Patents, Search of Prior Art and Revelation of Information

Corinne Langinier* and Philippe Marcoul†

December 2007

Abstract

This paper examines the strategic non-revelation of information by innovators when applying for patents. In a model of a bilateral search of information, we show that innovators may conceal information, and that examiners make their screening intensity contingent upon the received information. We then analyze the effects of a double review policy and a policy in which examiners *ex ante* commit to screening efforts. The implementation of the former policy reduces strategic non-revelation, but its overall implication remains unclear. The latter policy involves equal screening intensity across all applications, requires a limited commitment power from the examiner and induces truthful revelation.

Keywords: Patents, Information, Incentives

JEL classification: O31, O34, D83

*Iowa State University, Ames. langinier@econ.iastate.edu

†Iowa State University, Ames. marcoul@iastate.edu

We would like to thank Josh Lerner, Cecil Quillan and participants in the seminar at INRA Grenoble, at CREST-LEI in Paris, at the University of Cergy Pontoise, ESEM and IIOC for many helpful comments on a previous version of the paper.

1 Introduction

Performances within the U.S. Patent and Trademark Office (PTO) have been strongly questioned, and examiners are often accused of granting questionable patents. This may be due to their poor knowledge of relevant prior art – the existing set of related inventions – especially in new technological fields, as was the case in e-commerce at the beginning of 2000[1] or is now the case in nanotechnology (Sampat, 2005). Sampat (2005) finds strong evidence that supports the fact that examiners are less informed than innovators about relevant prior art in nanotechnology, and face particular challenges in searching for it. On the other hand, according to Alcacer and Gittelman (2006), over the period 2001-2003, forty percent of patents had all citations (i.e., prior art information) listed by examiners. In other words, innovators initially applied for patents with no prior art in less than half of the patents studied. These empirical observations suggest, in a non-exclusive way, that patent applicants may not have the proper incentives to search and reveal prior art, and examiners may also have a hard time finding the relevant prior art in some fields.

In the absence of thorough knowledge of previous existing innovations, it is difficult for patent examiners to assess the novelty of innovations. In the U.S. patent system, to be patentable, an innovation must be useful, novel and non-obvious.[2] A patent application must contain references to previous literature and patents upon which the innovation improves or from which it diverges. The nature of prior art can be diverse and any relevant piece of evidence can constitute prior art; for instance, it can be a thesis in a French university or a scientific article in an Italian journal. Innovators should provide information in order to demonstrate that the innovation has not been patented or published prior to the time the patent is filed. Legally, they have a duty of candor in disclosing prior art information,[3] but they have no duty to search for it before filing

[1] See Coppel (2000), Kesan (2002), Lemley (2001), and Merges (1999) for a discussion on the relevance of the patent protection system in the e-commerce world. Many "business-method software" patents have little prior art. According to Greg Aharonian, slightly fewer than half of all patents, over a period of 20 years, cite no non-patent prior art, and the average patent cites about two non-patent prior art items. Information can be found on the Greg Aharonian's web page, http://www.bustpatents.com/.

[2] In the European patent system, an innovation must be novel, mark an inventive step and be commercially applicable. The patent deliverance process in the two systems is different. See Graham, Hall, Harhoff and Mowery (2002) for a detailed description of the two systems.

[3] In the European patent system, innovators do not have to provide a full list of prior art. The European

an application: they must only disclose information of which they are aware. Furthermore, according to the doctrine of inequitable conduct, innovators should disclose all of the relevant prior art information they have, and should not disclose false information with the intent to deceive the PTO. However, the PTO has made it clear that applications will not be investigated and rejected based on violation of the duty to disclose prior art, as the PTO is not well-equipped to enforce such a rule (Kesan, 2002). Hence, innovators have no explicit (and possibly weak) incentives to search for relevant information, and perhaps even fewer to reveal it.[4] It is worth mentioning that, even though innovators may have an incentive to conceal information, patent lawyers may not. Indeed, they do not want to suffer reputational harm, either within the PTO or with other innovators. Although the PTO does not prosecute behavior through the doctrine of inequitable conduct, courts do, even if rarely invoked, and that will substantially impact patent lawyers. Therefore, what we have in mind here is that innovators can hide information from their patent attorneys. If lawyers do not ask questions, innovators do not give answers and, thus, the integrity of lawyers is not involved. Even though innovators are likely to hire patent lawyers, or to have their own patent attorney team in-house, to perform part of the prior art search, we believe that the non-patented information, that is more difficult to access, can be provided directly by innovators themselves (e.g., notebooks filled with valuable information that are sitting in laboratories).

In this paper we investigate the determinants of patent quality by focusing on the processes employed both by innovators and patent examiners in gathering information. We analyze the patenting process as a sequential bilateral information gathering game in which players have different objectives. On the applicant side, innovators search for prior art information and, if discovered, decide whether or not to reveal it. On the other hand, from the PTO's perspective, as there is often uncertainty on patent applications, the ultimate goal of the PTO is to reject non-patentable innovations and accept patentable ones.

We model the PTO as an imperfect "auditor," whose task is to determine patent validity.

patent office (EPO) provides a search report to the innovator, who decides whether or not to request the patent examination (Graham, Hall, Harhoff and Mowery, 2002).

[4]This is again consistent with empirical findings by Sampat (2005); many applicants do not search for, or fail to disclose, prior art, as suggested by the fact that examiners tend to insert relevant patents that are owned by the applicants themselves. It is unlikely that innovators are unable to find information about their own patents. Lerner (2002) presents examples of financial patents where the prior art cited seems clearly incomplete.

Arguably, establishing the patentability of an innovation depends both on the quality of the information cues (e.g., innovation attributes, prior art cited) given by the applicant and on the quality of the information sources used by the examiner (e.g., prior art database) to screen the application. An examiner knows that the amount of prior art reported by the innovator depends on the field to which the innovation belongs. In mature fields – say pharmaceuticals – the examiner often has rich prior art databases and is able to perform a quick and exhaustive prior art search. Moreover, she expects to receive more prior art, as she believes it is more abundant and freely available. This is unlike emerging fields – say nanotechnology – where prior art, which may or may not be abundant, is often unavailable to examiners. Indeed, it is more likely for prior art to appear in scientific publications or other sources, rather than in patent databases.[5] In the latter case, the examiner has a hard time determining whether the innovation originates from a rich or a poor prior art field (or subfield), and must process the application with what the innovator has chosen to disclose.[6] In this setup, releasing less information essentially increases the screening cost of the examiner, who, in turn, performs less scrutiny on applications with low informational content. Because innovators have some private information about the patentability of their innovations, this naturally creates incentives for applicants with non-patentable innovations to conceal some information so as to maximize their chances of getting through the patent process.[7]

Our objective is to address several questions: What is the behavior of innovators when applying for a patent? What should be the optimal PTO examiner response to a given patent application? How are innovators' search efforts and examiners' scrutiny related? Should an examiner devote more time to an innovation that appears difficult to judge?

In the absence of scrutiny commitment from the PTO, we show that the screening intensity of patent examiners is contingent upon the level of prior art transmitted; the more information

[5] This is because in these fields, when prior art exists, it is usually not in the form of patents. As pointed out by Jaffe and Lerner (2004), "Patent examiners are not very good at finding non-patented prior art." Allison and Hunter (2006) and Sampat (2005) make similar observations.

[6] Sampat (2005) shows that in emerging fields, innovators usually have better knowledge of non-patented prior art.

[7] In practice, the PTO sorts out applications according to relevant prior art categories. Each of these categories has a team of specialized examiners in a particular prior art field. As noted by Allison and Hunter (2006), this sorting process often gives rise to strategic drafting, as "skilled patent attorneys can often draft applications so as to opt out of a predefined category." For a concise description of the patenting process, see also Lerner (1995).

transmitted, the higher the screening intensity. As such, innovators with non-patentable innovations tend to direct their innovations toward fields that are reputedly poor in prior art. As a result, emerging fields, where scrutiny is less intense, tend to attract more bad applications. We discuss the empirical validity of this equilibrium and its consequences. Although the main focus of our work is to develop a theoretical framework to analyze the strategic behavior of patent applicants, an important question is whether our equilibrium analysis reflects existing behaviors. In a recent contribution, Allison and Hunter (2006) describe the change in the behavior of patent applicants that has occurred since the PTO strengthened the application review procedure for innovations belonging to one specific emerging field. This program, called the Second Pair of Eyes Review (SPER), consists of a second examination of patents granted in the main class 705 (e.g., data processing, financial, business practice). We analyze the effects of the introduction of the SPER in our theoretical framework. Our results are consistent with the empirical findings of Allison and Hunter (2006): many applicants seem to alter the nature of their patent applications in order to avoid the additional scrutiny of the SPER program. Even though this policy helps to reduce strategic non-revelation of information, its success remains unclear. Indeed, the reduction of strategic behavior in the poor prior art field implies that more bad innovators will apply in the rich prior art field, therefore reducing the "quality" of patents in this latter field. Thus, it is difficult to assess whether this policy is successful by looking only at its implications in the poor prior art field. It is necessary to understand how a change in one field will affect other fields. We then introduce another policy, in which we investigate whether the *ex ante* commitment of the PTO to a certain level of complementary search can induce innovators to search for more prior art, and then to reveal their findings. From a policy implication perspective, we find that the PTO should not have different levels of search, but, rather, should commit to an equal screening intensity across all applications. This simple rule has two advantages: first, it requires a limited commitment power from the PTO and, second, it induces truthful information transmission from innovators.

To the best of our knowledge, in the economic patent literature, little attention has been devoted to issues related to the search and revelation of prior art information. Related to our model, Caillaud and Duchêne (2005) analyze the determinants of patent quality, but they are concerned with the "overload" problem facing the patent office. In their model a patent examiner undertakes a costly search and examination that depends on the volume of applications. We do not account for the overload problem in our setting.

Most of the patent literature has focused on the importance of patent litigation (Lanjouw and Schankerman, 2001) or settlement in case of patent infringements (Crampes and Langinier, 2002). Many contributions are concerned with the patent rules that affect the value of a patent in the context of sequential innovation (Chang, 1995; Scotchmer, 1996; O'Donoghue, 1998; Schankerman and Scotchmer, 2001). Scholars in law and economics have brought attention to the problem of search of prior art information, yet no formal framework has emerged to analyze the patent granting process (see Farrell and Merges, 2004; Kesan, 2002; Lemley, 2001; Merges, 1999). Our paper is a contribution to this literature.

Because of the lack of accessible data, only recently has some empirical attention been focused on prior art problems (Sampat, 2005; Alcacer and Gittelman, 2006). The roles of patent examiners and applicants have been studied. Their findings are mostly consistent with issues we are tackling in this paper.

One can also think of new ways of rewarding PTO examiners, or implementing an opposition system similar to what exists in Europe, as has been suggested by Merges (1999).[8] But it is not just the PTO examiners' responsibility; innovators are liable, too. Because it is well-established that (non-patent) prior art information is not easily available and that the PTO does not (and cannot) enforce the "doctrine of inequitable conduct,"[9] innovators have no incentive to make the effort to search for prior art, and little incentive to reveal it. However, in many instances, the relevant information exists and can be accessed at a cost.[10,11]

Another related strand of literature is the literature on auditing and monitoring. In the context of a principal-agent model, Levitt and Snyder (1997) put the emphasis on the role of the transmission of information from agent to principal. They show that contracts must sometimes reward agents for announcing bad news. Thus, as we find in our model, the principal commits *ex ante* to an inefficient *ex post* outcome. Also related to our analysis, Khalil's (1997) model

[8] For details on the opposition system, see Graham, Hall, Harhoff and Mowery (2002) and Friebel, Koch, Prady and Seabright (2006) for a detailed report on the European Patent Office.

[9] See Kesan (2002) for details about the law. Farrell and Merges (2004) are also in favor of providing better incentives for applicants to find and disclose prior art.

[10] Moreover, intuition suggests that innovators, being familiar with their innovation, know where to search.

[11] On the website Bountyquest.com, one can post an announcement to find prior art concerning a patent for a reward of from $10,000 to $30,000. There exist other websites where prior art information can also be added to a patent (e.g., PatentFizz).

studies the optimal contract when there is no commitment to an audit policy from the principal. More recently, Strausz (2005) analyzes the strategic effect of monitoring versus auditing, and Mitusch (2006) focuses on auditing in a sequential game without commitment. In common with this literature, we show that in the absence of any credible mechanism for committing to an auditing procedure, there is no plausible equilibrium in which only good innovators apply for patents.

The paper is organized as follows. In section 2, we present the model and the technologies of patent examination and prior art search. In section 3, we show that, in case of non-commitment from the USPTO, there is no equilibrium in pure strategies. An equilibrium exists only in mixed strategies in which the innovator does not always reveal the information obtained. In section 4, we analyze the effects of a policy change called the Second Pair of Eyes Review initiative. Section 5 is devoted to the analysis of a second policy change in which the PTO can *ex ante* commit to certain levels of scrutiny. We conclude and derive policy implications in section 6.

2 The Model

We consider a sequential game with two players: a patent applicant endowed with an innovation and a PTO examiner who must judge the granting of a patent.[12] At the outset, neither the innovator nor the PTO know the (social and private) value of the innovation. A "good" innovation should be patented because it is novel, non-obvious and useful. A "bad" innovation should not be granted a patent, as it is a non-patentable innovation that infringes upon existing patents or is not novel. Both the applicant and the PTO share common prior beliefs about the value of the innovation: it is good with probability p.

The private (respectively, social) value of a good innovation when it is patented is $\overline{V}$ (respectively, $\overline{W}_G$); whereas, when it is not patented, it is v (respectively, $\overline{W}_R$) with $\overline{V} > v$ ($\overline{W}_G > \overline{W}_R$).[13] The applicant gets a positive benefit from exploiting his non-patented patentable innovation because it is new. On the other hand, the private (respectively, social) value of a bad

[12] We consider that the PTO and examiners have the same objective functions and, thus, the PTO and PTO examiners represent the same decision maker. However, it is unlikely that they always have the same objectives. Langinier and Marcoul (2007) analyze the problem of examiners' career concerns.

[13] The upper (respectively, lower) bar indicates a good (respectively, bad) innovation, and the subscript G (respectively, R) indicates granting (respectively, refusing) a patent.

innovation that is wrongly patented is $\underline{V}$ (respectively, $\underline{W}_G$) and 0 (respectively, $\underline{W}_R$) if it is not patented, with $\underline{V} > 0$ ($\underline{W}_R > \underline{W}_G$). The applicant prefers to be wrongly granted a patent, as the probability of it being invalidated in court is relatively small, or a trial may invalidate only part of the claims. Overall, $\overline{V} > \underline{V}$, and we assume that $\Delta V \equiv \overline{V} - \underline{V} - v > 0$; that is, the difference in private value between good and bad innovations is greater when the innovation is patented. We further assume that granting a patent on a patentable innovation has a higher (or potentially equal) social value than refusing a patent on a non-patentable innovation, which, in turn, has a higher value than refusing a patent on a good innovation, which is better than granting a patent on a bad innovation, i.e., $\overline{W}_G \geq \underline{W}_R > \overline{W}_R > \underline{W}_G$. This assumption implies that $\overline{W}_G - \underline{W}_G > \overline{W}_R - \underline{W}_R$. Finally, we define $\Delta W \equiv \overline{W}_G - \overline{W}_R - \underline{W}_G + \underline{W}_R > 0$, which represents the social gain from avoiding errors (an error being refusing a patent on a good innovation, or granting a patent on a bad innovation).

