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Prior art: To search or not to search

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ABSTRACT

To determine patentability, inventions are evaluated in light of existing prior art. Innovators have a duty to disclose any prior art that they are aware of, but have no obligation to search. We study innovators' incentives to search for prior art, their search intensities and the timing of search. We distinguish between early state of the art search—conducted before R&D investment, and novelty search—conducted right before applying for a patent. We identify conditions in which innovators have no incentive to search for prior art. Search intensity increases with R&D cost, the examiners' expected search effort, and with patenting fees. We also find that innovators prefer to correlate their search technology with that of the patent office. In light of our model, we discuss the implications of some proposed policy reforms.

1. Introduction

The patent system was designed to provide incentives to innovate and to disclose research findings. Two central conditions for patentability of an invention—novelty and non-obviousness—are evaluated in light of the existing prior art. Broadly speaking, prior art could refer to any prior knowledge. However, for the purpose of determining patentability, prior art is defined in the U.S. Patent Act by stating that an invention is *not* patentable if "the invention was known or used by others in this country, or patented or described in a printed publication in this or a foreign country, before the invention thereof by the applicant for patent," and if such knowledge existed more than one year before the filing of the patent (35 U.S.C. §102). According to Rule 56 of the Rules of Practice in Patent Cases (37 CFR §1.56), "each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability…"[1] Thus, Rule 56 requires a patent applicant and his representatives not to intentionally omit any information they have that appears to be "by itself or in combination with other information" relevant for determining patentability. Violation of Rule 56 is considered "inequitable conduct" in court. However, there is no duty to search for prior art, only to disclose what is known. According to Cotropia (2007), "(t)he immediate results from a finding of inequitable conduct create a tremendous deterrent against non-disclosure," and there is a "perverse incentive for the relevant parties to remain ignorant about relevant information since the more the party knows, the greater is their exposure under the doctrine."

Patent examination is imperfect. Patents on "innovations" that are either not novel or obvious are often granted. Had the examiner been sufficiently informed, such patent would not have been granted. These "bad patents"—for which invalidating prior arts exist but are not found—might curtail future innovation, unnecessarily limit market activities and unduly create welfare reducing market power. Bad patents are also likely to result in waste due to litigation costs and disadvantage those who cannot afford it. Amid concerns over the patent office granting a growing number of bad patents, many have called for reform of the patent system and proposed remedies, such as a patent opposition system (Merges, 1999), patent bounties (Thomas, 2001), "gold-plate" patents (Lemley et al., 2005), and community patent review (Noveck, 2006).

In August 2007, the United States Patent and Trademark Office (USPTO) published a set of new rules that included a requirement to

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[1] See Manual of Patent Examining Procedure http://www.uspto.gov/web/offices/pac/mpep/.

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submit, with any application that has more than five independent claims or twenty-five total claims, an examination support document (ESD) that contains a detailed prior art search statement by the innovator. On October 31, 2007, just before the new rules were set to become effective, the United States District Court for the Eastern District of Virginia issued a decision temporarily enjoining the USPTO from implementing the new rules.[2] On April 1, 2008, the court handed down a decision that permanently blocks implementation of the USPTO's proposed new rules.[3] These proposed rules could be seen as an attempt to shift the duty of prior art search from examiners to innovators (at least in some instances).

According to Alcacer and Gittelman (2006), more than 500,000 utility patents were issued by the USPTO between 2001 and 2003, of which, around 40% had all the prior art references inserted by the examiners. Additionally, two-thirds of all the citations on an average utility patent are contributed by the examiners. The goal of our paper is to better understand innovators' incentives to search for (and thus reveal) prior art and the policy levers that affect these incentives. We study the benefits, intensity and the timing of prior art search and the potential implications of related proposed policy changes.

Our analysis distinguishes between ex ante search (conducted before R&D investment), which we refer to as "*early state of the art* search" and ex post or "*novelty* search" (conducted after successful R&D but before filing for the patent). Early state of the art search might help avoid duplication when it is not profitable to duplicate (saving investment cost) and it could shape innovation by guiding the researcher to a path that is more likely to be novel, whereas novelty search can save on patenting costs. Since search lowers the probability of being granted a patent, and even bad patents may be profitable to the awardee, an innovator might prefer to avoid or limit prior art search. We derive payoff maximizing search intensities and compare them to the socially optimal ones.

We study prior art search strategies in a sequential decision process. In the model, an innovator chooses her early state of the art search intensity before investing in R&D. She learns from search results and updates her belief on patentability. As more search effort produces no invalidating prior art, she becomes increasingly optimistic. After this initial search, she decides whether to invest in risky R&D. If R&D is successful, the innovator chooses the intensity of novelty search and files for a patent if no invalidating prior art was found. At the patent office, an examiner follows a pre-determined search routine and grants the patent if no invalidating prior art was found.

We determine the innovators' optimal prior art search strategies under different policy rules and patent examination regimes. We find that the innovator's effort level is weakly increasing with the examiner's expected search effort. Innovators search more when R&D investment and patenting costs are higher. We identify conditions under which an innovator would prefer not to search at all. If the cost of patenting is sufficiently low compared to the gain from a bad patent, then the innovators under-invest in search compared to the social optimum. There are conditions under which a suitable patent fee can give innovators incentives for optimal search.

Patent policy has long been a subject of interest and debate in the economic literature. Such work examined various aspects of patent policy, for example, optimal patent length and breadth (Klemperer, 1990; Gilbert and Shapiro, 1990), the novelty or patentability requirement (O'Donoghue, 1998; Scotchmer and Green, 1990), infringement and litigation (Chang, 1995; Crampes and Langinier, 2002). Prior art search and disclosure incentives have been discussed by many legal scholars. Yet, these issues have received relatively little formal consideration in the economic literature. To the best of our knowledge, the first model of prior art search and disclosure is due to Langinier and Marcoul (2008; an earlier draft appeared in 2003). Their paper examines "the strategic non-revelation of information by innovators when applying for patents." They recommended that a patent examiner should undertake identical scrutiny effort on all patent applications irrespective of the number of citations by the applicant. In our analysis, we assume this is the case. Lampe (2008) also considers innovators' incentives not to disclose prior art. He predicts that innovators would conceal information about prior arts which are most "closely related" to their invention and thus, the most important pieces of prior art are not cited by the patent applicants.

In contrast to these contributions, our main focus is on the incentives to search for prior art, its timing and intensity. In most of our analysis, innovators comply with the duty to disclose, but they may choose not to search. This premise is in line with the writing of legal scholars such as Thomas (2001): "(a)lthough Rule 56 mandates that the applicants disclose known prior art, it does not require them to search in the first place. Coupled with the draconian consequences of a holding of inequitable conduct, many applicants are discouraged from conducting prior art searches in the first place." Our private communications with innovators, IP attorneys and search experts also suggested that more often search is strategically avoided rather than its results illegally not disclosed. We argue that in fact, even if the consequences of inequitable conduct are not severe, as long as prior art search requires effort, it is in the researcher's best interest to remain ignorant rather than search and conceal. Given no legal obligation to search, a researcher would not have an incentive to invest in prior art search in the first place unless, in the event prior art is found, she would change her actions—either not investing in this particular innovation, or not filing for the patent.

Caillaud and Duchêne (2007) examine the impact of the patent office on firms' incentives to innovate and to apply for patent protection, and the overload problem patent examiners face. They show that given imperfections in the examination process, some granting of bad patents are inevitable. In their model, innovators know the quality of their patents before deciding whether or not to apply. In contrast, since we focus on incentives to search for prior art, in our model innovators can learn about their innovations' quality by investing in prior art search. Caillaud and Duchêne (2007) also consider the role of patent fees as a policy instrument. They consider the effects of patenting fees on R&D investment and on incentives to apply for patents. Our paper, on the other hand, shows that patenting fees can also provide incentives to search for prior art. Recent literature has also attempted to improve our understanding of examiner incentives and examination procedures in the USPTO, for example, Cockburn et al. (2002) and Langinier and Lluis (2009). We discuss some of their findings in Section 6.

