation, the lower the optimal search effort of the examiner if $\pi > \pi_1$,*
2. *the higher the probability of the patent being challenged in court, the higher the optimal search effort of the examiner if $p \leq p_1$.*

If $\pi \leq \pi_1$, we cannot conclude as both effects work in opposite direction as p increases. Indeed, an increase in p induces more effort from the examiner for a given b , but it also increases b if $g'(b) > 0$ (or decrease if $g'(b) < 0$). On the other hand, if the probability that the patent will be challenged in court is relatively high, that is, $\pi > \pi_1$ if $g'(b) > 0$, the search effort of the examiner decreases first less rapidly as $b^* = 0$ (because $\Delta < 0$). Then, as p increases, b^* becomes positive and the search effort decreases more rapidly as both effect go in the same direction. Similar arguments apply to the impact of a change in p on the optimal search effort.

6.3 Specific functional form

We now consider the following functional form

$$g(b) = 1 + b - 2b^{\frac{1}{2}}. \tag{21}$$

As already pointed out, the exact shape of $g(b)$ might be linked to the ease with which the applicant can find prior art information. With this functional form, the cost function (1) has some interesting features. First, when the patent applicant provides relatively few but pertinent prior art information, it helps the examiner as it makes his search less costly. The patent applicant provides information that helps the examiner to direct his research in the right stream of research. However, as the applicant provides more information, it comes to the point where it becomes too costly for the patent examiner to read it all, and to process all the information. It does not help him anymore, it is making his search more difficult. This relatively general function captures the idea that little but relevant information is helpful, whereas too much information does not help. With this specification, we can determine the shape of the optimal effort e_1^* and optimal salary S_1^* as defined by equation (6) and (7), respectively. Figure 1 provides a graphical representation of the optimal effort as a function of b . For a given level of reward R , an increase in the information provided by the patent applicant first increases and then reduces the effort of the examiner. First, because the examiner will put more effort in applications with relatively small amount of information, the PTO does not have to provide a higher salary. However, when the examiner's effort is reduced because the applicant provided too much information, the PTO must rectify the lack of incentive due to an increase in b by increasing the reward R that is given to the examiner. However, the increase in R is not sufficient to induce the patent examiner to make as much effort as before the change. Hence, it is important to consider how the incentive scheme of the examiner will affect the incentive of the applicant the provide information.

The more talented the examiner, the higher his effort for a given level of reward. Talented examiner will find more easily invalidating information, and therefore it is in his interest to intensify his search effort. However, the PTO does not need to provide extra incentives to search for information and can thus reduce the level of reward R . Overall, the salary increases with the talent as the effort increases more than the reward decreases. As the probability of having a patentable innovation increases, for a given R , the effort of the examiner decreases. He has less

incentive to search for information that might not exist. Therefore, the PTO must increase the reward to restore the incentive to search. Overall, the salary decreases with the probability of having a patentable innovation. Conditional on having a non-patentable innovation as it stands, an increase in the probability of having a non-patentable innovation intensifies the search effort of the examiner, for a given R . The PTO does not have to give more incentive to search for information.

With the functional form $g(b)$ specified in equation (21), both the examiner's utility (8) and the PTO's benefit (9) have an inverted U-shape. Both of these functions are increasing with the effort of the examiner, but the optimal effort will increase or decrease with b . The optimal effort $e_1^*(b)$ is also an inverted-U shape function of b . If only a few prior art information has been transmitted by the applicant, the effort of the examiner is increasing with b . In other words, an increase in b would trigger an increase in the effort of the examiner. On the other hand, if too much prior art information is provided in the patent application, it goes the other way around as an increase in b triggers a reduction of the effort. There exists a value of b for which the effort is maximum, $\tilde{b} = 1$ (see figure 1). Therefore, an increase in b for low (respectively, high) values of b , will increase (respectively, reduce) the effort of the examiner, and increase (respectively, reduce) the benefits for both the examiner and the PTO. In other words, in our setting, if too much information is reported by the applicant, it will lower the scrutiny effort of the examiner, and also lower his utility, even though the PTO increases the salary to compensate for the lack of incentives to search for information. On the other hand, when less information is provided but it is relevant, the examiner will make more effort and get a higher utility if the information provided is increased, even though his salary does not increase.

The optimal choice b^* is now solution of

$$-\frac{1}{4}\bar{\alpha}\Delta[1 - b^{-\frac{1}{2}}] - c'(b) = 0.$$

With a convex cost function (e.g., $c(b) = b^2$), we do not have a simple analytical solution as we obtain a cubic first-order condition that has three roots, one real and two complex solutions.