Having done the original work, the applicant is, nonetheless, aware of the inventive degree of his innovation. It can be new or an improvement of another innovation, but can still be novel enough to be patented. In the latter case, it is more likely that there exists substantial prior art information. Hence, the innovator is aware of the field of prior art to which his innovation belongs, whereas the PTO is not. An innovation can belong to a field where there is, from the PTO's perspective, very little prior art, called a "poor prior art field" (or "emerging field") or, conversely, it can belong to a "rich prior art field"(or "mature field"). The notion that a field is poor in prior art is, of course, relative, and we have in mind a situation in which prior art is more difficult to find, either because it is scarce or because it is scattered across many sources, as would be the case for non-patent prior art (Sampat, 2005). When she receives an application, the examiner may not be certain about the exact field to which the innovation belongs. This is typically the case with "cross-disciplinary" innovations. If the innovation is a standard drug, there is little doubt in the mind of the examiner about the field to which it belongs. However, if the innovation – say a molecular device – is used for therapeutic ends, it is less clear in which "category" the patent belongs.[14] Similarly, even if two fields are rich in prior art, the nature of the existing prior art may actually differ. An examiner (or a patent

[14] In practice, a supervising primary examiner sorts out and allocates every application to one of 235 art units. Every unit specializes in a given field and will evaluate the patentability of the innovation. As Allison and Hunter (2006) report, "skilled patent attorneys can often draft applications so as to opt out of a predefined category."

attorney) will typically be well-informed when there is abundant "patent" prior art.[15] However, in absence of patent prior art, the PTO has an (informational) disadvantage, as there still may exist substantial "non-patent" prior art. Thus, if an application does not contain non-patent prior art, the examiner will have a hard time telling if the prior art is missing because it has not been revealed or because there was simply none to be found. To represent this ambiguity about the true nature of the innovation, we let γ (respectively, $1-\gamma$) be the probability that the innovation belongs to a mature (respectively, emerging) field.

We now detail each of the components of the model.

2.1 Search of Prior Art Information

At the outset, the patent applicant decides the level of effort to devote to prior art search. If he exerts an effort e he will find a certain amount of prior art $x \in \{\underline{x}, x_i, \overline{x}\}$ with $0 \leq \underline{x} < x_i < \overline{x} \leq 1$. To simplify, we assume that the effort of the innovator generates a probability of finding prior art $e \in [0,1]$ and has a disutility equal to $c(e) = e^2/2$.

The amount of prior art found is private information to the applicant and can take three values: the minimum value $\underline{x}$ that we normalize to be 0, the intermediate level x_i or the maximum amount $\overline{x}$ that we normalize to be 1. How much prior art is found depends on the field to which the innovation belongs. When it belongs to a mature (respectively, emerging) field, the innovator finds the maximum amount 1 (respectively, the intermediate amount x_i) with probability e, and during the search he learns whether his innovation is good or bad.[16] This reflects the superior knowledge of patent applicants about the innovative value of their innovations (Sampat, 2005). It also underlies the fact that a fair amount of learning about novelty takes place when innovators prepare their patent application (Trajtenberg et al., 2000). We assume that the discovery of the patentability is soft information and, if necessary, its content can be omitted without altering the overall amount of prior art submitted.[17] Independent of the prior art field, with probability

[15] In fact, patent attorney offices employ many former PTO examiners, either as advisers or as patent attorneys. For a description of PTO examiner careers in the U.S., see Jaffe and Lerner (2004).

[16] We assume perfect learning by innovators. This assumption only simplifies the finding of the results, and one would obtain the same qualitative results by relaxing this assumption and assuming, for instance, that only a fraction of innovators learn their type.

[17] Typically, the innovator can find a citation that may invalidate his patent or significantly reduce the scope of his claims. He may simply remove this citation and pretend he never encountered it.

$(1-e)$ the innovator discovers no information and learns nothing about the patentability of his innovation. After having searched for prior art, he decides to apply for a patent and to reveal $\widetilde{x}$.

The PTO examiner does not observe the effort of the patent applicant or what he actually found, she is just aware of the announced level of prior art $\widetilde{x}$ when she receives a patent application, and updates her beliefs accordingly. We assume that if the application contains no prior art, it does not provide enough information to be eligible for evaluation.[18] When the examiner receives x_i or 1 she makes a scrutiny effort $E \in [0,1]$ to search for complementary information in order to be able to determine the patentability of the innovation.

Our decision-making technology for granting or refusing patents to innovations emphasizes the importance of the beliefs that the examiner holds about the quality of a given innovation. When she exerts an effort E, the examiner receives with probability E a signal indicating the true nature of the innovation. Conversely, with probability $(1-E)$, she receives an uninformative signal distributed according to her updated beliefs. Formally, these assumptions imply that if the examiner believes that an innovation is patentable with probability μ, conditionally on the innovation being patentable (*Good*), the probability of (rightly) granting a patent is

$$P\left(granting \mid Good\right) = E + \left(1-E\right)\mu,$$

whereas the probability of (incorrectly) refusing a patent to a good innovation is

$$P(refusing \mid Good) = \left(1-E\right)\left(1-\mu\right).$$

In our model, although a higher scrutiny effort results in a patentable innovation being more often granted a patent, the unconditional acceptance rate is independent of the effort exerted by the examiner. In other words, the signal received by the examiner does not contain any information about the quality of the signal received and, therefore, her decision rule is to follow the signal received. The cost of the complementary information search is

$$C_{\widetilde{x}}\left(E\right) = \tfrac{K}{\widetilde{x}(1-E)}, \tag{1}$$

where $\widetilde{x} \in \{x_i, 1\}$ and $K > 0$. The rationale for this cost function goes as follows. If the PTO wanted any potential innovation to be scrutinized with perfect accuracy, the cost would be

[18] In a more dynamic context, we could assume that the innovator can make another effort and eventually apply during the next period. Here we make the assumption that the PTO does not accept empty files to screen.

infinite. Furthermore, the cost is affected by the prior art $\widetilde{x}$ transmitted by the applicant. A lower amount of information tends to raise the overall cost of examination. This "complementarity" between the quality of the information provided by the applicant and PTO efficiency is an important aspect of this relationship.[19]

To summarize, the timing is the following:

- On date 0, the PTO designs the patent policy: *i*) non commitment case – the PTO examiner only responds to the information transmitted, *ii*) SPER – the PTO examiner puts more emphasize on emerging fields, *iii*) commitment case – the PTO examiner commits *ex ante* to certain levels of scrutiny efforts.

- In cases *i*) and *ii*),

  – on date 1, the innovator decides how much effort e to put into prior art search. He finds a certain amount of prior art x and learns whether his innovation is patentable or not. Then he files a patent application with announced prior art $\widetilde{x}$;

  – on date 2, the examiner observes the innovator's announcement $\widetilde{x}$, and decides to undertake a complementary search effort E. Depending on the signal received during the examination, she decides whether or not to grant a patent.

- In case *iii*),

  – on date 1, the examiner *ex ante* commits to certain levels of scrutiny effort;

  – on date 2, knowing the levels of effort of the examiner, the innovator chooses his search effort level e. He finds a certain amount of prior art x and learns whether his innovation is patentable or not. Then, he files a patent application with announced prior art $\widetilde{x}$;

  – on date 3, the examiner grants or not a patent based on the announced information.

In the rest of this section and the next, we focus on the commitment case (case *i*) where the examiner responds to the information transmitted in the patent application. The structure of

[19]Alternatively, we could assume that the innovator may provide the PTO with too much "non-relevant" information in order to discourage serious checking. In each case, the strategy of the innovator amounts to an increase in the search costs of the PTO that may result in a less accurate decision.

examination technology in case of the introduction of the SPER (case *ii*) and in the commitment case (case *iii*) will be introduced in later sections.

2.2 Examination Technologies and Prior Art Search

We now present the structure of the PTO's patent examination technology, and the innovator's prior art search technology when the PTO does not commit *ex ante* to any scrutiny level of efforts (case *i*).

2.2.1 PTO Examination Technology

The patent examiner decides to search for complementary information and grant a patent based on the announced prior art $\widetilde{x}$. If the application contains the intermediate or the maximum amount of prior art, the examiner first updates her beliefs and then decides how much effort to put into checking the application. Her updated beliefs depend crucially on her anticipation of the applicant's behavior. More precisely, the examiner draws some inference about validity by considering the amount of prior art reported in the patent application. Note that if the applicant has an incentive to withhold prior art information, the examiner has no reason to believe that a given application has a probability p of being patentable. Formally, $\mu_{\widetilde{x}}$ denotes the probability that the innovation is good, given that $\widetilde{x} \in \{x_i, 1\}$ has been revealed in the patent application. The maximization program of the examiner is

$$\underset{E}{Max}[B(E;\mu_{\widetilde{x}}) - C_{\widetilde{x}}(E)], \tag{2}$$

where her gross benefit is

$$\begin{aligned} B(E;\mu_{\widetilde{x}}) &= \mu_{\widetilde{x}}(E + (1-E)\,\mu_{\widetilde{x}})\overline{W}_G + \mu_{\widetilde{x}}\,(1-E)\,(1-\mu_{\widetilde{x}})\,\overline{W}_R \\ &\quad + (1-\mu_{\widetilde{x}})\,(E + (1-\mu_{\widetilde{x}})\,(1-E))\underline{W}_R + (1-\mu_{\widetilde{x}})\,(1-E)\,\mu_{\widetilde{x}}\underline{W}_G. \end{aligned} \tag{3}$$

The gross benefit depends on examiner effort E and on her updated beliefs $\mu_{\widetilde{x}}$, contingent upon the information received. The first part of $B(E;\mu_{\widetilde{x}})$ represents the expected social value of a good innovation. With probability $\mu_{\widetilde{x}}$, the innovation is good. The examiner receives a signal indicating that the innovation is good (respectively, an uninformative signal) with probability E (respectively, $(1-E)$) and grants a patent with probability 1 (respectively, with probability $\mu_{\widetilde{x}}$) to a good innovation that generates a value $\overline{W}_G$ to society, and does not grant a patent to a good innovation with probability $(1-E)(1-\mu_{\widetilde{x}})$ that generates a social value $\overline{W}_R$. This is a type I error of refusing a patent to a deserving innovation. The second part of the gross benefit represents the expected social value of a bad innovation. With probability $(1-\mu_{\widetilde{x}})$, the innovation is bad, the examiner receives an informative (respectively, uninformative) signal with probability E (respectively, $(1-E)$), and does not grant a patent with probability 1 (respectively, $(1-\mu_{\widetilde{x}})$), which generates a social value $\underline{W}_R$. On the other hand, she receives an uninformative signal and wrongly grants a patent to a bad innovation with probability $(1-E)\,\mu_{\widetilde{x}}$ that is worth $\underline{W}_G$ to society. This is a type II error.

To summarize, two types of errors can be made in the patent granting process with probability $\mu_{\widetilde{x}}(1-\mu_{\widetilde{x}})(1-E)$: either a type I error of refusing a patent to a good innovation, or a type II error of wrongly granting a patent to a bad innovation.

The solution to the maximization program (2) with gross benefit (3) and cost (1), can be written as

$$\mu_{\widetilde{x}}(1-\mu_{\widetilde{x}})\,\widetilde{x}\Delta W = \frac{K}{(1-E)^2}. \tag{4}$$

Solving (4) with respect to E leads to the generic level of effort

$$E^*_{\widetilde{x}} = 1 - \left[\frac{K}{\mu_{\widetilde{x}}(1-\mu_{\widetilde{x}})\widetilde{x}\Delta W}\right]^{\frac{1}{2}} < 1, \tag{5}$$

where $\widetilde{x} \in \{x_i, 1\}$ and $K < \mu_{\widetilde{x}}(1-\mu_{\widetilde{x}})\,\widetilde{x}\Delta W$ to insure interior solutions.

The PTO will exert a high level of scrutiny effort on a fraction $E^*_{\widetilde{x}} > 0$ of the applications that contain a level $\widetilde{x}$ of prior art, whereas a fraction $(1-E^*_{\widetilde{x}})$ will not be scrutinized as thoroughly.[20] The more information transmitted to the patent examiner, the greater her scrutiny effort.

2.2.2 Applicant Prior Art Search Technology

The applicant makes two sequential decisions: he first decides how much effort to put in prior art search and, second, chooses how much to report to the PTO. Using standard techniques, we first define the optimal report and, lastly, the optimal effort choice. For every effort level of the innovator, we characterize his expected benefit, after having determined the optimal level of examiner effort and the optimal amount of prior art that the innovator reveals.

[20] It is important to note that our model introduces some restriction on the parameters. In particular, the term $\mu_{\widetilde{x}}(1-\mu_{\widetilde{x}})\,\widetilde{x}\Delta W$ should be strictly greater than K. We assume that the value of an innovation to society is high, so that the previous condition is true for almost all possible beliefs of the PTO about the innovation.

We first determine what the (strategic) announcement of the applicant must be. After undertaking a search effort, he finds prior art information that can be x_i or 1, and learns the value of his innovation. For expositional purposes, we call a good (respectively, bad) applicant an innovator who learns that he has a patentable (respectively, non-patentable) innovation.

As the applicant cannot report more than he actually found, if he gets no information he reports nothing. If he finds the intermediate level of information, x_i, he can either report 0 or x_i. However, there is no gain from reporting 0, since in our setting, the PTO does not grant a patent if the patent application contains no prior art. Therefore, whatever the value of the innovation, he should always report truthfully, $\widetilde{x} = x_i$.

If the applicant finds all of the information $x = 1$, he can announce either 0, x_i or 1. As announcing nothing is a strictly dominated strategy, it is never chosen by the innovator. We then determine under what circumstances he reports truthfully.

Before doing so, to complete our analysis, we need to be more specific about the cost associated with lying. Indeed, concealing information may have an impact on the reputation of the innovator or, to some extent, of his lawyers. If the duty of candor was strong, and the rule was actually carefully enforced by the PTO (or the court), it would be crucial to account for the cost associated with a loss in reputation or with a sanction inflicted on the innovator who was proven not to report truthfully. To model this in a simple way, we assume that the private value of the innovation $V = \{\overline{V}, \underline{V}\}$ is negatively affected by the reputational cost F, where $\overline{V}$ (respectively, $\underline{V}$) is the private value of a patented good (respectively, bad) innovation. Hence, whenever the applicant does not reveal the truth, his payoff may be lower, i.e., $V(F) \leq V$ where $V'(F) < 0$ and $V(0) = V$. To simplify we assume that $V''(F) = 0$.