Finally, we mention that there is a relatively recent body of empirical research on prior art search. From 2001, the USPTO began indicating which prior art references were inserted by the examiner. This newly available data on prior art enabled empirical analysis of prior art (see, for example, the contributions in Sampat, 2005; Alcacer and Gittelman, 2006; Lampe, 2008; Alcacer and Gittelman, 2006; Alcacer et al., 2009).

The rest of this paper is organized as follows. Section 2 presents our basic model of prior art search; Section 3 derives preliminary results on the optimal search intensity; in Section 4, we discuss the innovator's incentives to mimic examiner's search process; Section 5 considers factors that affect the timing and intensity of search; in Section 6, we address policy issues; in Section 7, we discuss disclosure incentives and present an extension of the model where search influences the innovation process, here an incentive not to disclose prior art may arise; Section 8 offers concluding remarks. All proofs are provided in the Appendix A.

[2] Tafas v. Dudas, No. 1:07 Civ 846 (E.D. va. Oct. 31, 2007), see memorandum opinion 10-31-2007, available at http://www.jsslaw.com/publications.aspx.

[3] Tafas v. Dudas, No. 1:07 Civ 846 (E.D. va. Apr. 1, 2008), available at http://www.patentlyo.com/patent/2008/04/tafas-v-dudas-p.html.

2. The model

In our model, there is an innovator or a researcher (R) and an examiner (E). The researcher has an innovation idea which she at first believes to be patentable with probability $(1-\alpha)\in(0,1)$. With probability α, there exists invalidating prior art. There is a fixed cost for R&D denoted by I. R&D is risky, success occurs with a probability $\theta>0$. The innovator can apply for a patent on her invention. A patent application costs P including patenting fees and legal costs. We account for the cost of prior art search separately.

Patent applications are examined in the patent office. We assume that the patent office commits to prior art search intensities and examiners pursue this search.[4] We model prior art search technology with a function $F(X)$. If there was no search by the innovator, then conditional on the existence of invalidating prior art, examiner's search effort $X_E\in[0,\infty)$ reveals it with a probability $F(X_E)\in[0,1]$. This probability increases with search effort, $F'(X)=f(X)>0$, at a decreasing rate, $F''(X)=f'(X)<0$. We denote by $\lambda(X)=\frac{f(X)}{1-F(X)}$, the hazard rate of the distribution F. Search technology F likely varies by field. In matured technological areas, where a lot of the prior art is patented, search is likely to be more efficient than in areas where most of the prior arts are not patented.

The researcher can also search for prior art. The researcher's search technology could be correlated with that of the examiner. For example, both the innovator and the examiner might start with examining the USPTO database and use similar keywords in their search. If the innovator's search does not reveal prior art and if the examiner follows roughly the same search path as the innovator, then the examiner is not likely to find any invalidating prior art either. However, having been exposed to different research related experiences (interactions with colleagues, prior research or examination experience etc.), the researcher and the examiner could be using different data sources, different search engines, different search keywords and so on. Hence, our model accounts for the possibility that search technologies of the innovator and the examiner are somewhat but perhaps not perfectly correlated. To model varying levels of correlation, we assume that with probability ρ the innovator has the same search path as the examiner, that is, examiner's and researcher's searches are perfectly correlated. But, with probability $(1-\rho)$ the innovator has a different search path which is independent from that of the examiner. Search technologies are chosen by "nature" (i.e. determined by events not in the researcher's or examiner's control), but we discuss in Section 4 why researchers, if they can, might want to influence the degree of correlation between their search and that of the examiner.

Search efficiency of the examiner and the innovator could also differ. For simplicity, we take the same functional form for their search technologies $F(.)$, but differences in search efficiency can be captured by differences in search costs. For the innovator, we assume that a search effort X_R costs $C_R(X_R)=X_R$.[5] The examiner's search cost is an increasing function $C_E(X_E)$ for search effort X_E. When the examiner is less efficient than the innovator, this cost can be higher than X_E. For a given amount of examination time allocated to each application, examiner's "effective" units of search effort X_E would be lower in fields where his search technologies are less efficient, for example in emerging fields, where much of the prior art is not patented and examiners are less experienced.

Accounting for the researcher's search and the correlation in search technologies, we find that if the researcher's search effort was X_R and the examiner's search effort is X_E, then the probability that the examiner finds invalidating prior art (IPA) conditional on invalidating prior art existing but it was not found by the innovator, is given by

$$p(X_R,X_E)\ =\ pr(E\text{ finds IPA}\,|\,\exists\text{ IPA and }R\text{ did not find it}),$$

or,

$$p(X_R,X_E)=\begin{cases}(1-\rho)F(X_E) & \text{if}\quad X_R\geq X_E\\ \dfrac{\rho(F(X_E)-F(X_R))\ +\ (1-\rho)(1-F(X_R))F(X_E)}{1-F(X_R)} & \text{if}\quad X_R<X_E\end{cases}. \tag{1}$$

When $\rho=0$, the search technologies are independent and the probability that the examiner finds prior art conditional on its existence is

$$p(X_R,X_E)\ =\ F(X_E)$$

which only depends on the examiner's effort. When $\rho=1$, the search technologies are perfectly correlated and

$$p(X_R,X_E)=\begin{cases}0 & \text{if}\quad X_R\geq X_E\\ \dfrac{F(X_E)-F(X_R)}{1-F(X_R)} & \text{if}\quad X_R<X_E\end{cases}.$$

In the perfectly correlated case, if the examiner's search does not exceed that of the innovator, then if the innovator does not find any prior art, the examiner does not either.

We consider two stages of search. Early state of the art search, conducted before R&D investment, and novelty search, conducted after success in innovation but before filing for a patent. Before investment in R&D, the researcher chooses her early state of the art search intensity x_1. Observing the results of this initial search, she decides whether to invest in R&D. If any invalidating prior art is found, she does not engage in research.[6] When no invalidating prior art is found, the researcher updates her belief that her innovation is patentable. If innovation succeeds, the researcher chooses novelty search intensity level x_2. Search at this stage accumulates with the early state of the art search, that is, conditional on the existence of invalidating prior art, if the innovator exerted early search effort x_1 and novelty search effort x_2, then invalidating prior art is not found with probability $[1-F(x_1+x_2)]$.[7] After conducting novelty search, the researcher further updates her belief on the patentability of her innovation and chooses whether to file for a patent.

After the examination process, the patent examiner decides whether to grant the patent. Since the examination process is not perfect, it is possible that bad patents would be granted. A bad patent refers to a patent granted when invalidating prior art exists but the examiner was not aware of it. The researcher enjoys a benefit G if she is granted a patent which is truly novel and a benefit $g<G$ if she is granted a bad patent. An awardee may benefit from bad patents because of the reputation value of having a patent. Larger patent portfolios can be useful in cross-licensing agreements with other firms or as signals to investors. Patents, even bad ones, may also deter competitors from use of the innovation in fear of infringement suits, especially if the competitor is also unaware of the existing invalidating prior art or is unable to cover large litigation costs. But, it is reasonable to assume that the value of a bad patent is lower than that of a good patent since invalidating prior art can be exposed after its issuance. In

[4] We further discuss this assumption in Section 6.3.

[5] We assume here that search cost is incurred for a single innovation. It is possible however that innovators experience returns-to-scale when they engage in multiple innovation projects. The amount invested to search for prior art in one project can be used for another project as well. This is beyond the scope of our paper.

[6] We start by assuming that the innovator complies with the duty to disclose. Therefore, she does not invest if she finds invalidating prior art. We argue in Section 6 that we do not need this assumption.

[7] We implicitly assumed here, for simplicity, that the innovator's available search technology is the same before and after innovation. It is possible, however, that after successful innovation the innovator knows more and is better able to search. We generalize the model to allow for different search technologies ex ante and ex post under the assumption that $\rho=0$ in Proposition 7 in Section 5 as well as in Section 7.

particular, if a patent-holder plans to enforce it, the alleged infringer would likely make an effort to prove it invalid.

3. Innovator's optimal search

An innovator faces the following decisions: a choice of her early state of the art search effort x_1, investment decision, novelty search effort after innovation x_2 and patent filing. We derive the innovator's optimal search effort for prior art using backward induction.