With a linear cost function $c(b) = b$, to get an optimal solution requires that $\Delta < 0$, and we obtain a simple analytical solution

$$b^* = \left(\frac{\bar{\alpha}\Delta}{\bar{\alpha}\Delta - 4}\right)^2.$$

It is easy to check that $b^* < 1$, and therefore $g(b^*) < 0$. We can also verify that the comparative statics done in the general case are still consistent in this particular example.

7 Conclusion

Over the last decade, the quality of patent examination has often been questioned. It is well-established that patents of questionable validity are issued, but there are only a few studies that are aimed at understanding how patent examiners are granting patents. Having a better knowledge about patent examiners might be a start to attempt to propose policy recommendations to improve the patent system. It is nevertheless surprising that the internal organization of patent offices has attracted little attention from economists. Only recently the process by which patents are granted has started to be empirically studied and very little has been said in terms of salary scheme and career concerns. However, there exists a significant body of literature on career concerns, and on the study of salary within public institutions. To the best of our knowledge, our paper is the first attempt at analyzing the salary scheme of patent examiners. Our aim is to consider different incentive schemes, and to investigate what is the impact of career concerns on the behavior of patent examiners. We also analyze how patent applicants can shape the scrutiny of patent examiner with the information they provide in their patent application.

We find that rewarding patent examiners on disposal of a patent case (rejection or acceptance) does not provide more incentive to search for information. Salaries (or bonuses) could only be based on rejection. Furthermore, career concerns provide more incentive to search for relevant information. Indeed, in order to be discovered as being a skilled examiner, a patent examiner intensifies his search to make fewer mistakes. Explicit and implicit incentives push patent examiners to make more effort and grant patents to deserving innovations. In fact the

impact of accounting for the possibility that a patent might be challenged in court is (qualitatively) equivalent to let examiners have strong career concerns. When the uncertainty about the patentability of an innovation is high, both a high probability of having the patent challenged in court and reputational pressure push the examiner to intensify his scrutiny.

In terms of policy implications, our findings suggest that a salary (or bonus) scheme based on rejected patents might give more incentives to search for invalidating information, and that career concerns have a positive effect on the search effort. On the other hand, even with this rejection scheme, a tough post-patent policy (in terms of more patents being challenged in court) will induce the examiner to intensify his search effort.

References

- [1] Alcacer, J. and M. Gittelman. “Patent Citations as a Measure of Knowledge Flows: The Influence of Examiner Citations,” *The Review of Economic Statistics*, 88(4):774–779 (2006).
- [2] Alcacer J., M. Gittelman and B. Sampat. “Applicant and Examiner Citations in U.S. Patents: An Overview and Analysis,” *Research Policy*, 38:415–427 (2009).
- [3] Atal, V. and T. Bar. “Prior Art: To Search or Not To Search,” *working paper* (2008).
- [4] Caillaud, B. and A. Duchêne. “Patent Office in Innovation Policy: Nobody’s Perfect,” *Working paper* (2005).
- [5] Cockburn I, Kortum S. and S. Stern. *Are All Patent Examiners Equal: Examiners, Patent Characteristics, and Litigation Outcomes*. Washington, National Academy Press, 2003.
- [6] Dewatripont M, I. Jewitt and J. Tirole. “The Economics of Career Concerns, Part I: Comparing Information Structures,” *Review of Economic Studies*, 66:183–198 (1999a).
- [7] Dewatripont M., I. Jewitt and J. Tirole. “The Economics of Career Concerns, Part II: Application to Missions and Accountability of Government Agencies,” *Review of Economic Studies*, 66:199–217 (1999b).
- [8] Fama, E. “Agency Problems and the Theory of the Firm,” *Journal of Political Economy*, 88(2):288–307 (1980).
- [9] Farrell, J. and C. Shapiro. “How Strong are Weak Patents?,” *American Economic Review*, 98:4:1347–1369 (2008).
- [10] Friebel G., A. Koch, D. Prady and P. Seabright. “Objectives and Incentives at the European Patent Office,” *IDEI Report* (2006).
- [11] Gallini, N. “The Economics of Patents: Lessons from Recent U.S. Patent Reform,” *Journal of Economic Perspectives*, 16:131–154 (2002).