If the innovator learns that his innovation is good, his expected gain is

$$E_{\widetilde{x}}\overline{V} + (1 - E_{\widetilde{x}})[\mu_{\widetilde{x}}\overline{V} + (1 - \mu_{\widetilde{x}})v],$$

where v is the private value of a non-patented good innovation, $E_{\widetilde{x}}$ is the effort performed by the examiner, conditional upon receiving $\widetilde{x}$, and $\mu_{\widetilde{x}}$ is the corresponding updated belief. Thus, if a good innovator finds the maximum amount of prior art, he reveals all of it, as long as[21]

$$E_1\overline{V} + (1 - E_1)[\mu_1\overline{V} + (1 - \mu_1)v] > E_i\overline{V}(F) + (1 - E_i)[\mu_i\overline{V}(F) + (1 - \mu_i)v]. \quad (6)$$

[21] By a slight abuse of notation, we denote E_{x_i} by E_i and μ_{x_i} by μ_i.

On the other hand, a bad innovator who has an expected gain $(1-E_{\widetilde{x}})\mu_{\widetilde{x}}\underline{V}(.)$, reports truthfully if

$$(1-E_1)\mu_1\underline{V} > (1-E_i)\mu_i\underline{V}(F). \tag{7}$$

Inequalities (6) and (7) represent the conditions under which both types fully report their findings.

Finally, the patent applicant must choose his effort level in searching for prior art, which is the solution of

$$\underset{e}{Max}\{\Pi(e)-c(e)\},$$

where the gross benefit $\Pi(e)$ will be defined later.

3 Non Commitment Case: Equilibrium Outcomes

We first characterize the applicant's optimal transmission of information after finding prior art information and learning whether his innovation is good or bad, and we derive the Perfect Bayesian equilibrium. Second, we determine the optimal search strategy of the innovator.

3.1 Optimal Transmission of Information

We consider first that no matter what he learned, the applicant reports truthfully. The updated beliefs of the examiner, consistent with this behavior, are

$$\begin{aligned}
&\mu_1 = \Pr(Good \mid \widetilde{x}=1) = \tfrac{p\gamma}{p\gamma+(1-p)\gamma} = p,\\
&\mu_i = \Pr(Good \mid \widetilde{x}=x_i) = \tfrac{p(1-\gamma)}{p(1-\gamma)+(1-p)(1-\gamma)} = p,\\
&\Pr(Good \mid \widetilde{x}=0) = p,
\end{aligned}$$

where posterior beliefs are equal to prior beliefs.

The patent examiner chooses the optimal levels of effort depending on the transmitted information $\widetilde{x}$. When she observes $\widetilde{x}$, the first order condition (4) gives the optimal level of effort

$$E^*_{\widetilde{x}t} = 1-\left[\tfrac{K}{\widetilde{x}p(1-p)\Delta W}\right]^{\frac{1}{2}}, \tag{8}$$

where t stands for truthful for $\widetilde{x}=\{x_i,1\}$. The effort levels E^*_{1t} and E^*_{it} are increasing (respectively, decreasing) with the prior belief p, if p is smaller (respectively, higher) than 1/2. Beliefs and effort levels are substitutes in the mind of the examiner. Therefore, starting from a prior belief $p < 1/2$, the effort levels E_{1t}^* and E_{it}^* increase when the prior art belief p becomes more "diffuse" and approaches 1/2. When $p \geq 1/2$ and increases further, the examiner chooses to devote less effort to scrutiny and gives more weight to her priors when deciding to grant a patent. If there exists an equilibrium in which both good and bad applicants report truthfully, then $E_{1t}^* > E_{it}^*$ *for* $p \in [\underline{p}_i, \overline{p}_i]$ (all the proofs are relegated to the appendix). The intuition is straighforward. The examiner intensifies her scrutiny effort when she receives more information, as it is less costly to do so.

We now define the best revelation strategy of the applicant, depending on the PTO's complementary search effort. A good applicant who finds the full amount of prior art has no incentive to transmit less information. Indeed, knowing that his innovation is good, he is better-off fostering the chance that the PTO will discover the exact type of his innovation.[22] Formally, the inequality (6) is always satisfied, as $\overline{V} > v$. Indeed, if the inequality (6) is satisfied for $\overline{V}(F) = \overline{V}$, it is always satisfied for any $\overline{V}(F) < \overline{V}$. On the other hand, a bad applicant who finds the full amount of prior art reports truthfully if the inequality (7) is satisfied. Let us define F_1 such that $\underline{V}(F_1) = (1 - E_{1t}^*)\, \underline{V} / (1 - E_{it}^*)$. A bad applicant always report truthfully if $\underline{V}(F) \leq \underline{V}(F_1)$, or equivalently, for any $F \geq F_1$. On the contrary, for any $F < F_1$, he conceals information. In the latter case, the inequality (7) is never satisfied, since $E_{1t}^* > E_{it}^*$ for $p \in [\underline{p}_i, \overline{p}_i]$, and $E_{1t}^* > E_{it}^* = 0$ for $p \in]\underline{p}_1, \underline{p}_i] \cup [\overline{p}_i, \overline{p}_1[$ (see appendix for $\underline{p}_1$ and $\overline{p}_1$). Thus, when $F < F_1$, inequality (7) is never satisfied for $p \in]\underline{p}_1, \overline{p}_1[$, and there is no equilibrium in which the applicant reports truthfully. The intuition is the following. When the cost of not revealing the truth (in term of reputation, or direct sanction in the case of a lawsuit) increases, innovators are more likely to report truthfully. In fact, in a system where it would be possible to perfectly enforce the duty of candor rule, applicants would report all of the information they have. However, as explained in the introduction, the PTO does not currently enforce this rule, and it is more likely that the cost F is small.[23] Therefore, innovators do not report truthfully.

We posit our first set of findings, when the cost of concealing information is high:

[22] Another strong reason to reveal all of the prior art found is that uncited prior art is a more effective tool for invalidating patents in court than cited prior art (Allison and Lemley, 1998). In other words, when it is known that the innovation is novel, not including prior art could result in a weaker patent when it is later litigated.

[23] A patent attorney who fails to bring pertinent references to the examiner's attention can be disciplined or barred from practicing before the PAT, as in Mossinghoff, 822 F. 2d 1053 (Federal Circuit 1984). However, there are very few cases of court dispute.

Lemma 1 *If $F \geq F_1$, it is optimal for the applicant to report truthfully. The level of scrutiny exerted by the examiner depends on the amount of prior art transmitted $\widetilde{x}$. She always exerts a higher level of scrutiny effort when she receives more prior art ($E^*_{1t} > E^*_{it}$) for $p \in [\underline{p}_i, \overline{p}_i]$. Moreover, irrespective of the amount of prior art received, her effort is maximized when $p = 1/2$.*

The restriction on prior beliefs $p \in [\underline{p}_i, \overline{p}_i]$, with $0 < \underline{p}_i < 1/2 < \overline{p}_i < 1$, insures interior and strictly positive solutions E^*_{1t} and E^*_{it} to the maximization program (2). The intuition of this result goes as follows. When uncertainty about patentability is relatively high, the examiner exerts a higher level of scrutiny whenever she observes the intermediate or the full amount of prior art. When the uncertainty is very low (i.e., for values of p close to 0 or to 1), the examiner believes that the innovation is either bad or good, and it becomes too costly to exert a real scrutiny effort. She then prefers to grant patents according to her prior beliefs.

However, when $F < F_1$, there exists no equilibrium in pure strategies in which a bad innovator who finds the full amount of prior art reports truthfully when $p \in]\underline{p}_1, \overline{p}_1[$ (these restrictions insure interior or null solutions). For values of p close to 0 or to 1, as the examiner makes no effort whatever the information received ($E^*_{1t} = E^*_{it} = 0$), the innovator is indifferent between revealing the truth or not. If we assume that the innovator always reveals the truth when he is indifferent, we have an equilibrium in which the innovator reports truthfully and the examiner makes no complementary effort. This is only true when there is almost no uncertainty.

When uncertainty is reasonably high, and the reputational cost is relatively low, $F < F_1$, there exists no equilibrium in pure strategies in which a bad applicant reports truthfully when he finds the full amount of prior art. Using the same argument, we show that there is no equilibrium in pure strategies in which either the bad applicant always conceals some information and reveals only an intermediate amount, or both good and bad applicants conceal some information (see appendix for the proof on the non-existence of equilibrium).

We summarize these findings:

Lemma 2 *If $F < F_1$, there exists no equilibrium in pure strategies when $(p, \gamma) \in \Psi_l$.*

When it is not costly to conceal information, applicants have no incentive to always report truthfully or to always lie, but they can sometimes report truthfully. Therefore, we consider a Perfect Bayesian Equilibrium in which a bad applicant randomizes his report decision. We let θ denote the probability that a bad applicant who finds the full amount of prior art reports truthfully, $\widetilde{x} = 1$, and conceals information with the complementary probability, $(1 - \theta)$.

When the examiner receives a patent application containing $\widetilde{x} = 1$, it either originates from a good or a bad applicant. When she receives a patent application containing $\widetilde{x} = x_i$, it can come from a good or a bad applicant who has discovered the intermediate level, but also from a bad applicant who has found $x = 1$ but has concealed some information. However, it cannot come from a good applicant who has found $x = 1$.

The updated beliefs of the examiner consistent with randomization are

$$\begin{aligned} &\mu_1(\theta) = \Pr(Good \mid \widetilde{x} = 1) = \tfrac{p\gamma}{p\gamma + \theta(1-p)\gamma} = \tfrac{p}{p+\theta(1-p)}, \\ &\mu_i(\theta) = \Pr(Good \mid \widetilde{x} = x_i) = \tfrac{p(1-\gamma)}{1-\gamma+(1-\theta)(1-p)\gamma}, \\ &\Pr(Good \mid \widetilde{x} = \underline{x}) = p. \end{aligned} \tag{9}$$

In this equilibrium, a bad applicant must be indifferent between revealing the full amount of prior art and getting $\mu_1(1 - E_1)\underline{V}$, and revealing the intermediate level and getting $\mu_i(1 - E_i)\underline{V}(F)$. Thus, there exists a value of θ that must satisfy

$$\mu_1(\theta)(1 - E_1)\underline{V} = \mu_i(\theta)(1 - E_i)\underline{V}(F), \tag{10}$$

which is

$$\theta^* = \tfrac{(1-E_1)\underline{V}(1-p\gamma)-(1-\gamma)p(1-E_i)\underline{V}(F)}{(1-p)[(1-\gamma)(1-E_i)\underline{V}(F)+\gamma(1-E_1)\underline{V}]}, \tag{11}$$

where $0 < \theta^* < 1$.

We can posit the following result.

Lemma 3 *If $F < F_1$, whenever the equilibrium effort levels of the PTO are such that $E_1 > E_i$, there exists a unique probability θ^* defined by (11) with which a bad applicant discloses the full amount of prior art. This probability decreases with p and E_1, and increases with γ, F and E_i.*

These findings emphasize the main strategic tension faced by an innovator who has discovered that his innovation is non-patentable. The probability θ^* measures the extend to which the innovator behaves honestly. The effects are straightforward: when the examiner increases her scrutiny effort conditional on obtaining abundant prior art, a bad innovator tends to report less prior art in his application. Conversely, when the examiner focuses more on applications with less prior art (E_i^* higher), the applicant will transmit more information. Together, these effects suggest that to avoid strategic reporting, it might be optimal to commit to identical screening intensity, irrespective of the information provided by the applicant (the commitment case is developed in section 5). Not surprisingly, the higher the cost F, the higher θ^*. In fact, when it becomes too costly to report strategically, $\theta^* = 1$, which corresponds to an equilibrium with truthful revelation of information.

Finally, when it is more likely that the innovation belongs to an emerging field (i.e., $(1-\gamma)$ increases), a bad applicant tends to conceal information more often, and this behavior is likely to remain undetected. Thus, from an empirical standpoint, the low informational content of applications that is regularly observed in emerging fields (Sampat, 2005) can be explained not only by the natural scarcity of the prior art, but also by strategic concealment of prior art.

We now determine the set of optimal levels of examiner effort and show that it is an equilibrium. Before turning to the description of the objective functions of the examiner, it is worth describing her equilibrium beliefs. We use the probability that the applicant announces the full amount of prior art θ^* to define the updated beliefs of the examiner. By replacing θ^*, as defined by (11) in the updated probabilities (9), we obtain the equilibrium beliefs,

$$\mu_1^* = \frac{p[(1-\gamma)(1-E_i)\underline{V}(F)+\gamma(1-E_1)\underline{V}]}{(1-E_1)\underline{V}} > p \tag{12}$$

when the full amount of prior art has been revealed and

$$\mu_i^* = \frac{p[(1-\gamma)(1-E_i)\underline{V}(F)+\gamma(1-E_1)\underline{V}]}{(1-E_i)\underline{V}(F)} < p \tag{13}$$

when the intermediate amount has been revealed by the innovator.

The equilibrium efforts of the examiner account for the fact that the applicant does not behave truthfully. The solution of the maximization program (2) of the examiner (see appendix for the second order condition) when she receives $\widetilde{x} = 1$ is

$$\frac{\partial B(E_1;\mu_1^*)}{\partial E_1} = \frac{K}{(1-E_1)^2}, \tag{14}$$

and when she receives $\widetilde{x} = x_i$,

$$\frac{\partial B(E_i;\mu_i^*)}{\partial E_i} = \frac{K}{x_i(1-E_i)^2}. \tag{15}$$

In this setting, the effort levels of the examiner when she receives the full or intermediate levels of prior art are no longer independent. Indeed, if the applicant anticipates that the examiner will increase her effort if he reports $\widetilde{x} = 1$, he prefers to "retain" more information and submit an incomplete application. In equilibrium this should be anticipated by the examiner, who would then raise her level of effort E_i.

In order to find the effort E_1, the condition (14) must be solved with respect to the effort level, using the equilibrium prior μ_1^* and the randomization parameter θ^*:

$$E_1^*(E_i) = 1 - \left[\frac{K\underline{V}^2 - p(1-E_i)\underline{V}(F)(1-\gamma)\left(p(1-E_i)\underline{V}(F)\Delta W(1-\gamma) + \underline{V}(\overline{W}_G - \underline{W}_R)\right)}{\gamma p(1-p\gamma)\Delta W \underline{V}^2}\right]^{\frac{1}{2}}. \quad (16)$$

As E_1 is decreasing with E_i, a decrease in the examiner's effort when she receives the intermediate level of prior art E_i should trigger an increase in E_1. This increase in E_1 is necessary to make up for the increased number of strategic (and bad) applications made in the category with abundant prior art.