Consider first a successful researcher who did not find any invalidating prior art and is facing the decision whether to file for a patent or not. If invalidating prior art does not exist, then the innovator's benefit from the patent is G. If invalidating prior art exists (but the researcher's search effort did not reveal it), then the innovator's expected benefit from the patent application is $[1-p(X_R, X_E)]g$, since with probability $[1-p(X_R, X_E)]$ the patent examiner does not find invalidating prior art either. Having invested search efforts x_1 and x_2 and not found invalidating prior art (IPA), the innovator's belief that such prior art exists can be derived using Bayes' rule:

$$q(x_1+x_2) = pr(\text{IPA exists}|\text{IPA not found}) = \frac{\alpha[1-F(x_1+x_2)]}{1-\alpha F(x_1+x_2)}.$$

Hence, the expected payoff from filing for a patent on an innovation for which invalidating prior art was not found with search efforts (x_1, x_2) is

$$q(x_1+x_2)[1-p(X_R,X_E)]g+[1-q(x_1+x_2)]G-P-I-(x_1+x_2).$$

The first two terms capture the expected benefits from a bad or a good patent application using updated belief, then we subtracted patenting costs, R&D costs and search costs.[8] Given that the cost of investment and search are already sunk at this time, the innovator files for a patent only if

$$q(x_1+x_2)[1-p(X_R,X_E)]g+[1-q(x_1+x_2)]G \geq P.$$

We now consider the choice of effort for validity prior art search, x_2. The innovator who has exerted effort x_1 and yet did not find any invalidating prior art has the belief that such prior art exists with probability

$$q(x_1) = \frac{\alpha[1-F(x_1)]}{1-\alpha F(x_1)}.$$

This probability equals α if no search effort was exerted, it declines to zero as $x_1 \to \infty$. That is, the innovator is increasingly optimistic that her innovation is good the more search effort she exerted without finding invalidating prior art. Let the net expected gain from a bad patent application be

$$B(X_R,X_E) = (1-p(X_R,X_E))g-P.$$

Using our definition of $p(X_R, X_E)$ from Eq. (1), we obtain

$$B(X_R,X_E) = \begin{cases} B+\rho g & \text{if} \quad X_R \geq X_E \\ B+\left(\dfrac{1-F(X_E)}{1-F(X_R)}\right)\rho g & \text{if} \quad X_R < X_E \end{cases}, \tag{2}$$

where

$$B = (1-\rho)(1-F(X_E))g-P. \tag{3}$$

The innovator will choose her novelty search effort x_2 to maximize her expected payoff:

$$\pi(x_1,x_2) = q(x_1)\frac{[1-F(x_1+x_2)]}{[1-F(x_1)]}B(X_R,X_E) + (1-q(x_1))(G-P)-I-(x_1+x_2). \tag{4}$$

This payoff function is continuous in x_2, it is everywhere differentiable except at the kink $x_2 = X_E - x_1$. For any given state of the art search x_1, we can derive the optimal level of novelty search $x_2^*(x_1)$. In our first lemma, we identify a condition under which the innovator would not engage in novelty search before patenting. The proof of Lemma 1, and all other proofs, are provided in the Appendix A.

Lemma 1. *For any x_1, there is a unique level of novelty search $x_2^*(x_1)$ that maximizes Eq. (4). When the net benefit from a bad patent is large enough ($B \geq 0$), the innovator does not invest in novelty search, $x_2^* = 0$.*

We now consider the decision to invest in R&D. Having invested x_1 in early state of the art search and not found invalidating prior art, the researcher invests in R&D if

$$\theta\left[q(x_1)\frac{[1-F(x_1+x_2^*)]}{[1-F(x_1)]}B(X_R,X_E)+(1-q(x_1))(G-P)-x_2^*\right] \geq I. \tag{5}$$

Let us assume that the expected benefit from the innovation is high enough so that the innovator invests in R&D if she found no prior art in her early search. A sufficient condition (see Lemma 2 in the Appendix A) for this to hold is:

$$\theta[\alpha B+(1-\alpha)(G-P)] \geq I. \tag{6}$$

This condition states that the expected benefit from R&D investment, if the innovator does not search at all, exceeds its cost.

Consider now the choice of effort for initial prior art search, x_1. Before conducting any search, the researcher has a prior belief that with probability α there exists prior art that can invalidate her innovation. Thus, her expected payoff from the initial search is

$$\Pi(x_1,x_2^*(x_1)) = (1-\alpha)[\theta(G-P-x_2^*)-I] + \alpha[1-F(x_1)]\left[\theta\left(\frac{[1-F(x_1+x_2^*)]}{[1-F(x_1)]}B(X_R,X_E)-x_2^*\right)-I\right]-x_1. \tag{7}$$

Maximizing Eq. (7) with respect to early state of the art search intensity x_1, taking into account its effect on x_2^* as derived in Lemma 1, yields the optimal search intensities.[9]

We now identify some properties of optimal search efforts. Clearly the intensity of search would depend on parameter values. In the first proposition we find that when innovator's and examiner's search technologies are not independent ($\rho>0$), then there is a non-negligible range of parameter values for which the innovator's total search exactly matches that of the examiner. This result holds because when $\rho>0$, Eq. (7) has a kink at $X_R = X_E$. For an intermediate range of B (net value of a bad patent) and I (R&D cost), innovator's payoff is maximized at this kink. If B is very low and I is large, innovator's search effort could exceed examiner's effort while if B is high enough and I is low, innovator's search effort would be lower than the examiner's.

[8] Our analysis abstracts from the possibility that financial constraints limit innovator's ability to search for prior art or alter the amount invested in the R&D project. While it is possible that such financial constraints are sometimes in effect, we believe it is a reasonable simplification because in many cases R&D investments are on a much larger scale than the costs of prior art search. Basic prior art searches with search professionals can cost as little as $ 1000. Such cost is not likely to explain the large share of applicants who insert no prior art citations. Moreover, note that, large firms, who are less likely to be budget constrained, are more likely not to include prior art references (see Alcacer et al., 2009).

[9] This profit function is continuous. Search effort would never exceed the highest benefit $G-P$, hence x_1 is bounded in $[0, G-P]$. Therefore, a maximum is achieved.

Proposition 1. *When $\rho > 0$, there is a range of parameter values for which the researcher matches the examiner's search effort: $(x_1^* + x_2^*) = X_R = X_E$.*

We next find conditions under which innovators have no incentive to search for prior art.

Proposition 2. *If the expected benefit from a bad patent is large enough, then the innovator would not exert any effort searching for prior art, $x_1^* = x_2^* = 0$.*

The innovator is more likely not to search for prior art at all when patenting fee P is low and the examiner's search effort is low, when the cost of investment is small and the probability that invalidating prior art exists is small. There are also ranges of the parameter values for which the innovator might search either only before innovation ($x_1^* > 0$ and $x_2^* = 0$), or only prior to patenting ($x_1^* = 0$ and $x_2^* > 0$). Intuitively, early state of the art search is more important for innovations that require large R&D investment. If investment cost is large, the innovator would never engage only in novelty search. Thus, if she has an incentive to engage in novelty search, she must also have searched ex ante. On the other hand, when investment cost is low, if the innovator has no incentive to search ex post, then she has no incentive to search ex ante either.

Proposition 3. *(i) When investment cost is high enough $\left(I \geq \frac{(1-\theta)}{\alpha\lambda(0)}\right)$, then an innovator who has no incentive for an early search, has no incentive for a novelty search either: $x_1^* = 0$ implies $x_2^* = 0$.*

(ii) When investment cost is low enough $\left(I < \frac{(1-\theta)}{\alpha\lambda(0)}\right)$, then an innovator who has no incentive for a novelty search, has no incentive for early search either: $x_2^* = 0$ implies $x_1^* = 0$.

4. Think like an examiner

In this section, we take the possibility of correlated search technologies into account. Empirical evidence by Alcacer and Gittelman (2006) point to a striking similarity between the distributions of examiner and inventor citations, suggesting a "tracking scenario." Their paper suggests that "(a)ttorneys anticipate citations most likely to be added by examiners, so that examiner and inventor citations may come to resemble each other closely."