- [12] GAO. “U.S. Patent and Trademark Office: Hiring Efforts are Not Sufficient to Reduce the Patent Application Backlog,” (2007).
- [13] GAO. “Intellectual Property: USPTO Has Made Progress in Hiring Examiners, But Challenges to Retention Remain,” *US Government Accountability Office* (june 2005).
- [14] Hall, B. “Issues in and Possibly Reforms of the U.S. Patent System,” *presentation in the Cooperative Symposium on “21st century innovation systems for Japan and the US: lessons from a decade of change”* (2006).
- [15] Hall, B. and D. Harhoff. “Post-Grant Reviews in the U.S. Patent System-Design Choices and Expected Impact,” *Berkeley technology law journal*, 19:1–27 (2004).
- [16] Holmstrom, B. “Managerial Incentive Problems: A Dynamic Perspective,” *Review of Economic Studies*, 66:169–182 (1982, 1999).
- [17] King, J. *Patent Examination Procedures and Patent Quality*, 54–73. National Academy of Sciences, 2003.
- [18] Lampe, R. “Strategic Citation,” *Working paper Stanford University, available at SSRN* (2008).
- [19] Langinier, C. and P. Marcoul. “Patents, Search of Prior Art, and Revelation of Information,” *Working paper* (2009).
- [20] Lemley, M. and C. Shapiro. “Probabilistic Patents,” *Journal of Economic Perspectives*, 19(2):75–98 (Spring 2005).
- [21] Lemley M., D. Lichtman and B. Sampat. “What to Do About Bad Patents?,” *Regulation*, 10–13 (Winter 2005-2006).
- [22] Quillen, C. and O. Webster. “Continuing Patent Applications and Performance of the U.S. Patent Office,” *Federal Circuit Bar Journal*, 11(1):1–21 (2001).

- [23] Sampat, B. “Examining Patent Examination: An Analysis of Examiner and Applicant Generated Prior Art,” (2005).
- [24] Shapiro, C. “Patent System Reform: Economic Analysis and Critique,” *Berkeley Technology Law Journal*, 19:3:1017–1047 (2004).

Appendix

Proof of lemma 1

The proof consists in the calculation of the derivatives of the effort (6), the reward (5) and the expected salary (7) with respect to the following parameters $\gamma, \bar{\alpha}, b, p(1-\gamma), \pi$. Most of the calculations are straightforward and we find that the variations of the effort are the following

$$\begin{aligned} \frac{\partial e_1^*}{\partial \gamma} &< 0, \quad \frac{\partial e_1^*(b)}{\partial \bar{\alpha}} > 0, \quad \frac{\partial e_1^*}{\partial b} > 0 \text{ if } g'(b) < 0, \\ \frac{\partial e_1^*}{\partial p(1-\gamma)} &\geq 0 \text{ if } \pi \leq \pi_1 \equiv 1 - \frac{\bar{W}}{\bar{W}' - \underline{W}}, \\ \frac{\partial e_1^*}{\partial \pi} &\geq 0 \text{ if } p \leq p_1 \equiv \frac{\bar{W}'}{\bar{W}' - \underline{W}}. \end{aligned}$$

The variations of the reward R are

$$\begin{aligned} \frac{\partial R_1^*}{\partial \gamma} &> 0, \quad \frac{\partial R_1^*}{\partial \bar{\alpha}} < 0, \quad \frac{\partial R_1^*}{\partial p(1-\gamma)} < 0, \quad \frac{\partial R_1^*}{\partial b} > 0 \text{ if } g'(b) < 0, \\ \frac{\partial R_1^*}{\partial \pi} &\geq 0 \text{ if } p \leq p_1. \end{aligned}$$

Finally, the derivatives of the expected salary are

$$\begin{aligned} \frac{\partial S_1^*}{\partial \gamma} &< 0, \quad \frac{\partial S_1^*}{\partial \bar{\alpha}} > 0, \quad \frac{\partial S_1^*}{\partial b} > 0 \text{ if } g'(b) < 0, \\ \frac{\partial S_1^*}{\partial p(1-\gamma)} &\geq 0 \text{ if } \pi \leq \pi_1, \quad \frac{\partial S_1^*}{\partial \pi} \geq 0 \text{ if } p \leq p_1. \end{aligned}$$

Proof of lemma 2

This proof is similar to the proof of lemma 1. We calculate the derivatives of the effort e_2^* , the reward A and the expected salary (13). It is easy to calculate that

$$\frac{\partial e_2^*}{\partial \gamma} < 0, \quad \frac{\partial e_2^*(b)}{\partial \bar{\alpha}} > 0, \quad \frac{\partial e_2^*}{\partial b} > 0 \text{ if } g'(b) < 0, \quad \text{and} \quad \frac{\partial e_1^*}{\partial p(1-\gamma)} > 0 \text{ if } \pi < \pi_1.$$