We also obtain the level of effort E_i as a function of E_1 using (15), μ_1^*, and the randomization parameter θ^*,

$$E_i^*(E_1) = 1 - \left[\frac{K\underline{V}(F)^2 - (1-E_1)\underline{V}px_i\gamma\left(p\gamma(1-E_1)\underline{V}\Delta W + \underline{V}(F)(\overline{W}_G - \underline{W}_R)\right)}{px_i(1-\gamma)(p\gamma+1-p)\Delta W \underline{V}(F)^2}\right]^{\frac{1}{2}}. \quad (17)$$

The derivative of $E_i^*(.)$ with respect to E_1 is also negative.

Without putting more restrictions on the parameters, by using the reaction functions (16) and (17), it is not possible to obtain a general explicit expression for the equilibrium levels E_i^* and E_1^*. However, we can state the following proposition that holds for interior solutions:

Proposition 1 *If $F < F_1$, there exists a semi-separating equilibrium in which a bad applicant randomizes his revelation, whereas a good applicant always reports truthfully. Furthermore, the level of scrutiny effort exerted by the examiner after receiving a patent application with the full amount of prior art is higher than after receiving a patent application that contains the intermediate level, that is, $E_1^* > E_i^*$ for $(\gamma, p) \in \Omega$.*

There exists an equilibrium in which a bad applicant who finds $x = 1$ randomizes his reporting decision. In this case, the examiner intensifies her complementary search when she receives more prior art for $(\gamma, p) \in \Omega$, which insures interior solutions.

To simplify, and in order to get analytical solutions, let us assume that it is socially as beneficial to grant a patent on a good innovation as to refuse one on a bad innovation (i.e., $\overline{W}_G = \underline{W}_R$). Although this assumption may not be empirically sound, it allows us to obtain analytical expressions for optimal efforts without altering our (qualitative) results. We find the following optimal efforts:

$$E_1^* = 1 - \left[\frac{K\left[x_i(1-p(1-\gamma))\underline{V}^2 - p(1-\gamma)\underline{V}(F)^2\right]}{p\gamma x_i(1-p)\Delta W\underline{V}^2}\right]^{\frac{1}{2}}, \tag{18}$$

and

$$E_i^* = 1 - \left[\frac{K\left(\underline{V}(F)^2(1-p\gamma) - \underline{V}^2 p\gamma x_i\right)}{px_i(1-\gamma)(1-p)\Delta W\underline{V}(F)^2}\right]^{\frac{1}{2}}. \tag{19}$$

The comparison of these efforts confirms that $E_1^* > E_i^*$ when uncertainty is at its highest (for $(p,\gamma) \in \Gamma$, where Γ is defined in the appendix).

As we obtain explicit solutions for the optimal levels of effort, we can make some comparative statics. Some of these findings are derived in the general case, as well.

Corollary 1 *If $F < F_1$, $\overline{W}_G = \underline{W}_R$ and holding everything else constant,*

- *E_1^* is strictly increasing with p, and E_i^* is increasing (respectively, decreasing) with p for $(p,\gamma) \in \Gamma$ (respectively, for $(p,\gamma) \notin \Gamma$),*
- *E_1^* is decreasing (respectively, increasing) with γ for $p \in [x_i/(1+x_i), 1]$ (respectively, for $p \in [0, x_i/(1+x_i)]$), and E_i^* is decreasing (respectively, increasing) with γ for $p \in [0, 1/(1+x_i)]$ (respectively, for $p \in [1/(1+x_i), 1]$).*

The logic goes as follows. Let us start at the highest level of uncertainty concerning both the value of the innovation and the field to which it belongs (i.e., p and γ are close to 1/2). For a given γ, both levels of effort increase with the probability of a good innovation p. The PTO examiner is willing to put in more effort to make her judgement more accurate when she believes the innovation is worthwhile. However, after p reaches a certain threshold as it becomes even more likely that the innovation is good, and because of the strategic report from some innovators, the examiner makes less effort when she receives less information. Indeed, she prefers to concentrate on those applications with the full amount of information.

For a given p close to 1/2, as γ increases, both levels of effort decrease. The higher the probability that the innovation belongs to a mature field, the greater the chances the innovator will find relevant prior art. Therefore, because of the complementarity between the innovator and examiner efforts, she will reduce the intensity of her scrutiny. The effect is identical on both efforts, as the uncertainty about the value of the innovation is at its highest. For a given p small enough, the examiner intensifies her search effort when she receives full information, but reduces it when she receives intermediate information. Because it is more likely that the innovation is bad, it is expected that there will be more strategic reports from bad innovators. Therefore, the examiner will intensify her scrutiny effort when she receives more information to make a more accurate scrutiny, since she receives fewer applications with the full amount of information. Lastly, for a given p high enough, the converse will arise: as γ increases, the examiner reduces her search effort when she receives the full amount, and intensifies it otherwise. In this case, it is more likely that the innovation is good and, therefore, fewer strategic reports will be made by bad innovators.

We can also state the following:

Corollary 2 *If $F < F_1$, $\overline{W}_G = \underline{W}_R$ and holding everything else constant,*

- *E_1^* is increasing (respectively, decreasing) with ΔW (respectively, with F, K* and *x_i);*
- *E_i^* is increasing (respectively, decreasing) with ΔW, F and x_i (respectively, with K).*

The higher the social gain from avoiding mistakes (i.e., ΔW), the higher the scrutiny efforts of the examiner. She intensifies her scrutiny effort when the stakes are higher. Not surprisingly, the higher K, the lower the scrutiny efforts. When it is more costly to make a complementary search, the PTO cannot put too much effort into each application. The higher the intermediate amount of information x_i, the lower (higher) the scrutiny effort when she receives more (less) information. If she receives more information in the intermediate case, she will intensify her scrutiny effort and E_i^* becomes closer to E_1^*.

As it becomes more costly to conceal information (i.e., F increases and therefore $\underline{V}(F)$ decreases), a bad applicant has less incentive to report strategically (θ^* increases or, equivalently, $(1-\theta^*)$ decreases), and the updated belief of the examiner when she receives $\widetilde{x} = 1$ decreases. This triggers the examiner to reduce her scrutiny intensity, as more bad applicants will now file a patent application with $\widetilde{x} = 1$. On the other hand, as F increases, the updated belief of the examiner when she receives $\widetilde{x} = x_i$ increases, as less strategic reporting will occur. She then intensifies her scrutiny effort when she receives the intermediate level of effort.

As a last point, let us comment on an argument made by Lemley (2001) that the PTO should not be too worried if undeserved patents are granted. If we consider that it is, in the end, not too costly to grant bad patents, we posit the following result:

Corollary 3 *Assume that there is a social loss in granting a patent to a non-patentable innovation, that is* $\underline{W}_G < 0$*. If this loss becomes smaller, the examiner should exert less scrutiny effort.*

When the social loss of granting a bad patent $\underline{W}_G$ becomes smaller, the PTO examiner should optimally rely more on her prior beliefs and less on an informed decision (E small). This intuitive result of our model replicates the argument made by Lemley (2001), mentioned above. Nevertheless, this argument hinges on the assumption that $\underline{W}_G$ is small, which remains an open question (Farrell and Merges, 2004).

3.2 Search of Prior Art for the Innovator

The innovator's first decision is to search for prior art information. While making his search decision, the innovator can correctly infer the issue of the game and, therefore, his optimal report and the optimal PTO efforts.

For $F < F_1$, the gross benefit function of the innovator is

$$\begin{aligned}\Pi(e) = \quad & e[\gamma p(E_1\overline{V} + (1-E_1)(\mu_1\overline{V} + (1-\mu_1)\,v)) + \gamma(1-p)\theta(1-E_1)\mu_1\underline{V} \\ & +\gamma(1-p)(1-\theta)(1-E_i)\mu_i\underline{V}(F) \\ & +(1-\gamma)p(E_i\overline{V} + (1-E_i)(\mu_i\overline{V} + (1-\mu_i)\,v)) + (1-\gamma)(1-p)(1-E_i)\mu_i\underline{V}] \\ & +(1-e)pv.\end{aligned}$$

His effort generates a probability e of finding prior art. Therefore, after making an effort e, with probability $(1-e)$ the innovator does not find any prior art, does not discover the value of his innovation, and therefore does not apply for a patent. If his innovation is good, he nevertheless gets a positive benefit v. Otherwise, with complementary probability e, he finds either the intermediate level of prior art if the innovation belongs to an emerging field with probability $(1-\gamma)$, or the full amount of prior art if the innovation belongs to a mature field, with probability γ. In the latter case, with probability p, the innovation is good and the examiner discovers it with probability E_1 (which is her effort when she receives $\widetilde{x} = 1$) and grants a patent. However, with probability $(1-E_1)$, she grants a patent according to her updated beliefs μ_1 (type I error). The innovation is bad with probability $(1-p)$, even though it belongs to a mature field. In this case, with probability θ the innovator reports the full amount of prior art and will be discovered as having a bad patent with probability E_1, and wrongly granted a patent with probability $(1-E_1)\mu_1$ (type II error). With probability $(1-\theta)$, a bad innovator who has found the full amount of prior art does not report truthfully, and therefore reports $\widetilde{x} = x_i$. In this case, the examiner wrongly grants a patent with probability $(1-E_i)\mu_i$ (type II error). In the former case, when the innovation belongs to an emerging field (this happens with probability $(1-\gamma)$), with probability p it is good, and therefore is granted a patent with probability $E_i + (1-E_i)\mu_i$, and is refused with probability $(1-E_i)(1-\mu_i)$. The innovation is bad with probability $(1-p)$ and is not granted a patent with probability $(1-E_i)\mu_i$.

Overall, a type I error arises with probability $\gamma p(1-E_1)(1-\mu_1) + (1-\gamma)p(1-E_i)(1-\mu_i)$, and a type II error happens with probability, $\gamma(1-p)\theta(1-E_1)\mu_1 + (1-\gamma\theta)(1-p)(1-E_i)\mu_i$. These probabilities, evaluated at the appropriate values (12), (13) and (11), are identical and can be simplified to $(1-E_1)p\gamma(1-p\gamma-p(1-\gamma)\underline{V}/\underline{V}(F)) + (1-E_i)p(1-\gamma)(1-p(1-\gamma)-p\gamma\underline{V}(F)/\underline{V})$.

From the maximization program of the innovator

$$\underset{e}{Max}\{\Pi(e) - c(e)\},$$

we derive the effort

$$e^*(F) = Min\left\{1, e_1(F) - \sigma(F)\right\}, \tag{20}$$

where

$$e_1(F) = p\Delta V(1-p)(\gamma E_1^* + (1-\gamma)E_i^*) + p^2\Delta V + p\underline{V}$$

and

$$\sigma(F) = (\underline{V} - \underline{V}(F))p\gamma(1-\gamma)\left(\frac{(1-E_i^*)}{\underline{V}} - \frac{(1-E_1^*)}{\underline{V}(F)}\right)(p\Delta V + \underline{V}). \tag{21}$$

As $\theta^* < 1$ and $\Delta V = \overline{V} - \underline{V} - v$, it follows that $\sigma(F) > 0$.

Here we focus on the effect of an increase in F on the applicants's incentives to search for information. The optimal effort can be decomposed into the two expressions $e_1(F)$ and $\sigma(F)$, as an increase in F impacts the search effort in two ways. First, it modifies the levels of scrutiny exerted by the examiner, E_1^* and E_i^*. This is the baseline search incentives represented by the first term $e_1(F)$. However, an increase in F also entails a cost for the applicant, who no longer has the same latitude to apply strategically. The expression $\sigma(F)$ reveals that an increase in F results in a loss (i.e., $\underline{V} - \underline{V}(F)$), compounded with a lower probability that a (non-patentable) innovation is granted a patent when it is misrepresented (the term $(1-E_i^*)/\underline{V} - (1-E_1^*)/\underline{V}(F)$ represents the difference in errors across categories). If $F = 0$, the second term disappears as $\sigma(0) = 0$ and, therefore, $e^*(0) = e_1(0) = p(1-p)(\gamma E_1^* + (1-\gamma)E_i^*)\Delta V + p^2\Delta V + p\underline{V}$.

Therefore, when the patent applicant (or his representative lawyers) suffers no loss from concealing important information, he should clearly behave in a strategic way and violate the duty of candor. In our model, this is the case when F is null; this might represent a situation in which no patents are prosecuted through the doctrine of inequitable conduct. On the other hand, F may reach a level such that it no longer pays to conceal information. Thus, it is of interest to understand how search incentives are affected when F increases. The next result discusses this possibility.

Lemma 4 *If $F < F_1$, the optimal effort level $e^*(.)$ is a convex function of F.*

This result is essentially driven by the shape of the cost function of strategic reporting (21): it is low when F is close to 0 (i.e., the first term of (21) is small) or when there is no incentive to report strategically (i.e., when E_1^* is close enough to E_i^* and the second term of (21) is small). The search effort is thus maximized either when F is small (maximum strategic reporting) or when F is high (no strategic reporting).

For $F \geq F_1$, the gross benefit function of the innovator is simplified, as it does not account for any strategic report from bad applicants,

$$\begin{aligned}\Pi(e) = \quad & e[\gamma p((E_1 + (1-E_1)p)\overline{V} + (1-E_1)(1-p)v)) + \gamma(1-p)(1-E_1)p\underline{V} \\ & +(1-\gamma)p((E_i + (1-E_i)p)\overline{V} + (1-E_i)(1-p)v)) + (1-\gamma)(1-p)(1-E_i)p\underline{V}] \\ & +(1-e)pv,\end{aligned}$$

and, therefore, the optimal level of effort for the applicant is

$$e_t^* = p(1-p)(\gamma E_{1t}^* + (1-\gamma)E_{it}^*)\Delta V + p^2\Delta V + p\underline{V}.$$

Not surprisingly, in this case, the optimal innovator effort is decreasing with v (the value of a non-patented innovation), since an increase in v raises the cost of doing research and patenting the innovation relative to directly selling the innovation. The effort is also increasing (respectively, decreasing) with the value of a good patented innovation $\overline{V}$ (respectively, a bad patented innovation $\underline{V}$). Further, the effort of the innovator is sensitive to examiner efforts, as $\partial e^*/\partial E_j^* > 0$ for $j = 1, i$. The greater the efforts of the examiner, the more effort the innovator will put into his search for relevant prior art. This result emphasizes the link between examiner and innovator behaviors.

The innovator's effort also varies with the amount of intermediate prior art that he can find, x_i, with the probability of having a good innovation, p, and the probability of having an innovation that belongs to a rich prior art field, γ. To see how a change in these parameters affects the effort of the innovator, we need to differentiate equation (20) with respect to these variables, taking into account that examiner efforts will also vary with them. For instance, an increase in x_i induces the examiner to intensify her research effort E_i^*, whereas she devotes less effort to search for complementary prior art when she has received the full amount of prior art, $\partial E_1^*/\partial x_i < 0$. Thus, there are two effects that work in opposite directions. On one hand, if the intermediate level of prior art that the innovator can find increases due to an increase in the examiner's effort, if the intermediate amount is reported, the innovator intensifies his effort. But on the other hand, due to the decrease in the examiner's effort if the full amount of prior art is reported, the innovator reduces his effort. It is not clear which effect is greater than the other, and we cannot conclude.