A prior art search professional who took pride in his company's ability to "think like an examiner" motivated us to consider the possibility that correlation in prior art search can arise strategically when innovators seek to correlate their search effort with that of the examiner. If examiners follow a somewhat predictable search technology, then the researcher has an incentive to choose a search technology that is correlated with that of the examiner. In the industry, this is also sometimes referred to as "being in alignment with" the examiner.

We measured the degree of correlation between innovator's search and examiner's search with the parameter ρ. The higher is ρ, the more correlated search technologies are. In Eq. (1), we derived the probability that the examiner finds invalidating prior art when it exists but was not found by the researcher $p(X_R, X_E)$. For fixed search efforts, this probability decreases with the degree of correlation ρ. This implies that if $g \geq 0$, then the net expected benefit from a bad patent $B(X_R, X_E)$ increases with ρ, which in turn implies that for fixed levels of search, the researcher's payoff increases with correlation.

Proposition 4. *If the gain from a bad patent is positive, $g > 0$, and the researcher invests in search $X_R > 0$, then her payoff is higher the more correlated her search is with the examiner's search (i.e. the higher ρ).*

"Thinking like an examiner" increases the expected value of patent application when invalidating prior art exists and thus increases the researcher's payoff. If the researcher could choose the level of correlation between search technologies, then when $g > 0$, among equally efficient search technologies, one that is perfectly correlated with that of the examiner would maximize the researcher's payoff.

Varying levels of correlation in search technologies can affect the innovator's choice of search intensities. Let us consider, for simplicity, the levels of early state of the art search when $B > 0$, in this case $x_2^* = 0$ (see Lemma 1). The effect of correlation on search depends on whether the optimal level of search exceeds that of the examiner or not. For a researcher who (perhaps due to high-investment costs) invests in early state of the art search more than the examiner, a more correlated search technology would reduce search. However, for a researcher who exerts less than examiner's effort, correlation increases search efforts. Search is more beneficial to the innovator in this situation because with higher correlation, the examiner is less likely to find invalidating prior art conditional on the innovator not having found any. We summarize this discussion in the following proposition.

Proposition 5. *When $B > 0$, if innovator's optimal early state of the art search exceeds examiner's search ($x_1^* > X_E$), then it is (locally) decreasing with ρ (the measure of correlation between innovator's and examiner's search technologies); while if $x_1^* < X_E$, then early state of the art search increases with correlation ρ.*

From a policy perspective, it might be possible for the patent office to have some control over the level of correlation between search technologies. If it were desirable by the patent office to decrease correlation between search technologies, then this might be possible by making examination less predictable (for example guiding examiners to search more for non-patented prior art and use less conventional search technologies), reducing transparency about the examination process and perhaps signing contractual agreements with examiners that limit their ability to work as prior art searchers in the private sector when they leave the patent office.[10]

For a given effort by the examiner X_E, under the conditions of Proposition 5, we show (see Lemma 3 in the Appendix A) that

$$\frac{dp(X_R(\rho), X_E, \rho)}{d\rho} < 0.$$

This implies that less correlated search technologies (or lower ρ) result in a higher conditional probability of rejecting a bad patent. When the social value of a bad patent is negative, an increase in the probability of rejecting a bad patent is socially desirable. Note, however, that in the range where search efforts increase with ρ, innovator's own search can lead to less bad applications. Hence, we cannot unambiguously determine the effect of reduced correlation on welfare.

5. Search intensity and its timing

In this section, we examine determinants of the timing and intensity of prior art search. We first examine factors that affect the level of early state of the art search (x_1) when $B > 0$ (which implies $x_2^* = 0$).

Proposition 6. *When $B > 0$, early state of the art search (weakly) increases with investment cost I, the probability of a bad patent α, patenting fee P and examiner's search intensity X_E. Search (weakly) decreases with the value of a bad patent g. The value of a good patent G does not affect prior art search effort.*

Intuitively, early state of the art search helps the innovator to avoid investment in an innovation that is bad. Hence, the innovator has more to benefit from search the higher is the investment cost and the higher is the probability that her innovation is bad. The innovator is less likely to search the more she benefits from a bad patent. The net

[10] This idea would be similar to "non-compete clauses" or "covenant not to compete" which in contract law refer to a contract by which an employee agrees not to pursue a similar profession which competes with the employer.

benefit from a bad patent decreases with patenting fee and examination effort and it increases with g. Higher benefits from a good patent G make the innovator more likely to invest. However, as long as this benefit is large enough so that the investment condition holds, its value will not affect search because conditional on the innovation being good, invalidating prior art will not be recovered regardless of the level of search.[11]

To further investigate the intensity of search and its timing, we specialize the model to assume an exponential search technology function: $F(X)=1-e^{-\lambda X}$, where $\lambda>0$ is a constant hazard rate. The parameter λ measures the ease of locating invalidating prior art when it exists. For a given search effort x, the higher λ is, the more likely it is to find invalidating prior art when it exists. A high λ might, for example, prevail in fields where patenting is heavily relied on, more prior art is patented and is thus easier to find. λ may also be high for innovators who have multiple projects in the same technological area. Emerging fields are expected to have search technologies with a low λ. We also focus on the case of independent search technologies. This offers tractability as well as a benchmark (and the limit as $\rho\to 0$). These simplifications allow us to derive optimal search efforts and conduct a more comprehensive analysis of comparative statics. In this setting, we can also more easily account for differences in ex ante and ex post search technologies. We assume novelty search technology is at least as efficient as early state of the art search technology. Hence, the hazard rate for novelty search is at least as large, $\lambda_n\geq\lambda_s$, where λ_n and λ_s are the hazard rates for the novelty search technology and the early state of the art search technology, respectively. We begin with a discussion of our findings and how they relate to empirical observations. We summarize these findings in Proposition 7 at the end of this section.

The intensity of search depends on the gain from a bad patent. In situations when the applicant is expecting a large gain from a bad patent (g), she is less inclined to conduct both early state of the art search and novelty search, that is, x_1^* and x_2^* decrease if g increases. In a survey of R&D labs in the U.S. manufacturing sector, Cohen et al. (2000) found that in complex industries firms are "much more likely to use patents to force rivals into negotiations." In such industries, the size of the patent portfolio matters and firms are less likely than in discrete technologies (e.g. drugs) to use a single patent to block a rival or to generate licensing fees. In terms of our model, this seems to suggest a higher value of a bad patent g in complex industries (as any single patent is not likely to be involved in litigation). Hence our model predicts relatively less prior art search in complex industries. To the extent that patent citations not inserted by the examiner proxy the inventor's prior art search, this prediction is supported by the empirical findings of Alcacer et al. (2009) who found that in complex technologies (such as computers and electronics), patents have a higher share of examiner citation (which may indicate less search). Lanjouw and Schankerman (2004) found that "litigation risk is much higher for patents owned by individuals and firms with small patent portfolios." This suggests that small firms likely have lower values of bad patent and therefore, our model predicts that all else equal, small firms would search more for prior art. Indeed, the empirical work of Alcacer et al. (2009) found that small firms and those who are less experienced (measured by their number of patents) had a significantly lower share of examiner inserted citations.

For innovations that require high investments, the benefit of early state of the art search is higher. Early search can help save large R&D spending on duplication. As the cost of investment (I) rises, the intensity of early state of the art search x_1^* rises; this substitutes in part for the later novelty search, thus x_2^* drops. Overall, there is more search (larger $x_1^*+x_2^*$) for innovations that require large investment. This suggests, for example, that for patents of pharmaceutical drugs that are known to require large R&D investments, we should expect significant search effort, particularly early state of the art search. Indeed, Alcacer et al. (2009) found that, compared to other fields, the share of examiner inserted citations was significantly lower in the drug, medical and chemical fields. Sampat (2005) also found that "the share of applicant inserted citations to U.S. patents is significantly higher for chemical and biomedical patents than for patents in other technological fields. This is an intriguing result, especially in light of empirical research suggesting that patents are more important as mechanisms for appropriating returns to R&D in chemicals and pharmaceuticals than in other fields." Note that these technology areas are likely to be ones in which innovation requires large investments. Additionally, for a patent on an innovation that is likely to be commercialized, we can expect a small value to a bad patent due to the risk of infringement suits and the inability to enforce it. These two forces (high I and low g) work in the same direction suggesting firms in the drug industry would have more incentive to search for prior art.