We can rewrite the reward A as

$$A_2^* = \frac{1}{2(1-\gamma)(\pi-p)} [2(1-\gamma)pR_1^* - \frac{2\Phi}{\alpha}].$$

Therefore, the derivative with respect to $\bar{\alpha}$ is

$$\frac{\partial A_2^*}{\partial \bar{\alpha}} = \frac{1}{2(1-\gamma)(\pi-p)} [2(1-\gamma)p \frac{\partial R_1^*}{\partial \bar{\alpha}} - \frac{\partial}{\partial \bar{\alpha}} (\frac{2\Phi}{\alpha})].$$

The first part is negative as $\partial R_1^*/\partial \bar{\alpha} < 0$ whereas the second part is positive as $\frac{\partial}{\partial \bar{\alpha}} (\frac{2\Phi}{\alpha}) < 0$. Therefore it is not obvious to conclude. For low values of $\bar{\alpha}$, the first effect is lower than the second.

Proof of lemma 3

The proof consists in the comparison of the derivatives of the efforts under the two regimes, which is straightforward.

Proof of Proposition 1

Consider G_1^* and G_2^* as defined by equations (9) and (14), and let us rewrite G_2^* as

$$G_2^* = (1 - p(1 - \gamma))\bar{W} - \omega + 2(e_1^* - \frac{1}{2}\Phi)^2 - \Phi \frac{g(b)}{2} = G_1^* - 2\Phi(e_1^* + \frac{g(b)}{2} - \frac{1}{4}).$$

We then plug equation (6) in the previous one and we obtain

$$G_2^* = G_1^* - 2\Phi(\frac{\bar{\alpha}}{4}\omega - \frac{1}{4}\Phi).$$

As long as $\frac{\bar{\alpha}}{4}\omega - \frac{1}{2}\Phi > 0$, so does $\frac{\bar{\alpha}}{4}\omega - \frac{1}{4}\Phi$ and therefore $G_1^* > G_2^*$.

Proof of lemma 4

The proof consists in the calculation of the derivatives of the effort (17), with respect to the following parameters $\gamma, \bar{\alpha}, b, (1-\gamma)p, \pi$, and to compare them with the derivatives of (6). We can rewrite e_{cc}^* as defined by equation (17) as

$$e_{cc}^* = e_1^* + \frac{(1-p)(1-\gamma)}{4}\pi\delta\theta,$$

and therefore

$$\frac{\partial e_{cc}^*}{\partial y} = \frac{\partial e_1^*}{\partial y} + \frac{de_{cc}^*}{dy}.$$

It is easy to show that

$$\frac{\partial e_{cc}^*}{\partial \gamma} < \frac{\partial e_1^*}{\partial \gamma} < 0, \text{ and } \frac{\partial e_{cc}^*}{\partial \bar{\alpha}} > \frac{\partial e_1^*}{\partial \bar{\alpha}} > 0.$$

The derivative of e_{cc}^* with respect to π is such that

$$\frac{\partial e_{cc}^*}{\partial \pi} = \frac{\partial e_1^*}{\partial \pi} + \frac{(1-\gamma)}{4}(1-p)\delta\theta > 0 \text{ if } p \leq p_{cc} \equiv \frac{\bar{\alpha}\bar{W}' + \delta\theta}{\bar{\alpha}(\bar{W}' - \underline{W}) + \delta\theta} \text{ even though } \frac{\partial e_1^*}{\partial \pi} < 0 \text{ for } p > p_1.$$

Therefore,

$$\begin{aligned} \text{if } p &\in (0, p_1), \frac{\partial e_{cc}^*}{\partial \pi} > 0 \text{ and } \frac{\partial e_1^*}{\partial \pi} > 0, \\ \text{if } p &\in (p_1, p_{cc}), \frac{\partial e_{cc}^*}{\partial \pi} < 0 \text{ and } \frac{\partial e_1^*}{\partial \pi} > 0, \\ \text{if } p &\in (p_{cc}, 1), \frac{\partial e_{cc}^*}{\partial \pi} < 0 \text{ and } \frac{\partial e_1^*}{\partial \pi} < 0. \end{aligned}$$

The derivative of e_{cc}^* with respect to $(1-\gamma)p$ is such that

$$\frac{\partial e_{cc}^*}{\partial(1-\gamma)p} = \frac{\partial e_1^*}{\partial(1-\gamma)p} - \frac{(1-\gamma)}{4}\pi\delta\theta < 0 \text{ if } \pi > \pi_{cc} \equiv \frac{\bar{\alpha}(\bar{W}' - \underline{W} - \bar{W})}{\bar{\alpha}(\bar{W}' - \underline{W}) + \delta\theta} \text{ even if } \frac{\partial e_1^*}{\partial(1-\gamma)p} > 0 \text{ for } \pi < \pi_1.$$