We summarize these findings.

Lemma 5 *If $F \geq F_1$ and holding everything else constant, the effort of the innovator*

- *increases with the value of a patented good innovation, and decreases with a non-patented good innovation and a patented bad innovation;*
- *increases with optimal levels of effort of the PTO examiner.*

As pointed out by Sampat (2005), disclosure of known prior art may be more incentive compatible in fields where patents are important. Innovators may be more likely to search for prior art in fields where having a valid high quality patent is more important (e.g., chemical and pharmaceutical industries) because of the higher likelihood of litigation.

3.3 Quality of Examination

Our model depicts the strategic behavior of applicants who learn that their innovation is non-patentable. Because they know that the PTO makes mistake, they conceal information. We can link the report of information to the field of prior art to which the innovation belongs, as by reporting less information an innovator acknowledges that his innovation belongs to an emerging field. Patent applications that contain more information are concerned with innovations that belong to more mature fields where the prior art is more easily available. Therefore, one of our main findings (and a testable assumption, as well) is that innovators are constantly trading-off the benefit of applying in one "class" (e.g., within a more mature field) rather than another (e.g., within an emerging field). Even though the benefit of applying for a patent with a bad innovation tends to be equalized across classes, the probability of granting a patent to a bad innovator is higher when the applicant reveals less information. This result is summarized in the following corollary.

Corollary 4 *The probability of granting a patent to a bad innovation is lower when applicants report* $\widetilde{x} = 1$ *rather than* $\widetilde{x} = x_i$*.*

Note that another consequence of our model is that the ratio of good patents accepted over all accepted patents must, in equilibrium, be higher when more abundant prior art is cited. In other words, if we define this ratio as being the "average quality" of the patents granted by the examiner, it increases with the quantity of prior art. The average qualities when the full and the intermediate amount of prior art are revealed are, thus,

$$Q_1 = \frac{\mu_1[E_1+\mu_1(1-E_1)]}{\mu_1[E_1+\mu_1(1-E_1)]+(1-\mu_1)\mu_1(1-E_1)} = E_1 + \mu_1(1-E_1), \tag{22}$$

$$Q_i = \frac{\mu_i[E_i+\mu_i(1-E_i)]}{\mu_i[E_i+\mu_i(1-E_i)]+(1-\mu_i)\mu_i(1-E_i)} = E_i + \mu_i(1-E_i). \tag{23}$$

The equilibrium quality difference can be simplified to

$$Q_1 - Q_i = (E_1 - E_i)(1-\mu_i) + (\mu_1 - \mu_i)(1-E_1) > 0.$$

This finding seems to be consistent with empirical observations related to the issuance of low quality patents in emerging fields. For instance, Allison et al. (2004) find that an important predictor of the patent's observable validity is, among others, the number of prior art references reported in the patent application. This raises an interesting question: how do scrutiny efforts affect patent quality in both classes? The answer to that question is presented in the following lemma:

Lemma 6 *The quality of patents issued in the emerging (respectively, mature) field, increases with E_i (respectively, E_1). However Q_1 decreases with E_i and Q_i decreases with E_1.*

Although the direct effects are relatively straightforward, the cross impact of scrutiny in one class on the quality of the other class illustrates the interdependence between patenting classes. Any change that affects one class also affects the other, because applicants can strategically draft their patents. We further explore this interdependence with a recent reform implemented at the PTO that can illustrate the effects at work in our setting.

4 Second Pair of Eyes Review

In this section, we study the effects of the implementation of an existing new policy called the Second Pair of Eyes Review (SPER) as a possible policy remedy to the strategic behavior of bad innovators.

In March 2000, in reaction to numerous quality-related criticisms about the granting of business-method patents (main class 705), the PTO began a quality patent improvement initiative involving several measures, such as the hiring of additional, better-trained examiners, the obligation for them to consult non-patent prior art information sources and, perhaps most importantly, a second-level examination applied only to patents granted within the main 705 classification. The effects of this initiative, called the "Second Pair of Eyes Review" (SPER), have been empirically studied in Allison and Hunter (2006). They first argue that an innovator endowed with a business-method innovation has substantial latitude to choose whether to submit it in the main class (705) or in other main classes related to business methods (i.e., with secondary 705 classification). Then they empirically analyze the composition of patent applications before and after the SPER initiative.

By slightly modifying our setting, we model the SPER initiative by allowing for a second review of awarded patents in the emerging field. To simplify the analysis, we assume that when a patent has been granted to a patentable innovation the second review does not invalidate it, whereas it eliminates a fraction $\beta \in [0,1]$ of bad patents accepted during the first review. In this setup, a bad innovator who anticipates the second review chooses θ such that

$$\mu_1(\theta)\,(1-E_1)\,\underline{V} = \mu_i(\theta)\,(1-E_i)\,(1-\beta)\,\underline{V}(F).$$

By solving this last equality we obtain

$$\theta^*_{SPER} = \frac{(1-E_1)\underline{V}(1-p\gamma)-(1-\gamma)p(1-E_i)\underline{V}(F)(1-\beta)}{(1-p)[(1-\gamma)(1-\beta)(1-E_i)\underline{V}(F)+\gamma(1-E_1)\underline{V}]}.$$

Note that although β can take any value between 0 and 1, any $\beta \geq \overline{\beta}$ where $\overline{\beta} = 1-(1-E_1)\underline{V}/[(1-E_i)\underline{V}(F)]$ induces $\theta^*_{SPER} = 1$ (no strategic revelation), whereas for $\beta \in \left[0,\overline{\beta}\right]$ we have $\theta^*_{SPER} \in [\theta^*, 1]$. It is straighforward to show that θ^*_{SPER} increases with β (i.e., $\partial\theta^*_{SPER}/\partial\beta > 0$), so that an increase in the precision in the second review reduces the strategic concealment of information.

If $\overline{W}_G = \underline{W}_R$ and $F < F_1$, the equilibrium efforts of the examiner under the SPER regime are

$$E_1^{SPER} = 1 - \left[\frac{K\left[x_i(1-p(1-\gamma))\underline{V}^2\Delta W^{SPER}-(1-\gamma)p\underline{V}(F)^2\Delta W(1-\beta)^2\right]}{p\gamma x_i(1-p)\underline{V}^2\Delta W\Delta W^{SPER}}\right]^{\frac{1}{2}}, \tag{24}$$

$$E_i^{SPER} = 1 - \left[\frac{K[(1-\beta)^2(1-p\gamma)\underline{V}(F)^2\Delta W - x_i p\gamma\underline{V}^2\Delta W^{SPER}]}{px_i(1-\gamma)(1-p)\underline{V}(F)^2\Delta W\Delta W^{SPER}(1-\beta)^2}\right]^{\frac{1}{2}}, \tag{25}$$

where $\Delta W^{SPER} = \overline{W}_G - \overline{W}_R + (1-\beta)(\underline{W}_R - \underline{W}_G)$.

A comparison of the levels of effort leads to the following findings:

Lemma 7 *If $F < F_1$, as β increases, the examiner reduces her scrutiny effort when she receives the full amount of prior art, whereas she increases her effort when she receives the intermediate amount. Furthermore, she exerts more effort when she receives more information, $E_1^{SPER} > E_i^{SPER}$ for $\beta < \beta_s$.*

The implementation of the SPER initiative reduces the strategic reporting of information by allowing the examiner to intensity her search effort when she receives an intermediate amount of prior art and to reduce it whenever she gets more information.

For the sake of simplicity, we do not take into account the cost of implementing the SPER policy. In fact, introducing a second examination should be more costly to the PTO. However, the introduction of a such cost would make our model intractable and would not change the flavor of the results. Indeed, our findings would be more dramatic, as it would make the screening of patents in mature fields more costly, and therefore would reduce the examiner's efforts in mature fields.

To analyze the effects of the SPER initiative on patents, we compare the number of patent applications and granted patents in each class, as well as their quality, before and after the implementation of the SPER initiative. Our findings are summarized in the following proposition:

Proposition 2 *If $F < F_1$, for any $\beta > 0$, the implementation of the SPER initiative has the following effects:*

1. *Fewer (respectively, more) patent applications in the emerging (respectively, mature) field are scrutinized;*

2. *Fewer patents are granted in the mature field;*

3. *The quality of patents issued in the mature (respectively, emerging) field decreases (respectively, increases).*

These findings lead us to propose several potential testable assumptions for a reform in the spirit of SPER. Some of these hypotheses have already been explored in Allison and Hunter (2006). For instance, they show that there is a sharp decrease in the proportion of main-class 705 patents relative to the total class 705 patents (i.e., main plus secondary) in the years following the implementation of the SPER initiative.[24] They also show that the number of patents granted in the main 705 classification increased substantially after the implementation of the SPER initiative. Finally, they analyze the content of several patents granted in secondary class 705 and show that an unusual proportion of them would potentially fall in the main 705 patent category.[25]

We also consider the effect of the SPER initiative on the effort of the innovator, as derived in the previous section. For the innovator, efforts in both the emerging and mature fields are important in determining his incentives to search for prior art. Thus, as evidenced by equations (16) and (17), any reform that increases the search effort of examiners in one field is likely to decrease the search effort in another field (provided innovators engage in strategic drafting).

[24] This is also true in our model.

[25] Unfortunately, the authors do not have data on validity to test whether, as suggested by our model, these patents are of inferior quality.

From a theoretical standpoint, the effect on innovator search efforts is unclear. At the least, we expect innovators' efforts to change when such a reform is introduced. This would be consistent with other findings of Allison and Hunter (2006), that after SPER, the amount of prior art disclosed in patent applications is significantly higher in the main 705 classification, and also in patents with secondary 705 classification. In our model, rather than the amount of prior art discovered per patent, an increase in examiner effort increases the fraction of innovations for which substantial prior art is discovered; that is, there are more patents with $x \in \{x_i, 1\}$ than patents with no prior art.[26]

5 *Ex ante* commitment of the PTO

In this section, we investigate whether an *ex ante* commitment policy induces more truthful revelation of prior art. The answer to this question is not obvious and depends on a trade-off. On one hand, a policy that encourages truthful behavior will limit the power of incentives that can be given to foster research efforts. On the other hand, a policy that gives incentives for a high level of effort will probably make truthful revelation impossible. The patent examiner can choose to *ex ante* commit to exert certain levels of effort. We denote by E_{1c} and E_{ic} the levels of effort of the examiner when, respectively, the full amount and the intermediate amount of prior art are provided and, to simplify, we assume that the reputational cost is $F = 0$. Two cases must be considered: whether $E_{ic} \geq E_{1c}$ or $E_{ic} < E_{1c}$.

We first consider the case where $E_{ic} < E_{1c}$. By finding the full amount of prior art, the innovator learns the type of his innovation. Therefore, a good innovator will report all prior art, whereas a bad innovator may decide to transmit only the intermediate amount. The next result is the first step in finding the optimal commitment policy of the PTO.

Lemma 8 *It is always possible to find a policy that strictly dominates a policy in which the PTO ex ante commits to given levels of scrutiny (E_{ic}, E_{1c}), with $E_{ic} < E_{1c}$.*

A policy that involves $E_{ic} < E_{1c}$ has two major drawbacks. First, it is cost-dominated by another policy with a lower gap between E_{1c} and E_{ic} (see appendix). We believe that this drawback is not so acute. A second drawback is that the commitment problem of the examiner

[26] In our model, for instance, we could assume that an increase in e also increases the quantities x_i and $\overline{x}$.

is very intense when $E_{ic} < E_{1c}$, because the gains of reneging on her commitment are very high. Indeed, in this context, the examiner would gain $C(E_{1c}^A)$ monetary units by reneging on her commitment, without altering the quality of screening.

The commitment policy involving $E_{ic} \geq E_{1c}$ induces truthful revelation of information. However, this policy has a much lower intensity. Indeed, in a truthtelling equilibrium, it is certain that (E_{ic}, E_{1c}) are *ex post* inefficient. However, the gains from reneging on her commitment (i.e., switching to E_{1t}^* and E_{it}^*) are likely to be much lower. Relative to the case $E_{ic} < E_{1c}$, the PTO faces a low-intensity commitment problem when $E_{ic} \geq E_{1c}$. We now proceed to the analysis of this case.

When $E_{1c} = E_{ic}$, the innovator who learns the nature of his innovation is indifferent between reporting $\widetilde{x} = 1$ (truthful reporting) and reporting only part of the found prior art (strategic reporting). For definitiveness, we make the assumption that when the innovator is indifferent, he reports truthfully. Given that the innovator is induced to be truthful, and if the innovator reports some prior art information, the gross benefit function of the PTO is

$$B_c\left(E_{1c}, E_{ic}\right) = \gamma B(E_{1c}; p) + (1-\gamma) B(E_{ic}; p),$$

where c stands for commitment, and $B(E_{jc}; p)$ for $j = 1, i$ is defined by equation (3).

The *ex ante* commitment contract of the PTO that induces information search and truthful revelation by the innovator is the solution of the following program:

$$\max_{E_{1c}, E_{ic}} \left\{ e\left(E_{1c}, E_{ic}\right)\left[B_c\left(E_{1c}, E_{ic}\right) - \gamma \tfrac{K}{(1-E_{1c})} - (1-\gamma)\tfrac{K}{x_i(1-E_{ic})}\right]\right\},$$

subject to

$$E_{1c} \leq E_{ic}. \tag{26}$$

The next result simplifies the analysis of the examiner's program when she wants to induce truthful reports.

Proposition 3 *If the PTO wants to induce truthful reports, the unique optimal commitment policy is such that* $E_{1c} = E_{ic}$.

We know that, if they exist, the *ex post* efficient levels of effort are such that $E_1^* > E_i^*$. By committing to levels of effort *ex ante*, the PTO would like to reduce *ex post* inefficiencies as much as possible. More precisely, the PTO would like to raise E_{1c} as much as possible. Therefore, among all of the possible levels of effort that satisfy $E_{1c} \leq E_{ic}$, those that minimize *ex post* inefficiency are such that $E_{1c} = E_{ic} = E_c$.

Using this result, the program of the PTO can now be stated as

$$\max_{E_c}\{e\,(E_c)\,[B_c\,(E_c) - \tfrac{\gamma K}{(1-E_c)} - \tfrac{(1-\gamma)K}{x_i(1-E_c)}]\},$$

where

$$e\,(E_c) = p[\Delta V(1-p)E_c + p\Delta V + \underline{V}]$$

and $B(E_{1c};p) = B(E_{ic};p) = B(E_c;p)$; thus,

$$B_c\,(E_c) = -p(1-p)\Delta W(1-E_c) + p(\overline{W}_G - \underline{W}_R) + \underline{W}_R.$$

We cannot obtain an analytical solution due to the complexity of the *ex ante* program.

The levels of effort of the examiner when they are performed *ex post* generate too few incentives on the part of the innovators. By committing to effort *ex ante,* the patent examiner can threaten to lower the innovator's benefit. The commitment thus helps the PTO to shift, to some extent, the burden of the information search to innovators.