As mentioned above, in the current model, as long as the investment condition holds, the gross benefit of a valid innovation, G, has no effect on search intensity. This feature of the model is not, however, in odds with empirical findings that more important patents include more prior art citations (suggesting perhaps more prior art search), see Sampat (2005) and Lampe (2008). Two of the parameters of the model, investment cost I and the value of a bad patent g, are likely to be related to the benefit from a valid innovation G. First, for the investment condition to hold, G needs to be high enough compared to the investment cost. Hence, high-investment patents likely also have a high value of a good patent. Second, the value of a bad patent might also be related to the value of a good patent, but it is not clear in what direction this relation goes. On one hand, it seems that owning intellectual property rights on a more important innovation could be more valuable and hence g is large for large G. On the other hand, if an innovation is important, it is also more important for others who would then have stronger incentives to challenge the patent. Thus, there is likely to be more risk of litigation and exposure of invalidating prior art after the granting of the patent and hence g can be small for large G.

All else equal, innovators tend to search more for prior art, both before investment and after investment but before patenting, when there is a higher probability that invalidating prior art exists (α). In some fields, like software patenting, there may be a high probability that invalidating prior art exists, but still low search efforts since at the same time investment cost is low and the examiner's probability of finding invalidating prior art is also low.

We summarize the results of this section in the following proposition. In the proof, we solve for the optimal search efforts and then derive comparative statics with respect to various parameters of the model.

Proposition 7. *Assume search technology is given by $F_s(X)=1-e^{-\lambda_s X}$ for early state of the art search and $F_n(X)=1-e^{-\lambda_n X}$ for novelty search and assume $\rho=0$ (i.e., search technologies of the examiner and innovator are independent), then all else equal, optimal search efforts weakly*[12] *satisfy the following:*

(i) As investment (I) rises, x_1^* rises, x_2^* falls, but $(x_1^*+x_2^*)$ rises.
(ii) As the value of a bad patent (g) rises, both x_1^* and x_2^* fall. Search is not directly affected by the value of a good patent (G) if the investment condition holds.
(iii) As the patenting fees (P) rise or the examiner's search effort (X_E) increases, both x_1^* and x_2^* rise.
(iv) As the probability of invalidating prior art (α) rises, x_1^* and x_2^* rise.

[11] In Section 7, we offer a generalization of the model in which search increases with G.

[12] By "weakly" we mean that when we say search effort "rises," search effort could either increase or remain unchanged. The qualification accounts for ranges of parameters with corner solution.

6. Policy implications

6.1. Simple interventions

Using our solution for the optimal search efforts as derived in the proof of Proposition 7 (with exponential search technologies and independent search efforts), we found that a decrease in the net expected benefit from a bad patent B would result in an increase in both the early state of the art search and novelty search efforts, x_1^* and x_2^*. The net expected value of a bad patent is given by $B=[(1-F(X_E))g-P]$ which depends negatively on the patenting fee P and on the examiner's search intensity when reviewing applications X_E. B also increases with the value of a bad patent g. Hence, all else equal, in our simple model, an increase in examiner effort or in the patenting fee would result in higher search for prior art by the applicant. The three parameters that determine the net value of a bad patent X_E, P and g can serve as policy levers to influence search.

One element is common to several proposals to reform the patent system and reduce the number of bad patents granted, namely, the patent office should gather prior art information from third parties. We do not describe any of the suggested reforms in detail, but we briefly discuss how these can be thought of in terms of our model. Noveck (2006) advocates a “Community Patent Review” system. In this proposal, for each patent application, there would be a window of time during which patent examination is open to the public. Facilitating the addition of prior art by the public pre-granting of the patent can be seen as an increase in the probability that invalidating prior art would be detected when it exists, that is, an increase in X_E. Thomas' (2001) proposal combines a pre-examination period in which informants might submit pertinent prior art, with a bounty to any party who succeeds in providing invalidating prior art. The bounty would be financed by charging a fine to the applicant, thus, in addition to an increase in the probability of finding invalidating prior art X_E, the expected value of a bad patent B further decreases due to the possibility of being fined in the event such prior art is found. Merges (1999) considers the possibility of establishing a patent opposition system. This would increase the probability that invalidating prior art be revealed after the granting of a patent. Hence, it can be seen as a decrease in the value of the patent conditional on it being a bad patent, g.

All these proposals suggest a decline in the net expected benefit of a bad patent B, which would result in an increase in both early prior art search and novelty search. Note, however, that we have taken the gross value of a bad patent g to be fixed. Improvements in the examination process as described in the policy reforms mentioned could result in an increase in value of any granted patent, including the value of a bad patent g, which in turn has a positive effect on B. Hence, these policies would result in an increase in search efforts as long as this latter effect is small enough not to offset the decline in B.

Lemley et al. (2005) “gold-plate” patent-reform policy proposes that applicants should have an option to certify their patent with a “gold-plate” by opting for an examination procedure that would have more careful examination (higher X_E) for a higher patenting fee P. “Gold-plated” patents are likely to have significantly higher value (first, since the gold plate would signal a more carefully examined patent; second, since the authors expect selection of higher value innovations for this option). Hence, an increase in g is expected for gold plated patents. The effect on applicant's prior art search is therefore ambiguous, but we expect it to be positive with a sufficient increase in patenting fee.

Finally, note that a policy intervention that weakens the presumption of validity would likely lower the value of a bad patent g and increase the incentive to search.

6.2. Social planner's problem

The question we address here is as follows: if a hypothetical social planner could mandate certain search intensities as well as disclosure of all relevant prior art, then what would the social planner's choice of search efforts be? We then compare innovators' search efforts to these “first best” levels of search and discuss policy levers that could motivate optimal search.

Innovators might not have socially optimal incentives to search since the private values of innovations are different than their social values. First, an innovator is unable to appropriate the full surplus generated by a novel invention. Hence, the social value of a true innovation is larger than its private value, $\hat{G}>G$. Second, while we argued that there are private benefits to be made from a bad patent, from a social point of view these benefits are likely offset by losses to others. Hence, we assume that the social value of a bad patent is lower than its private value, $\hat{g}<g$, and possibly, $\hat{g}<0$. Finally, an innovator's patenting fees P might be different than the social cost of patenting $\hat{P}$. Assume a common probability α that there exists invalidating prior art, and a common probability of success in R&D, θ.

Note that if the planner could dictate search intensities and disclosure, then, as long as the examiner's search technology is not more efficient than the innovator's, the planner would put the burden of search entirely on the innovator rather than on the examiner. Innovator's search can help save investment costs by avoiding duplication as well as patenting cost. Thus, it is better to find invalidating prior art before patent application rather than after. The social planner's choice now amounts to applying our earlier findings on the optimal search efforts only using the social parameter values $\hat{g}$, $\hat{P}$ and $X_E=0$. We can then compare the socially optimal search effort to that chosen by the payoff maximizing innovator. In Proposition 8, we show that when the value of a bad patent for the innovator net of patenting fee $(g-P)$ is higher than the social net value of a bad patent, innovators have too little incentive to search.

Proposition 8. *If the cost of patenting is sufficiently low compared to the gain from a bad patent such that* $(\hat{g}-\hat{P})<(g-P)$, *then the researcher always under-invests in search compared to the socially optimal search level.*

If the benefits of innovation are high enough to ensure that the investment condition (6) holds, patent policy could induce efficient search with a high enough patenting fee $P=\hat{P}+(g-\hat{g})$. This, however, is not likely to be a practical policy to implement. First, because such patenting fees can be very high (when the researcher's private benefit from a bad patent is significantly larger compared to the social value of a bad patent) which might lead to under-investment in R&D. Second, because the right choice of patenting fees requires information on the value of a bad patent as well as an ability to charge differentiated patenting fees. It is impossible to do this for every single innovation. Patent policy typically sets rules that apply to the universe of patent applications, or to large subsets of patent applications (e.g. a uniform patent length on most patents and a uniform patent fee, with a lower fee for small innovators). Finally, as we will see in Section 7, in reality, there may be situations where the innovator has an incentive not to disclose prior art. Nevertheless, even if the first best is not feasible, patenting fees that depend on the technological field could help induce more search in fields where we suspect search is inefficiently low and where an increase in fee would not significantly lower the incentive to innovate.