Therefore,

$$\begin{aligned} \text{if } \pi &\in (0, \pi_{cc}], \frac{\partial e_{cc}^*}{\partial(1-\gamma)p} > 0 \text{ and } \frac{\partial e_1^*}{\partial(1-\gamma)p} > 0, \\ \text{if } \pi &\in (\pi_{cc}, \pi_1), \frac{\partial e_{cc}^*}{\partial(1-\gamma)p} < 0 \text{ and } \frac{\partial e_1^*}{\partial(1-\gamma)p} > 0, \\ \text{if } \pi &\in (\pi_1, 1), \frac{\partial e_{cc}^*}{\partial(1-\gamma)p} < 0 \text{ and } \frac{\partial e_1^*}{\partial(1-\gamma)p} < 0. \end{aligned}$$

Proof of lemma 5

Let us denote

$$F(y, b) = \frac{\bar{\alpha}}{2}\Delta g'(b) - c'(b) = 0,$$

where $y = \gamma, \pi, \bar{\alpha}, p$. If there exists a positive solution b^* to the concave program, then

$$\text{sign}\left(\frac{db^*}{dy}\right) = \text{sign}\left(\frac{dF}{dy}\right).$$

We can therefore determine that

$$\begin{aligned} \frac{db^*}{d\pi} &< 0, \frac{db^*}{d\gamma} < 0, \frac{db^*}{dp} > 0 \\ \frac{db^*}{d\bar{\alpha}} &< 0 \text{ if } g'(b) < 0 \text{ and } \frac{db^*}{d\bar{\alpha}} > 0 \text{ if } g'(b) > 0 \end{aligned}$$

Proof of lemmas 6 and 7

The derivative of the optimal search effort is

$$\frac{\partial e_1^*}{\partial y} = \frac{de_1^*}{dy} + \frac{de_1^*}{db} \frac{db^*}{dy}$$

where $\frac{de_1^*}{dy}$ represents the direct effect whereas $\frac{de_1^*}{db} \frac{db^*}{dy}$ represents the indirect effect for $y = \gamma, \bar{\alpha}, p(1 - \gamma), \pi$. We calculate that

$$\frac{\partial e_1^*}{\partial \gamma} < 0 \text{ if } \frac{de_1^*}{db} \frac{db^*}{d\gamma} < 0 \text{ which is true iff } g'(b) < 0 \text{ and } \Delta < 0$$

$$\frac{\partial e_1^*}{\partial \bar{\alpha}} > 0 \text{ if } \frac{de_1^*}{db} \frac{db^*}{d\bar{\alpha}} > 0 \text{ which is true iff } g'(b) < 0 \text{ and } \Delta < 0$$

The derivatives with respect to π and $p(1 - \gamma)$ depends on both the sign of $\frac{de_1^*}{dy}$ and $\frac{de_1^*}{db} \frac{db^*}{d\gamma}$, which have been determined above.

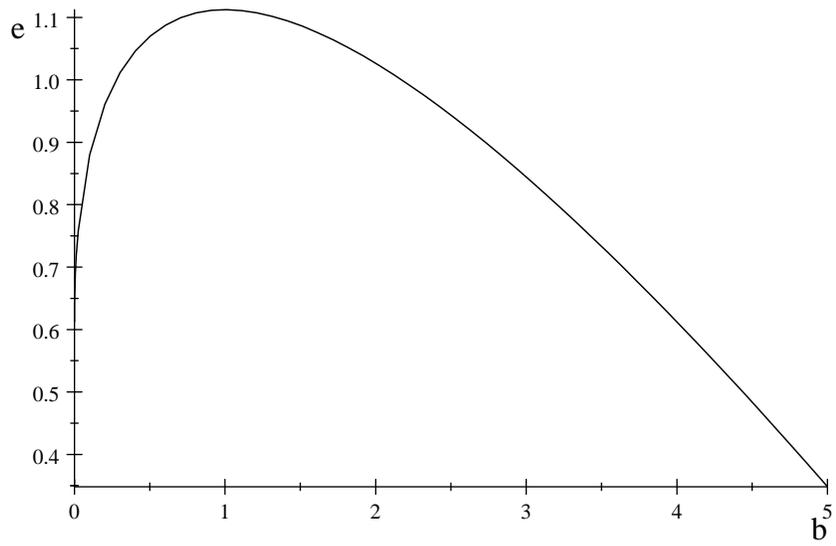


Figure 1: optimal effort $e_1^*(b)$