The comparison between the optimal efforts in the commitment case and in the non-commitment case leads to $E_i^* < E_c < E_1^*$ when the uncertainty about the value of the innovation and the field it belongs to is the highest, i.e., for some constellation of parameters (p, γ) (see appendix). The commitment case allows the patent examiner to intensify (respectively, reduce) her search effort when she receives less (respectively, more) prior art, because there is no longer strategic revelation of information.

In terms of average qualities as defined by (22) and (23), the commitment policy induces the same quality level across fields.

6 Conclusion

Patent examiners must assess the patentability of an innovation by comparing the application to related information that is already in the public domain, called prior art information. When the initial application contains little prior art information, and when the prior art is not easily accessible to examiners, it may be difficult to judge the novel content of an innovation. Prior art information may be more difficult for examiners to gather when the innovation belongs to an emerging technological field and much of the prior art is non-patent information. Sampat (2005) shows that patent examiners' abilities to locate prior art embodied in U.S. patents exceed their ability to locate other types of prior art (non-patent). Therefore, if most of the prior art is not related to U.S. patents, examiners may be unable to assess the patentability of an innovation. This, in turn, may lead to a reduction in patent quality, as more questionable patents are issued.

In the current U.S. patent system, while applying for a patent, an innovator is supposed to disclose the prior art information of which he is aware, but is not required to search for more prior art. Thus, innovators have little incentive to reveal the information they have and to search for more.

In this paper, we analyze the issues related to the gathering of prior art information. In our setting, innovators decide to apply for patent protection after gaining private information about the value of their innovation. Their decisions depend both on the private information they gather and the patent policy adopted by the PTO. After receiving an application, the patent examiner undertakes a costly complementary search effort that depends on her beliefs about the value of the innovation. To be as realistic as possible, we allow the examiner to make two kinds of mistakes: to refuse a patent on a good innovation and to grant a patent to a bad innovation.

We consider different policies: one in which the PTO cannot commit to any search effort, one in which there is a second review for an emerging field, and one in which the examiner *ex ante* commits to a screening intensity. In the former case, an innovator who has learned he has a non-patentable innovation might conceal some information from the examiner to increase his probability of being granted a patent. The optimal policy of the examiner is to intensify her scrutiny effort when she receives more prior art. Therefore, she devotes more effort to those applications that are more likely to come from good innovators. In the second case, the introduction of a more thorough screening in emerging fields reduces the strategic non-revelation of information, but its overall success remains unclear. Indeed, the imposition of a stricter screening in an emerging field may improve the quality of patents in this field, but will negatively affect the quality of patents in another field. We then go further into our investigation of policy remedies, and, in the latter case, we show that by *ex ante* committing to the same screening effort across fields, the examiner induces truthful revelation of information. It is important to note that we have interpreted our model in terms of "too little" relevant information transmitted. However, by making an intensive search, the innovator finds an important amount of related (but possibly not relevant) information. Alternatively, we could assume that an innovator has the option to transmit "too much" related but not relevant information when he discovers that his innovation is not good. If, after examination, the examiner is able to judge the relevance of the information transmitted (and we believe she could), then it is also possible to commit to a mechanism that will allow truthful information transmission.

In this paper, we consider different policies, but we are not able to provide guidance as to how those policies should be implemented. For instance, it is not clear how the patent examiner should commit not to renege on her effort later on. If one thinks about a more dynamic structure in which reputation can play a role, because of the interaction between innovators and the PTO it is likely that the examiner, for reputation sake, may want not to renege on her *ex ante* commitment.

We also assume that two types of errors can be made by the examiner. This is actually what we should observe, especially if more applications were refused. In reality, however, it seems that it is more common to grant a patent to a bad innovation than to refuse a patent to a good innovation, as a very high percentage of patent applications are approved.

References

[1] Alcacer, J. and M. Gittelman. "Patent Citations as a Measure of Knowledge Flows: The Influence of Examiner Citations," *Review of Economic Studies*, *88(4)*:774–779 (2006).

[2] Allison, J. and S. Hunter. "On the Feasibility of Improving Patent Quality One Technology at a Time: The Case of Business Methods," *Berkeley Technology Law Journal.*, *21*:729–794 (2006).

[3] Allison, J. and M. Lemley. "Empirical Evidence on the Validity of Litigated Patents," *AIPLA Quarterly Journal*, *26*:229 (1998).

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

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

[6] Coppel, J. *E-Commerce: Impact and Policy Challenges*. Technical Report wp n. 252, Economics Department, 2000.

[7] Crampes, C. and C. Langinier. "Litigation and Settlement in Patent Infringement Cases," *RAND Journal of Economics*, *33*:228–274 (2002).

[8] Farrell, J. and R. Merges. "Incentives to Challenge and Defend Patents: Why Litigation Won't Reliably Fix Patent Office Errors and Why Administrative Patent Review Might Help?," *Berkeley Technology Law Journal*, *19:1*:2–28 (2004).

[9] Friebel G., A. Koch, D. Prady and P. Seabright. "Objectives and Incentives at the European Patent Office," *IDEI Report* (2006).

[10] Graham S., B. Hall, D. Harhoff and D. Mowery. "Post-Issue Patent "Quality Control:" A Comparative Study of US Patent Re-Examinations and European Patent Oppositions," *NBER* (2002).

[11] Jaffe, A. and J. Lerner. *Innovation and its Discontents: How our Broken Patent System is Endangering Innovation and Progress, and What to Do About It*. Princeton University Press, 2004.

[12] Kesan, J. "Carrots and Sticks to Create a Better Patent System," *Berkeley Technology Law Journal*, *17*:145–179 (2002).

[13] Khalil, Fahad. "Auditing Without Commitment," *RAND Journal of Economics*, *28*:625–640 (1997).

[14] Langinier, C. and P. Marcoul. "Incentives of the PTO Examiners," (2007).

[15] Lanjouw, J. and M. Schankerman. "Characteristics of Patent Litigation: A Window on Competition," *RAND Journal of Economics*, *32*:129–151 (2001).

[16] Lemley, M. "Rational Ignorance at the Patent Office," *Northwestern University Law Review*, *95*:1–34 (2001).

[17] Lerner, J. "Patenting in the Shadow of Competitors," *Journal of Law and Economics*, *XXXVIII*:463–495 (1995).

[18] Lerner, Josh. "Where Does State Street Lead? A First Look at Finance Patents, 1971 to 2000," *The Journal of Finance*, *LVIII*:901–930 (2002).

[19] Levitt, S. and C. Snyder. "Is No News Bad News? Information Transmission and the Role of "Early Warning" in the Principal-Agent Model," *RAND Journal of Economics*, *28*:641–661 (1997).

[20] Merges, R. "As Many as Six Impossible Patents Before Breakfast: Property Rights for Business Concepts and Patent System Reform," *Electronic Commerce Symposium*, *14*:578–615 (1999).

[21] Mitusch, K. "Non-Commitment in Performance Evaluation and the Problem of Information Distortions," *Journal of Economics Behavior and Organization*, *60*:507–525 (2006).

[22] O'Donoghue, T. "A Patentability Requirement for Sequential Innovation," *RAND Journal of Economics*, *29*:654–679 (1998).

[23] Sampat, B. "Examining Patent Examination: An Analysis of Examiner and Applicant Generated Prior Art," (2005).

[24] Schankerman, M. and S. Scotchmer. "Damages and Injunctions in Protecting Intellectual Property," *RAND Journal of Economics*, *32*:199–220 (2001).

[25] Scotchmer, S. "Protecting Early Innovators: Should Second Generation Product Be Patentable?," *RAND Journal of Economics*, *27*:322–331 (1996).

[26] Strausz, R. "Timing of Verification Procedures: Monitoring versus Auditing," *Journal of Economic Behavior and Organization*, *59*:89–107 (2005).

[27] Trajtenberg, M, A. Jaffe and M. Fogarty. "Knowledge Spillovers and Patent Citations: Evidence from A Survey of Inventors," *American Economic Review, Papers and Proceedings*, *90*:215–218 (2000).

Appendix

Proof of Lemma 1

We first determine for which values of prior beliefs the examiner makes a complementary search effort, depending on the prior art transmitted. Second, we compare the different levels of effort.

The optimal efforts

$$E^*_{\widetilde{x}t}(p) = 1 - (\tfrac{K}{p(1-p)\widetilde{x}\Delta W})^{\frac{1}{2}},$$

for $\widetilde{x} = x_i, 1$ are first increasing and then decreasing with p. As the second derivative is negative, the benefit function is concave and reaches a maximum for $p = 1/2$ (the last part of Lemma 1 is proved). We now define for what values of p the efforts are such that $E^*_{\widetilde{x}t}(p) = 0$. These values belong to the interval $[0,1]$ as the limits of $E^*_{\widetilde{x}t}(p)$ are $-\infty$ when p tends toward 0 or 1, and are

$$\begin{aligned} \underline{p}_{\widetilde{x}} &= \tfrac{\widetilde{x}\Delta W - [(\widetilde{x}\Delta W)^2 - 4\widetilde{x}K\Delta W]^{\frac{1}{2}}}{2\widetilde{x}\Delta W}, \\ \overline{p}_{\widetilde{x}} &= \tfrac{\Delta W + [(\widetilde{x}\Delta W)^2 - 4\widetilde{x}K\Delta W]^{\frac{1}{2}}}{2\widetilde{x}\Delta W}, \end{aligned}$$

if $K < \widetilde{x}\Delta W/4$. It is easy to verify that $\underline{p}_1 < \underline{p}_i < \frac{1}{2} < \overline{p}_i < \overline{p}_1$ where $\underline{p}_i \equiv \underline{p}_{x_i}$ and $\overline{p}_i \equiv \overline{p}_{x_i}$. Hence, for values of $p \in]0, \underline{p}_1[\cup]\overline{p}_1, 1[$, the examiner does not make any effort. For values of $p \in]\underline{p}_1, \underline{p}_i[\cup]\underline{p}_i, \overline{p}_1[$, she does not make any effort after receiving x_i, but makes the effort $E^*_{1t} > 0$ after receiving $\widetilde{x} = 1$. And finally, for values of $p \in]\underline{p}_i, \overline{p}_i[$, she makes efforts E^*_{1t} and E^*_{it}. It is straighforward to show that $E^*_{1t} > E^*_{it}$, as $x_i < 1$.

Proof of Lemma 2: No equilibrium in pure strategies for $F < F_1$

Another pure strategy to consider is the one in which the same innovator always conceals part of the prior art found and reveals only an intermediate amount. To see whether this can be an equilibrium, we need to compute the updated beliefs of the PTO.

Consider first that the PTO believes that a bad innovator who finds $x = 1$ always conceals some information. The set of beliefs consistent with this behavior is computed as

$$\begin{aligned} &\mu_1 = \Pr(Good \mid \widetilde{x} = 1) = \tfrac{p\gamma}{p\gamma} = 1, \\ &\mu_i = \Pr(Good \mid \widetilde{x} = x_i) = p\tfrac{1-\gamma}{1-\gamma p} < p, \\ &\Pr(Good \mid \widetilde{x} = 0) = p. \end{aligned}$$

If she receives the maximum amount of prior art, the PTO prefers not to make any complementary search effort, as only an innovator with a good innovation will reveal the full amount. If she observes the intermediate level, the first order condition (4) gives

$$E_{il}^{*} = 1 - \left[\frac{K}{\mu_i(1-\mu_i)x_i\Delta W}\right]^{\frac{1}{2}} < 1,$$

as long as $(p,\gamma) \in \Psi_l \equiv]\underline{p}(\gamma), \overline{p}(\gamma)[$ where

$$\begin{aligned}\underline{p}(\gamma) &= \frac{(1-\gamma)x_i\Delta W+2K\gamma-[((1-\gamma)x_i\Delta W+2K\gamma)^2-4K((1-\gamma)x_i\Delta W+\gamma^2K)]^{\frac{1}{2}}}{2[(1-\gamma)x_i\Delta W+\gamma^2K]},\\ \overline{p}(\gamma) &= \frac{(1-\gamma)x_i\Delta W+2K\gamma+[((1-\gamma)x_i\Delta W+2K\gamma)^2-4K((1-\gamma)x_i\Delta W+\gamma^2K)]^{\frac{1}{2}}}{2[(1-\gamma)x_i\Delta W+\gamma^2K]}.\end{aligned}$$

We then show that $\underline{p}(\gamma)$ and $\overline{p}(\gamma)$ are increasing with γ. Therefore, as long as $(p,\gamma) \in \Psi_l$, the examiner makes a strictly positive effort, and $E_{il}^{*} > E_{1l}^{*} = 0$. Thus, unlike the previous case, revealing an intermediate amount yields more scrutiny effort from the examiner. If $(p,\gamma) \in \Psi_l$, not only must uncertainty as to the value of the innovation be high enough, uncertainty about the prior art field must also be high. A maximum is reached for $p = 1/(2-\gamma) > 1/2$ that solves $dE_{il}^{*}/dp = 0$. Otherwise, if $(p,\gamma) \notin \Psi_l$, the efforts are such that $E_i^{*} = E_1^{*} = 0$.

Can this strategy be part of an equilibrium? A good innovator has no incentive to deviate from revealing the truth, as the examiner infers that only good innovators reveal the truth. Formally, inequality (6) is always satisfied, as $\overline{V} > v$. Nevertheless, a bad innovator is expected to always conceal some prior art. Thus, we should have $(1-E_i^{*})\mu_i\underline{V}(F) > (1-E_1^{*})\mu_1\underline{V}$. Because $E_1^{*} = 0$ and $\mu_1 = 1$, this inequality is equivalent to $(1-E_i^{*})\mu_i\underline{V}(F) > \underline{V}$, which is never satisfied. Therefore, the innovator may decide to report truthfully in order to fool the examiner, who believes that only good innovators report the full amount of prior art. By reporting as expected, a bad innovator can get a patent by chance, when the examiner grants a patent based on her updated beliefs. If he now decides to report all of the prior art he found, he definitively obtains a patent, as the examiner believes he has a good innovation and reports truthfully. This confirms that this is not an equilibrium.

Using the same argument, we show that the examiner will not make any effort when she observes the full amount of prior art, but she will not give a patent, either. When she observes the intermediate level of prior art, she makes a positive effort. A good innovator will not deviate, whereas one who has a bad innovation will deviate, as he can get a patent by fooling the examiner. This is not an equilibrium. The examiner can also believe that no innovators will report truthfully. By the same token we show that this cannot be an equilibrium.