6.3. Commitment to examination procedure

Our premise in this paper is that the examination process is not influenced by search and disclosure of prior art. This requires that the patent office would be able to commit to an examination process. The following questions thus arise. Can the patent office commit? Should the patent office commit to an examination process that is independent of prior art disclosure? And if examiners respond to applicants' prior art, how would this affect the incentives to search and disclose prior art?

We argue that it is reasonable to assume that the patent office can commit to a search process. The patent office is a government agency and it interacts with innovators repeatedly. Thus it is likely to be able to create a reputation on examination procedures. The budget of the patent office, the number of its employees and the time allocated to patent examination (at least on average) can be made public. According to Cockburn et al., "examiners are allocated fixed amounts of time for completing the initial examination of the application, and for disposal of the application." Examiners can however average these times over their case-loads. While individual examiners are heterogeneous and may use different examination technologies, a patent examiner is assigned to each application not chosen by the innovator. Cockburn et al. also document that "USPTO operates various internal systems to ensure "quality control" through auditing, reviewing and checking examiner's work." Additionally, for the first several years of their career, examiners are routinely reviewed by a more senior primary examiner. It seems reasonable that by and large the patent office can make sure its employees follow the guidance provided to them for examination procedure and intensity.

Should the patent office commit to an examination process that is independent of prior art disclosure? Note that the innovator's search effort cannot directly be observed by the examiner. Hence, the examiner could make search contingent on the volume of prior art disclosure, but not on actual search effort. Innovators are likely to strategically choose the amount of prior art they disclose if this could affect the intensity of examination to their benefit. Langinier and Marcoul (2008) focus on innovators' strategic non-disclosure of prior art. In their model, prior art disclosure by the innovator lowers the examiner's search cost and the examiner exerts more search effort the more prior art the innovator discloses. Under this complementarity assumption on innovators' and examiners' search efforts, they find that "an examiner should not have different scrutiny levels but rather, should commit to an equal screening intensity across all applications. This simple rule has two advantages: first, it requires a limited commitment and, second, it induces truthful information transmission from applicants."

If, instead, prior art disclosure by the innovator would induce less search by the examiner, then the innovator might have an incentive to increase the volume of prior art disclosed. More citations do not necessarily imply more search, for a given search level, innovators could be more permissive in their decision what to include as relevant citations. Concerns over excess disclosure of prior art (although for a different reason) were raised in a symposium on the Federal Circuit in March 2009. Senator Orrin Hatch (speaking on the issue of inequitable conduct) said that "(e)xaminers are buried in references by patent applicants for fear that they will be found to have withheld something. If the applicant does anything to try to focus the examiner on the closest prior art, this is also considered fodder for inequitable conduct claims." Thus some innovators may disclose excessive volumes of prior art, not all of it highly relevant. Assessing the quality and relevance of prior art citations also requires examiner effort. The volume of disclosure does not necessarily indicate higher search intensity. If examination procedure were to be tied to the level of disclosure, then, depending on how examiners respond, this may create incentive to manipulate the level of disclosure and the informativeness of the number of applicant added prior art citations would be reduced.

7. Prior art disclosure

Existing literature has emphasized the innovator's strategic choice not to *disclose* prior art. In Langinier and Marcoul's (2008) work, the main driver of this incentive is their assumption that higher information transmission increases examiner's search intensity. Lampe (2008) assumes that disclosure of prior art information increases the probability that the applicant will be found to have willfully infringed upon an existing patent. In the model we analyzed thus far, innovators do not have an incentive not to disclose prior art, rather they might choose not to *search* for it in the first place. We first explain why this is true here and then suggest circumstances when strategic non-disclosure of prior art may arise. We then pursue an extension of our model in which R&D process is influenced by early state of the art search. In this case, strategic non-disclosure of information may arise.

7.1. Ignorance is bliss

Consider novelty search. Suppose a successful innovator is deciding how much to invest in novelty search before the filing of a patent application. Suppose that the innovator could choose not to disclose prior art. The innovator would engage in novelty search if this could save the cost of patenting in the event she finds invalidating prior art. Such search is worthwhile only if she would refrain from patenting in the event she finds invalidating prior art. If she is better off patenting even when invalidating prior art is found (only not disclosed), then she is better off not searching for it in the first place. Similarly, the innovator only engages in early state of the art search if she intends to save on R&D investment in case invalidating prior art is found. She would not invest in search only to ignore her findings.

The argument above relies on the assumption that finding prior art requires a conscious effort. If, however, in some circumstances, innovators could stumble on prior art without searching for it, an incentive not to disclose might arise. If R&D investment is costly enough, still it is likely that if invalidating prior art is found before investment then the innovator would not invest. But, if the innovator unintentionally comes across invalidating prior art for innovations that require only small R&D investment or after R&D investment is sunk, and if the expected value of a bad patent is positive, $B \geq 0$, then an incentive not to disclose prior art might arise. Recall, however, as we discussed in the introduction, that knowingly concealing prior art is considered inequitable conduct and would be very risky practice on part of the innovators. Thus, in fact, innovators could even have an incentive to make conscious efforts not to accidentally find prior art after innovation and prior to filing for a patent.[13]

It is hard to tell empirically whether innovators strategically concealed prior art or whether they did not search for it. The overwhelming proportion of patents that have only examiner inserted citations (40% according to Alcacer and Gittelman (2006)) seems to us as strong evidence of a weak incentive to search for prior art. Sampat (2005) as well as Alcacer and Gittelman (2006) provide evidence on examiners' and assignees' propensity to add assignee–assignee self-citations. According to Sampat, "(t)he fact that examiners insert a significant share of self-citations provides prima facie evidence that a significant share of applicants do not search for, or fail to disclose, material prior art." While such cases may seem more likely consistent with non-disclosure (as one expects an assignee to be aware of her own patents), other explanations are also plausible. Some assignees (for example, big software companies) have a lot of patents and they may not be fully aware of their own portfolios. Moreover, given that the assignee is not likely to fear litigating herself, she might be less careful searching her own patents. It is also possible that there is not always full agreement on the relevance of previous patents. An assignee who is familiar with the details of her own innovation may consider it sufficiently distant from the new invention not to be material to patentability.

[13] As an anecdotal example, an individual in a high technological industry told us that some companies in his industry block their employees' access to the patent office database to avoid finding prior art and risk inequitable conduct allegations.

7.2. When search shapes innovation

In the model we analyzed in the previous sections, researchers never had an incentive not to disclose prior art. This was partly because we abstracted from some of the potential benefits from prior art search, particularly in the early stages of research. Prior art searches might help the innovator decide in what direction research will go. Finding that one path of research is not novel can lead the researcher to invest in another related direction. An early state of the art search may help shape the innovation, not just decide whether or not to invest. Hence, search can interact with the innovation process. With such additional potential benefits, an incentive not to disclose prior art may arise.

We illustrate this idea with a modified version of our model. Suppose the innovator has two research paths to choose from. As before, the cost of innovation in either path is I and the probability of success is θ. The prior probability that invalidating prior art exists for the innovation pursued in path i is α_i, $i \in \{1, 2\}$, with path 1 being the more promising choice, $\alpha_1 \leq \alpha_2$. We assume that early search is not yet focused, early state of the art search effort x_1 reveals prior art relevant to either path with a probability $F_s(x_1)$ which satisfies the earlier assumptions we made. If the search reveals no invalidating prior art, then the researcher would invest in research path 1—the more promising direction. If search reveals invalidating prior art on one path, then pursuing that path—imitating it—costs less, $I_m < I$, and uncertainty about the probability of success is reduced, we assume the success probability becomes 1. If search reveals invalidating prior art for one path but not the other, the researcher faces a choice between investing in the path for which no prior art was found, or investing in the bad path (which is now less costly and more certain) with the intention not to disclose the invalidating reference. If search reveals invalidating prior art on both paths, the researcher could abandon the project, or invest with the intention not to disclose.