Proof of Lemma 3: Concavity of the benefit functions of the PTO

In the case of mixed strategies, we show that the benefit functions are concave in their own argument (namely, E_1 and E_i). If the examiner receives $\widetilde{x} = 1$ or $\widetilde{x} = x_i$, her payoffs are respectively $B(E_1; \mu_1) - K/(1 - E_1)$ and $B(E_i; \mu_i) - K/x_i(1 - E_i)$, where the gross benefit functions $B(.)$ are defined by (3), and μ_1 and μ_i are defined by equations (12) and (13). After rewriting these benefit functions, we calculate the first and second derivatives. When the examiner receives $\widetilde{x} = 1$ (we find a similar equation for $\widetilde{x} = x_i$), the second order condition is

$$-\frac{K - p^2(1-E_i)^2(1-\gamma)^2 \Delta W - p(1-E_i)(1-\gamma)(\overline{W}_G - \underline{W}_R)}{(1-E_1)^3},$$

which is always negative at the equilibrium values. Therefore, the benefit functions are locally concave. This is the first step of the proof of the existence of solutions.

Subgame Perfect Bayesian Equilibrium

There exists a semi-separating equilibrium in which a bad innovator randomizes his revelation decision. Equations (10), (16) and (17) must be satisfied. From the first equation, $\mu_1(\theta)(1 - E_1)\underline{V} = \mu_i(\theta)(1 - E_i)\underline{V}(F)$, we derive a unique $\theta^* \in [0, 1]$,

$$\theta^* = \frac{(1-E_1)\underline{V}(1-p\gamma) - (1-\gamma)p(1-E_i)\underline{V}(F)}{(1-p)[(1-\gamma)(1-E_i)\underline{V}(F) + \gamma(1-E_1)\underline{V}]},$$

where $\theta^* < 1$ is always satisfied if $E_1^* > E_i^*$, and $\theta^* > 0$ if $p < \overline{p}_\theta(\gamma) = (1 - E_1)/((1 - \gamma)(1 - E_i) + \gamma(1 - E_1))$. This last condition is equivalent to checking that $\mu_1(\theta^*) < 1$. Assume for the moment that $E_1^* > E_i^*$ and that $p < \overline{p}_\theta(\gamma)$ (we will determine under what circumstances this condition holds in the last part of the proof).

To prove the last part of the Lemma 3 we calculate the following derivatives $\partial\theta^*/\partial p < 0$, $\partial\theta^*/\partial\gamma > 0$, $\partial\theta^*/\partial E_1 < 0$, and $\partial\theta^*/\partial E_i > 0$.

Proof of Proposition 1: Semi-separating equilibrium

We need to check that

i. there exists a solution (E_1^*, E_i^*), where $E_1^* \in [0, 1]$ and $E_i^* \in [0, 1]$,

ii. this solution is unique in the interval considered.

Before doing so, recall that the two functions $E_1(E_i)$ and $E_i(E_1)$ are decreasing, and thus we rewrite them as

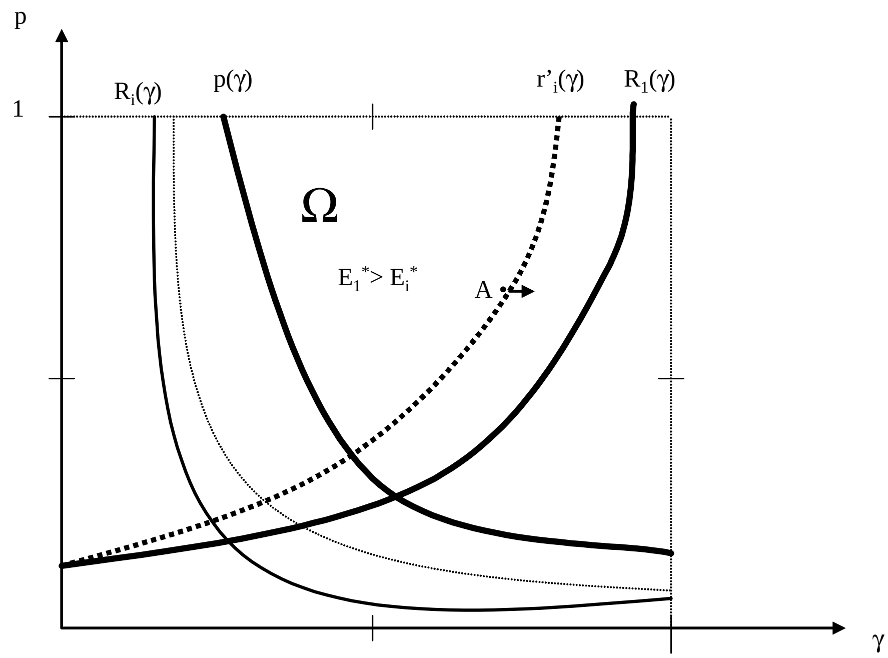
$$E_1(E_i) = 1 - \phi_1(E_i)^{\frac{1}{2}},$$
$$E_i(E_1) = 1 - \phi_i(E_1)^{\frac{1}{2}}.$$

By analogy to the Cournot model, we call these expressions 'reaction functions'. Some assumptions are crucial in order to have solutions; in particular, to insure real solutions, we need to impose that $\phi_1(E_i) \geq 0$ and $\phi_i(E_1) \geq 0$. So the crucial assumptions are $E_{\widetilde{x}}(1) < 1$ (or, equivalently, $K > 0$) and $E_{\widetilde{x}}(0) < 1$ (to insure that $\phi_{\widetilde{x}}(0) \geq 0$). Let us now detail the analysis of the existence and unicity of positive solutions.

i. Existence

We know that the benefit functions of the PTO are concave. We then have to prove that the solutions are positive. Ideally, we need to have $E_1^{-1}(0) > E_i(0)$ and $E_i^{-1}(0) > E_1(0)$. However, because of the complexity of the reaction functions, we will not explicitly find the constellation of parameters (γ, p) such that these two conditions hold.

We first consider a weaker condition. According to the reaction functions, if $E_1(1) > 0$ and $E_i(1) > 0$, then $E_1(0) > 0$ and $E_i(0) > 0$ and, thus, there exist interior solutions between 0 and 1. We can easily derive a constellation of parameters such that these two conditions are satisfied. However, these conditions are very restrictive, and if one, or even both, of them are not satisfied, we can still have positive solutions (we will consider that problem later). It is easy to check that $E_1(1) > 0$ if $p \in [r_1'(\gamma), r_1''(\gamma)]$ where $r_1'(\gamma) = [\Delta W - \sqrt{(\Delta W)^2 - 4K\Delta W}]/2\gamma\Delta W$ and $r_1''(\gamma) = [\Delta W + \sqrt{(\Delta W)^2 - 4K\Delta W}]/2\gamma\Delta W$. Similarly, $E_i(1) > 0$ is satisfied if $p \in [r_i'(\gamma), r_i''(\gamma)]$, where $r_i'(\gamma) = [x_i\Delta W - \sqrt{(x_i\Delta W)^2 - 4x_iK\Delta W}]/2(1-\gamma)x_i\Delta W$ and $r_i''(\gamma) = [x_i\Delta W + \sqrt{(x_i\Delta W)^2 - 4x_iK\Delta W}]/2(1-\gamma)x_i\Delta W$. We represent these functions in a graph (γ, p) (figure 1). Thus, for a constellation of parameters $(\gamma, p) \in \{(\gamma, p)/p \geq r_i'(\gamma), p \geq r_1'(\gamma)\}$, there exists a positive set of efforts. However, on the left of $r_i'(\gamma)$, for instance, we can still have a candidate pair. So the constellation (γ, p) such that $p = r_i'(\gamma)$ corresponds to $E_i(1) = 0$. For a given p, the limit $E_i(1)$ decreases as γ increases (i.e., $\partial E_i(1)/\partial\gamma < 0$), for $p < 1/2(1-\gamma)$. Hence, there exists a function $R_i(\gamma)$ such that for $p \leq R_i(\gamma)$, the optimal solution is $E_i^* \leq 0$. If



we start from point A in figure 1 and increase γ, first the optimal solution can still be positive, but as the limit decreases there is one value of γ for which the optimal solution becomes negative. By the same token, the same reasoning applies to $E_1(1)$, and a function $R_1(\gamma)$ exists such that for $p < R_1(\gamma)$, the optimal solution is $E_1^* < 0$.

We have defined explicit functions, $R_i(\gamma)$ and $R_1(\gamma)$, such that there exists a pair of efforts $(E_1^*, E_i^*) \in [0,1] \times [0,1]$, that we represent in figure 1 for a constellation of parameters $(\gamma, p) \in \Upsilon = \{(\gamma, p) \mid p \geq R_i(\gamma), p \geq R_1(\gamma)\}$ (a set that is less restrictive than the previous set).

For some values of p, $E_1^* > 0$ is satisfied, whereas $E_i^* > 0$ is not. In other words, the examiner makes an effort E_1 after observing the maximum prior art, but no effort after observing the intermediate level. Equation (10) becomes $\mu_1(\theta)(1 - E_1) = \mu_i(\theta)$ and we derive

$$\theta_1^* = \tfrac{1-p-E_1(1-\gamma p)}{(1-p)(1-E_1\gamma)},$$

that belongs to $[0,1]$ if $p < \overline{p_1} = \frac{1-E_1}{1-E_1\gamma}$. We check that $\overline{p_1} > r_1''$, and thus $\theta_1^* \in [0,1]$.

For another constellation of parameters, none of the inequalities $E_1^* > 0$ and $E_i^* > 0$ are satisfied. Thus, the examiner will not make any effort and the innovator is indifferent if $\mu_1(\theta) = \mu_i(\theta)$, which is only satisfied for $\theta = 1$. This is actually the equilibrium in pure strategies that we defined earlier.

ii. Uniqueness

To show that the solution is unique, we need to show that

$$\left|\frac{\partial^2(B_1(.)-C(.))}{\partial E_1^2}\right| > \left|\frac{\partial^2(B_1(.)-C(.))}{\partial E_1 \partial E_i}\right|.$$

After computation of these two second derivatives, a simple comparison shows that this is true as long as $E_1^* > E_i^*$. Thus, we have shown that there exists a unique pair of solutions $(E_1^*, E_i^*) \in [0,1] \times [0,1]$ for $(\gamma, p) \in \Upsilon$.

So far, we have assumed that $E_1^* > E_i^*$. We now have to show for which constellation of parameters (p, γ) the inequality $E_1^* > E_i^*$ holds, inside the constellation of parameters Υ. Let us first re-define the functions $E_1(E_i)$ and $E_i(E_1)$ as

$$\begin{aligned} E_1(E_i) &= 1 - \phi_1(E_i, p, \gamma)^{\frac{1}{2}}, \\ E_i(E_1) &= 1 - \phi_i(E_1, p, \gamma)^{\frac{1}{2}}. \end{aligned}$$

We then define the value of E_1 (respectively, E_i) when the reaction function $E_1(E_i)$ (respectively, $E_i(E_1)$) cuts the function $E_i = E_1$. In other words, we determine E such that $E_1(E) = E$, which is $(1-E)^2 = \phi_1(E, p, \gamma)$, and $E_i(E) = E$, which is $(1-E)^2 = \phi_i(E, p, \gamma)$. As $E_1 = E_i$, there exists a value of E such that $\phi_1(E, p, \gamma) - \phi_i(E, p, \gamma) = 0$. The solution of this equation is $E(p, \gamma)$. If we plug this solution back into the previous equation we have $\phi_1(E(p,\gamma), p, \gamma) - \phi_i(E(p,\gamma), p, \gamma) = 0 \equiv G(p, \gamma)$ that only depends on p and γ. By totally differentiating $G(.)$, we determine the sign of the function $p(\gamma)$ that represents all the values of (p, γ) $(p = p(\gamma))$ such that $E_1^* = E_i^*$. Indeed,

$$\frac{dp}{d\gamma} = -\frac{\partial G}{\partial \gamma} / \frac{\partial G}{\partial p}.$$

Therefore, $dp/d\gamma < 0$, as long as $sign(\partial G/\partial \gamma) = sign(\partial G/\partial p)$.

So we have defined the function $p(\gamma)$ such that $E_1^* = E_i^* = E$. Let us depart from this point. Assume that $E_1^* = E + \varepsilon$, where ε is small. We have $(1-E)^2 + \varepsilon = \phi_1(E, p, \gamma)$ and $(1-E)^2 = \phi_i(E, p, \gamma)$, that gives $\phi_1(E(p,\gamma), p, \gamma) + \varepsilon - \phi_i(E(p,\gamma), p, \gamma) = 0$. Hence, $E_1^* > E_i^*$ for $p > p(\gamma)$.

Lastly we must check that $p < \overline{p}_\theta(\gamma)$, in order to get an equilibrium (i.e., $\theta^* > 0$). Thus, p must be larger than $p(\gamma)$, as well as smaller than $\overline{p}_\theta(\gamma)$, so $(\gamma, p) \in \Psi = \{\gamma, p/p > p(\gamma)$ and $p < \overline{p}_\theta(\gamma)\}$.

Therefore, there exists a unique pair of solutions $(E_1^*, E_i^*) \in [0,1] \times [0,1]$ and $\theta^* \in [0,1]$, such that $E_1^* > E_i^*$ for $(\gamma, p) \in \Upsilon \cap \Psi \equiv \Omega$.

Static comparative in the general case

In the absence of an analytical formulation for efforts, we need to study how the functions $E_1^*(E_i)$ and $E_i^*(E_1)$ are affected by a change in one parameter in order to determine the impact of the change of this parameter on the equilibrium values. Let us call this parameter y, which can be ΔW (with $\overline{W}_G - \underline{W}_R$=constant), p, x_i, γ and K. Let us rewrite $E_1^*(E_i) = 1 - \sqrt{\phi_1(y)}$ and $E_i^*(E_1) = 1 - \sqrt{\phi_i(y)}$, where $\phi_1(y)$ and $\phi_i(y)$ are defined in equation (16) and (17). Thus, $\frac{dE_j^*}{dy} = -\frac{1}{2}(\phi_j(y))^{-\frac{1}{2}}\phi_j'(y)$, where $j = 1, i$. We show that $\phi_1'(y) < 0$ for $y = \Delta W, p$ (for $p < 1/2\gamma$), $\phi_1'(y) = 0$ for $y = x_i$, and $\phi_1'(y) > 0$ for $y = K, \gamma$ (for $\gamma > 1/2p$). The function $E_1^*(E_i)$ is decreasing (respectively, increasing) with K, γ (respectively, $\Delta W, p$) and is constant with x_i. By the same token, we find that $\phi_i'(y) < 0$ (respectively, positive) for $y = \Delta W, x_i, p$ (for $p < 1/2$), and γ (for $\gamma < (2p-1)/2p$) (respectively, $y = K$). The function $E_i^*(E_1)$ is increasing with $\Delta W, x_i, p$, γ (respectively, decreasing with K).

Proof of Corollary 1. Case where $\overline{W}_G = \underline{W}_R$: Necessary condition for interior solutions

Showing that $E_1^* > E_i^*$, where E_1^* is defined by (18) and E_i^* by (19), is equivalent to showing that

$$p(1-2\gamma) > \tfrac{x_i}{1+x_i} - \gamma.$$

If $1 - 2\gamma > 0$, then

$$p < \frac{\gamma - \frac{x_i}{1+x_i}}{2\gamma - 1} \equiv h_1(\gamma),$$

and if $1 - 2\gamma < 0$, then

$$p > \frac{\frac{x_i}{1+x_i} - \gamma}{1 - 2\gamma} \equiv h_2(\gamma).$$

Therefore, $E_1^* > E_i^*$ for $(p, \gamma) \in \Gamma = \{(p, \gamma) \mid (1 + x_i)(p(1-2\gamma) + \gamma) - x_i > 0\}$.