The researcher decides whether or not to invest and which path to pursue. We assume that the researcher can only pursues one path of innovation. If she does not succeed with the path she chose or if she finds invalidating prior art during the ex post novelty search, she abandons the project.[14]

After innovation, the researcher chooses how much to invest in novelty search before filing for a patent. Novelty search technology can be more focused than the early state of the art search as the researcher is more informed at this point. Nevertheless, the earlier search effort still contributes to novelty prior art search. We denote the novelty search technology by $F_n(X)$, with $F_n(X) > F_s(X)$ for any $X > 0$. To account for the contribution of the early state of the art search to the novelty search stage, we express early search effort x_1 in terms of equivalent novelty search effort units as follows: an investment of x_1 in search before R&D is equivalent to an effort $\widetilde{x_1}$ which satisfies $F_s(x_1) = F_n(\widetilde{x_1})$, that is $\widetilde{x_1} = F_n^{-1}(F_s(x_1))$. Hence, an innovator needing to decide how much to invest in novelty search faces the same decision as if early search had the same technology as novelty search F_n and she had exerted effort $\widetilde{x_1}$. Finally, we assume that the innovator and examiner search technologies are independent.

We first consider the choice of novelty search. If the researcher chooses path i, then her expected payoff from x_2 is

$$(1-q_i(x_1))(G-P) + q_i(x_1)\frac{[1-F_n(\widetilde{x_1} + x_2)]}{[1-F_n(\widetilde{x_1})]}B - I - (x_1 + x_2)$$

where

$$q_i(x_1) = \frac{\alpha_i[1-F_s(x_1)]}{[1-\alpha_i F_s(x_1)]}.$$

[14] As in our earlier analysis, finding prior art in novelty search and not disclosing it is a dominated strategy. If finding prior art and not disclosing it is preferred to abandoning the project, the researcher would have been better off not finding it in the first place.

Maximizing researcher's payoff results in novelty search effort given by:

$$x_{2i}^*(\widetilde{x_1}) = \begin{cases} f_n^{-1}\left(\dfrac{[1-\alpha_i F_n(\widetilde{x_1})]}{-\alpha_i B}\right) - \widetilde{x_1}, & \text{if } B < \dfrac{[1-\alpha_i F_n(\widetilde{x_1})]}{-\alpha_i f_n(\widetilde{x_1})}, \\ 0, & \text{if } B \geq \dfrac{[1-\alpha_i F_n(\widetilde{x_1})]}{-\alpha_i f_n(\widetilde{x_1})}. \end{cases} \tag{8}$$

Novelty search effort is the same function of early search effort as we derived in the proof of Proposition 7.

Again, we assume a sufficient condition for the researcher to invest in R&D:

$$\theta[\alpha_2 B + (1-\alpha_2)(G-P)] \geq I.$$

Consider now the situation in which an early state of the art search has revealed prior art to invalidate both research paths. In this case, the researcher either abandons her innovation idea, or pursues it with the intension of not disclosing the invalidating prior art. Abstracting from the risks associated with inequitable conduct, the researcher would invest with the intention not to disclose if the net expected value of a bad patent exceeds the cost of imitation, $B > I_m$.

Proposition 9. *(i) If $B < I_m$, then the researcher never has an incentive not to disclose prior art. (ii) If $B > I_m$, an incentive not to disclose invalidating prior art that was revealed in early state of the art search may arise; in this situation, the innovator does not invest in novelty search.*

When the net value of a bad patent is low compared to the cost of imitation, early state of the art search can help the innovator avoid "stepping on" existing innovations and either choose a path that is more likely to be novel, or avoid R&D spending altogether when both paths are not novel. In this situation, strategic non-disclosure does not arise, invalidating prior art alters the innovator's choice of path of investment and she avoids investing in a non-novel path. However, when the net value of a bad patent is high compared to the cost of imitation, early search can result in imitation and non-disclosure of prior art.

Considering the optimal choice of ex ante search, we find, as in the earlier version of our model, that there are parameter values for which the innovator has no incentive to search for prior art: $x_1^* = x_2^* = 0$. Focusing on the range of parameters for which the innovator does not imitate and only has an incentive for early search, we derive comparative statics results that help us understand the determinants of early search in the two-paths model. We describe these results in the following proposition.

Proposition 10. *Suppose $0 < B < I_m$ (implying no imitation and no ex post search). In an interior solution ($x_1^* > 0$), early state of the art search increases with investment cost (I), examination effort (X_E), the probability that path 1 is bad (α_1), patenting fee (P) and the value of a good patent (G). Early state of the art search decreases with the value of a bad patent (g). The increase in the probability that path 2 is bad (α_2) has an ambiguous effect on x_1^*.*

These results are the similar to what we found in Proposition 7 (when we had a single path) except that in the two-paths model, early state of the art search increases with the value of a good patent, whereas in the single path model G had no effect on search. Search in this version of the model helps shape the path of innovation making it more likely to pursue a good path. This benefit is more significant when the value of a good innovation is larger, which explains why there is more incentive to search when the value of a good patent is larger.

8. Concluding remarks

In this paper, we strive to better understand what drives prior art search by innovators. We focus on two motivations for search: innovators might engage in early state of the art search to avoid spending on costly R&D, and/or conduct novelty search to save on patenting costs. While earlier work focused on incentives not to disclose, we show that when revealing invalidating prior art requires search effort, innovators may refrain from searching rather than avoid disclosure. In the current patent system, where innovator's net private benefit from a bad patent is likely to be higher than its social value, innovators have too little incentive to search. Policy interventions that lower the net expected benefit of a bad patent would induce more search and may increase social welfare. An increase in patenting fee, for example, would serve this purpose (as long as it does not discourage innovation). Several recently proposed policy interventions such as a patent–opposition system, community patent review or patent bounties are likely to decrease the net value of bad patents. Thus, such interventions not only make bad patents less likely to be granted, but also create incentives for prior art search by innovators before filing for a patent, which would reduce the number of bad patent applications and increase the quality of patents. Our analysis also found that innovators are better off if they can correlate their search technology with that of patent examiners. Higher correlation between innovators' and examiners' search technologies results in a lower conditional probability of rejecting a bad patent application.

We also consider an extension of our model in which early state of the art search can influence the choice of research path. Early search can help the innovator avoid research paths that are not novel. When cost of imitation is low and the value of a bad patent is high, innovators might pursue non-novel research paths with the intention of applying for the patent without disclosing invalidating prior art references. Hence, when early state of the art search shapes innovation, incentives not to disclose prior art may arise.

Our analysis simplifies on several dimensions that could be interesting for future research. We assumed a simple state space—an invalidating prior art reference either exists or it does not exist. In reality, however, there could exist prior art references that invalidate some but not all claims of a patent, or that invalidate the patent in combination with other references but not alone. We have also assumed a simple binary investment decision. However, finding related prior art before innovation can have an effect on the process and cost of innovation. We provided one simple extension of the model in which search affects innovation, but did not fully account for the possibility that innovators can learn from others' experiences and build on existing knowledge to lower costs of innovation, even when this knowledge does not invalidate their own innovation. Knowledge of patented prior art could also guide the innovator how to innovate around or tailor the patent application so as not to infringe on existing patents. Such additional benefits from search might provide additional incentives for ex ante search, but as the two-paths version of our model suggests, possibly also additional incentives not to disclose prior art. Finally, we mention that we have assumed that the patent office commits to a uniform examination process. A more careful look at the inside operation on the patent office and its relation to prior art search is another important direction for future work.