Proof of Corollary 2

The proof consists in the calculation of the derivatives of E_1^* and E_i^* with respect to p, γ.

Proof of Corollary 3

The result of Corollary 3 is trivial for $F \geq F_1$ from the calculation of the derivatives $\partial E^*_{1t}/\partial \underline{W}_G < 0$ and $\partial E^*_{it}/\partial \underline{W}_G < 0$.

Proof of Corollary 4

This result is simply derived from equality (10). Indeed

$$\mu_1(\theta)(1-E_1) = \quad \mu_i(\theta)(1-E_i)\frac{\underline{V}(F)}{\underline{V}} < \mu_i(\theta)(1-E_i)$$

as $\underline{V}(F) \leq \underline{V}$.

Proof of Lemma 4

The maximization program of the innovator is

$$\underset{e}{Max}\Pi(e),$$

that gives

$$e^*(F) = Min\{1, e_1(F) - \sigma(F)\} \tag{27}$$

where $e_1(F) = p\Delta V(1-p)(\gamma E^*_1 + (1-\gamma)E^*_i) + p^2\Delta V + p\underline{V}$ and $\sigma(F) = (\underline{V} - \underline{V}(F))p\gamma(1-\gamma)(\frac{(1-E^*_i)}{\underline{V}} - \frac{(1-E^*_1)}{\underline{V}(F)})(p\Delta V + \underline{V}) > 0$ as $\theta^* < 1$ and $\Delta V = \overline{V} - \underline{V} - v$.

If $F = 0$, $\phi(0) = 0$ and, therefore, $e^*(0) = e_1(0) = p(1-p)(\gamma E^*_1 + (1-\gamma)E^*_i)\Delta V + p^2\Delta V + p\underline{V}$.

For $F > F_1$, $e^*_t = p(1-p)(\gamma E^*_{1t} + (1-\gamma)E^*_{it})\Delta V + p^2\Delta V + p\underline{V}$.

We first study the shape of $e_1(F)$:

$$\frac{de_1(F)}{dF} = p\Delta V(1-p)(\gamma\frac{dE^*_1}{dF} + (1-\gamma)\frac{dE^*_i}{dF})?,$$
$$\frac{d^2e_1(F)}{dF^2} = p\Delta V(1-p)(\gamma\frac{d^2E^*_1}{dF^2} + (1-\gamma)\frac{d^2E^*_i}{dF^2}) > 0.$$

We then study $\sigma(F) = (\underline{V} - \underline{V}(F))p\gamma(1-\gamma)b(F)(p\Delta V + \underline{V}) > 0$ where $b(F) = \frac{(1-E^*_i)}{\underline{V}} - \frac{(1-E^*_1)}{\underline{V}(F)}$

$$\frac{d\sigma(F)}{dF} = p\gamma(1-\gamma)(p\Delta V + \underline{V})[-\underline{V}'(F)b(F) + (\underline{V} - \underline{V}(F))b'(F)]?,$$
$$\frac{d^2\sigma(F)}{dF^2} = p\gamma(1-\gamma)(p\Delta V + \underline{V})[-\underline{V}''(F)b(F) - \underline{V}'(F)b'(F) + (\underline{V} - \underline{V}(F))b''(F)] < 0,$$

where

$$b(F) = \frac{(1-E^*_i)}{\underline{V}} - \frac{(1-E^*_1)}{\underline{V}(F)} > 0,$$
$$b'(F) = -\frac{dE^*_i}{dF}\frac{1}{\underline{V}} + \frac{\frac{dE^*_1}{dF}\underline{V}(F) + (1-E^*_1)\underline{V}'(F)}{\underline{V}(F)^2} < 0,$$
$$b''(F) = -\frac{d^2E^*_i}{dF^2}\frac{1}{\underline{V}} + \frac{(\frac{d^2E^*_1}{dF^2}\underline{V}(F) + (1-E^*_1)\underline{V}''(F))2V'(F) - (\frac{dE^*_1}{dF}\underline{V}(F) + (1-E^*_1)\underline{V}'(F))4V'(F)\underline{V}(F)^2}{\underline{V}(F)^3},$$
$$= -\frac{d^2E^*_i}{dF^2}\frac{1}{\underline{V}} + \frac{2\frac{d^2E^*_1}{dF^2}\underline{V}(F)V'(F) - 4V'(F)\underline{V}(F)^2(\frac{dE^*_1}{dF}\underline{V}(F) + (1-E^*_1)\underline{V}'(F))}{\underline{V}(F)^3} < 0.$$

Therefore,

$$\frac{d^2e(F)}{dF^2} = \frac{d^2e_1(F)}{dF^2} - \frac{d^2\sigma(F)}{dF^2} > 0.$$

Proof of Lemma 5: Static comparative for the optimal effort of the innovator

We study how the optimal level of innovator effort e^* varies with y, where $y = x_i, p, \gamma$,

$$\frac{de^*}{dy} = \frac{\partial e^*}{\partial y} + \frac{\partial e^*}{\partial E_1}\frac{\partial E_1^*}{\partial y} + \frac{\partial e^*}{\partial E_i}\frac{\partial E_i^*}{\partial y}.$$

Proof of Lemma 6

The proof consists in computing the derivatives of the quality expressions (22) and (23) with the appropriate values for μ_1 and μ_i, as defined in equations (12) and (13).

Proof of Lemma 7

The efforts (24) and (25) can be written as

$$\begin{aligned} E_1^{SPER} &= 1 - \phi_{S1}(\beta)^{\frac{1}{2}}, \\ E_i^{SPER} &= 1 - \phi_{Si}(\beta)^{\frac{1}{2}}, \end{aligned}$$

and we need to study the functions $\phi_{S1}(\beta)$ and $\phi_{Si}(\beta)$. First, we determine that

$$\frac{\partial \phi_{S1}(\beta)}{\partial \beta} = \frac{K(1-\gamma)p\Delta W(1-\beta)}{x_i \Delta W \Delta W^{SPER}(1-p)p\gamma}(\overline{W}_G - \overline{W}_R) > 0,$$

and, therefore, we can conclude that

$$\frac{\partial E_1^{SPER}}{\partial \beta} < 0.$$

Similarly, we compute $\partial \phi_{Si}(\beta)/\partial \beta$ and show it is negative as long as a pair of solutions exists. Therefore,

$$\frac{\partial E_i^{SPER}}{\partial \beta} < 0.$$

Further, there exists a value of $\beta \in (0, 1)$ such that $\phi_{S1}(\beta) = \phi_{Si}(\beta)$. Denote β_s such a value. Hence, for any $\beta < \beta_s$, $\phi_{S1}(\beta) < \phi_{Si}(\beta)$ and, therefore, $E_1^{SPER} > E_i^{SPER}$.

Proof of Proposition 2

We first show that for any $\beta > 0$, the introduction of the SPER initiative increases (respectively, reduces) the number of patent applications submitted with $\widetilde{x} = 1$ (respectively, $\widetilde{x} = x_i$).

In the emerging field, it is easy to show that the the number of patent applications in absence of the SPER initiative regime is higher than in its presence:

$$\begin{aligned}(1-\gamma)+\gamma(1-p)(1-\theta^*) &> p(1-\gamma)+(1-p)(1-\gamma)+\gamma(1-p)(1-\theta^*_{SPER}),\\ \text{as } \theta^*_{SPER} &> \theta^*.\end{aligned}$$

In the emerging field, the number of applications is higher under the SPER regime, as

$$p\gamma+(1-p)\gamma+(1-p)\gamma\theta^*_{SPER} > p\gamma+(1-p)\gamma+(1-p)\gamma\theta^*.$$

Second, we show that the total number of patents granted is lower in the mature field as $\mu_1^{SPER} < \mu_1$, where

$$\mu_1^{SPER} = p\tfrac{(1-\gamma)(1-\beta)(1-E_i)+\gamma(1-E_1)}{(1-E_1)}.$$

To see that, we differentiate μ_1^{SPER} with respect to β,

$$\tfrac{d\mu_1^{SPER}}{d\beta} = \tfrac{\partial\mu_1^{SPER}}{\partial\beta} + \tfrac{\partial\mu_1^{SPER}}{\partial E_1}\tfrac{\partial E_1}{\partial\beta} + \tfrac{\partial\mu_1^{SPER}}{\partial E_i}\tfrac{\partial E_i}{\partial\beta} < 0,$$

as $\partial\mu_1^{SPER}/\partial\beta < 0$, $\partial\mu_1^{SPER}/\partial E_1 > 0$, $\partial E_1/\partial\beta < 0$, $\partial\mu_1^{SPER}/\partial E_i < 0$ and $\partial E_i/\partial\beta > 0$.

Third, to show that the quality of patents granted in the mature field decreases with β, we first rewrite the quality as

$$\begin{aligned}Q_1^{SPER} &= E_1^{SPER}+(1-E_1^{SPER})\mu_1^{SPER},\\ &= p\gamma+E_1^{SPER}(1-p\gamma)+p(1-\gamma)(1-\beta)(1-E_i^{SPER}).\end{aligned}$$

The total derivative of the quality is

$$\tfrac{dQ_1^{SPER}}{d\beta} = \tfrac{\partial Q_1^{SPER}}{\partial\beta} + \tfrac{\partial Q_1^{SPER}}{\partial E_1^{SPER}}\tfrac{dE_1^{SPER}}{d\beta} + \tfrac{\partial Q_1^{SPER}}{\partial E_i^{SPER}}\tfrac{dE_i^{SPER}}{d\beta} < 0,$$

as $\partial Q_1^{SPER}/\partial\beta < 0$,$\partial Q_1^{SPER}/\partial E_1^{SPER} > 0$, $\tfrac{dE_1^{SPER}}{d\beta} < 0$, $\tfrac{\partial Q_1^{SPER}}{\partial E_i^{SPER}} < 0$ and $\tfrac{dE_i^{SPER}}{d\beta} > 0$. The quality of patents issued in the emerging field can be written as

$$Q_i^{SPER} = \tfrac{E_i^{SPER}+(1-E_i^{SPER})\mu_i^{SPER},}{E_i^{SPER}+(1-E_i^{SPER})(1-\beta(1-\mu_i^{SPER}))}.$$

The total derivative of Q_i^{SPER} is

$$\tfrac{dQ_i^{SPER}}{d\beta} = \tfrac{\partial Q_i^{SPER}}{\partial\beta} + \tfrac{\partial Q_i^{SPER}}{\partial\mu_i^{SPER}}\tfrac{d\mu_i^{SPER}}{d\beta} + \tfrac{\partial Q_i^{SPER}}{\partial E_i^{SPER}}\tfrac{dE_i^{SPER}}{d\beta} > 0,$$

as all of the derivatives are positive with respect to β.

Proof of Lemma 8

Let $A=(E^A_{1c},E^A_{ic})$ be a policy such that $E^A_{ic}<E^A_{1c}$. In such a policy, the equilibrium beliefs of the examiner are

$$\begin{aligned}\mu^A_{1c} &= 1,\\ \mu^A_{ic} &= p\tfrac{1-\gamma}{1-\gamma p}=\mu_i<p.\end{aligned}$$

Now consider a policy $A'=(E^{A'}_{1c},E^{A'}_{ic})$, such that $E^{A'}_{ic}=E^A_{ic}$ and $E^{A'}_{1c}=E^A_{1c}-\varepsilon$, with $\varepsilon>0$ but with $E^{A'}_{1c}>E^{A'}_{ic}$. With this new policy, upon receiving $\widetilde{x}=1$, the examiner will check with accuracy $E^{A'}_{1c}>E^{A\prime}_{ic}$. Thus, a bad innovator will never choose to report $\widetilde{x}=1$, even if he can. Thus, $\mu^{A'}_1=1$. A bad innovator will report $\widetilde{x}=x_i$, so that

$$\mu^{A'}_i=p\tfrac{1-\gamma}{1-\gamma p}<p.$$

The examiner exerts effort $E^{A'}_{1c}$, pays a cost $C(E^{A'}_{1c})=1/(1-E^{A'}_{1c})$, and follows her judgement. It is obvious that policy A' dominates policy A, since they have the same screening efficiency. But A is more costly than A', as $C(E^{A'}_{1c})<C(E^A_{1c})$, even though $C(E^{A'}_{ic})=C(E^A_{ic})$.

Ex Ante **Commitment: Comparison of the levels of effort**

In the case of commitment, E_c is the solution of

$$\tfrac{de(E)}{dE}[B_c\left(E_c\right)-\tfrac{\gamma K}{(1-E_c)}-\tfrac{(1-\gamma)K}{x_i(1-E_c)}]+e\left(E\right)[p(1-p)\Delta W-\tfrac{(\gamma x_i+(1-\gamma))K}{x_i(1-E)^2}]=0.$$

If we define $\underline{E}$ as the solution of

$$p(1-p)\Delta W-(\gamma x_i+(1-\gamma))\tfrac{K}{x_i(1-E)^2}=0,$$

it is easy to prove that $\underline{E}<E_c$.

Let us rewrite the condition to obtain E^*_1 as

$$p(1-p)\Delta W-\tfrac{x_i(1-p(1-\gamma))\underline{V}^2-p(1-\gamma)\underline{V}(F)^2}{\gamma\underline{V}^2}\tfrac{K}{x_i(1-E)^2}=0,$$

and the condition to obtain E^*_i as

$$p(1-p)\Delta W-\tfrac{\underline{V}(F)^2(1-p\gamma)-\underline{V}^2p\gamma x_i}{(1-\gamma)\underline{V}(F)^2}\tfrac{K}{x_i(1-E)^2}=0.$$

A comparison of these conditions leads to $E_i^* < \underline{E} < E_c$ for $p < d_1$, and that $E_1^* < \underline{E} < E_c$ for $p < d_2$, where

$$d_1 \equiv \frac{\underline{V}(F)^2[1-(1-\gamma)(\gamma x_i+1-\gamma)]}{\gamma(\underline{V}(F)^2+x_i\underline{V}^2)} \quad \text{and} \quad d_2 \equiv \frac{\underline{V}[x_i-\gamma(\gamma x_i+1-\gamma)]}{(1-\gamma)(\underline{V}(F)^2+x_i\underline{V}^2)},$$

and $d_2 < d_1$. The constellation of parameters (p, γ) for which $p < d_1$ is much larger than for which $p < d_2$. In fact, we can also show that there exists a function $H > d_2$ such that $E_1^* = E_c$ and, therefore, for values of $(p, \gamma) \in \{p, \gamma / d_1 > p > H\}$, $E_i^* < E_c < E_1^*$.