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Appendix A. Proofs of lemmas and propositions

A.1. Lemma 1

Proof. The innovator's payoff when she faces the choice of novelty search effort is given in Eq. (4). Using the definition of $B(X_R, X_E)$ in Eq. (2) we write the payoff in two ranges of search efforts. In the range $x_1+x_2=X_R\geq X_E$, the profit of the researcher is given by

$$q(x_1)\frac{[1-F(x_1+x_2)]}{[1-F(x_1)]}(B+\rho g)+(1-q(x_1))(G-P)-I-(x_1+x_2)$$

and in the range $x_1+x_2=X_R<X_E$, the profit of the researcher is given by

$$q(x_1)\frac{[1-F(x_1+x_2)]}{[1-F(x_1)]}\left[B+\frac{(1-F(X_E))}{1-F(x_1+x_2)}\rho g\right]+(1-q(x_1))(G-P)-I-(x_1+x_2).$$

Differentiating with respect to x_2 in each range, we find that

$$\frac{\partial\pi(x_1,x_2)}{\partial x_2}=\begin{cases} q(x_1)\frac{[-f(x_1+x_2)]}{[1-F(x_1)]}(B+\rho g)-1 & \text{if} \quad x_2>X_E-x_1 \\ \text{undefined} & \text{if} \quad x_2=X_E-x_1 \\ q(x_1)\frac{[-f(x_1+x_2)]}{[1-F(x_1)]}B-1 & \text{if} \quad x_2<X_E-x_1 \end{cases}$$

and

$$\frac{\partial^2\pi(x_1,x_2)}{\partial x_2^2}=\begin{cases} q(x_1)\frac{[-f'(x_1+x_2)]}{[1-F(x_1)]}(B+\rho g) & \text{if} \quad x_2>X_E-x_1 \\ \text{undefined} & \text{if} \quad x_2=X_E-x_1 \\ q(x_1)\frac{[-f'(x_1+x_2)]}{[1-F(x_1)]}B & \text{if} \quad x_2<X_E-x_1 \end{cases}$$

We need to find the optimal novelty search effort x_2 given the early state of the art search level x_1. We consider several cases.

Case 1. $0\geq X_E-x_1$.

We are necessarily in the range $x_2\geq X_E-x_1$. In this range,

$$\frac{\partial\pi(x_1,x_2)}{\partial x_2}=q(x_1)\frac{[-f(x_1+x_2)]}{[1-F(x_1)]}(B+\rho g)-1.$$

If $(B+\rho g)\geq\frac{[1-F(x_1)]}{-q(x_1)f(x_1)}$, then $\pi(x_1, x_2)$ decreases everywhere and there is a corner solution. Otherwise, $(B+\rho g)<0$ which implies that the payoff function is concave and there is a unique solution that solves the first order condition.

$$x_2^*(x_1)=\begin{cases} f^{-1}\left(\frac{[1-F(x_1)]}{-(B+\rho g)q(x_1)}\right)-x_1, & \text{if} \quad B<\frac{[1-\alpha F(x_1)]}{-\alpha f(x_1)}-\rho g, \\ 0, & \text{if} \quad B\geq\frac{[1-\alpha F(x_1)]}{-\alpha f(x_1)}-\rho g. \end{cases}$$

Case 2. $X_E-x_1>0$.

Case 2.1. Solution in the range $x_2>X_E-x_1$.

If there is a solution in the range $x_2>X_E-x_1$, then $x_2=f^{-1}\left(\frac{[1-F(x_1)]}{-(B+\rho g)q(x_1)}\right)-x_1$ and $B<\frac{[1-\alpha F(x_1)]}{-\alpha f(x_1)}-\rho g$.

Because $(B+\rho g)<0$ and $X_E-x_1>0$, payoff function is concave on each range $x_2<X_E-x_1$ or $x_2>X_E-x_1$ separately. In this case,

$$\left.\frac{\partial\pi(x_1,x_2)}{\partial x_2}\right|_{X_E-x_1} = \frac{-[q(x_1)f(X_E)]}{[1-F(x_1)]}B-1>0$$

so the proposed x_2 is a global Max.

Case 2.2. Solution with $x_2=X_E-x_1$.

For this to be a solution, we need

$$\text{from below}: \left.\frac{\partial\pi(x_1,x_2)}{\partial x_2}\right|_{X_E-x_1} = \frac{-[q(x_1)f(X_E)]}{[1-F(x_1)]}B-1\geq 0 \,\text{and}$$
$$\text{from above}: \left.\frac{\partial\pi(x_1,x_2)}{\partial x_2}\right|_{X_E-x_1} = \frac{-[q(x_1)f(X_E)]}{[1-F(x_1)]}(B+\rho g)-1\leq 0$$

or,

$$\frac{[1-\alpha F(x_1)]}{-\alpha f(X_E)}\geq B\geq\frac{[1-\alpha F(x_1)]}{-\alpha f(X_E)}-\rho g.$$

If the above condition holds, then there is no solution in the range $x_2>X_E-x_1$ (from Case 2.1). Additionally, in this case, $B<0$. So $\pi(x_1, x_2)$ is concave and with a positive derivative from below, thus we know there is also no solution with $x_2<X_E-x_1$ either.

Case 2.3. Solution in the range $0<x_2<X_E-x_1$.

If there is such a solution, then we have

$$x_2=f^{-1}\left(\frac{[1-F(x_1)]}{-Bq(x_1)}\right)-x_1.$$

For this to exist, $B<0$ and thus $\pi(x_1, x_2)$ in this range is concave. Also, to be in the range, we need

$$\left.\frac{\partial\pi(x_1,x_2)}{\partial x_2}\right|_{X_E-x_1} = \frac{-[q(x_1)f(X_E)]}{[1-F(x_1)]}B-1<0$$
$$\text{and}\ \left.\frac{\partial\pi(x_1,x_2)}{\partial x_2}\right|_{0} = \frac{-[q(x_1)f(x_1)]}{[1-F(x_1)]}B-1>0$$

or,

$$\frac{[1-\alpha F(x_1)]}{-\alpha f(x_1)}>B>\frac{[1-\alpha F(x_1)]}{-\alpha f(X_E)}.$$

Case 2.4. Solution with $x_2=0$.

We have a solution with $x_2=0$ if

$$B\geq\frac{[1-\alpha F(x_1)]}{-\alpha f(x_1)}.$$

Summarizing the results, for any level of early state of the art search effort $x_1\geq X_E$, the payoff maximizing novelty search is given by:

$$x_2^*(x_1)=\begin{cases}0, & \text{if}\quad B\geq\dfrac{[1-\alpha F(x_1)]}{-\alpha f(x_1)}-\rho g,\\ f^{-1}\left(\dfrac{[1-\alpha F(x_1)]}{-\alpha(B+\rho g)}\right)-x_1, & \text{if}\quad B<\dfrac{[1-\alpha F(x_1)]}{-\alpha f(x_1)}-\rho g.\end{cases}\tag{9}$$

For any level of early state of the art search effort $x_1<X_E$, the payoff maximizing novelty search is given by:

$$x_2^*(x_1)=\begin{cases}0, & \text{if}\quad B\geq\dfrac{[1-\alpha F(x_1)]}{-\alpha f(x_1)},\\ f^{-1}\left(\dfrac{[1-\alpha F(x_1)]}{-\alpha B}\right)-x_1, & \text{if}\quad \dfrac{[1-\alpha F(x_1)]}{-\alpha f(x_1)}>B>\dfrac{[1-\alpha F(x_1)]}{-\alpha f(X_E)},\\ X_E-x_1, & \text{if}\quad \dfrac{[1-\alpha F(x_1)]}{-\alpha f(X_E)}\geq B\geq\dfrac{[1-\alpha F(x_1)]}{-\alpha f(X_E)}-\rho g,\\ f^{-1}\left(\dfrac{[1-\alpha F(x_1)]}{-\alpha(B+\rho g)}\right)-x_1, & \text{if}\quad B<\dfrac{[1-\alpha F(x_1)]}{-\alpha f(X_E)}-\rho g.\end{cases}\tag{10}$$

Therefore, when $B\geq 0$, then $x_2^*=0$. □

A.2. Sufficient condition for investment

Lemma 2. *A sufficient condition for the innovator to choose to invest (that is for Eq. (5) to hold) is $\theta[\alpha B+(1-\alpha)(G-P)]\geq I$.*

Proof. From Eq. (5), we find that after putting some effort on the early state of the art search x_1, the researcher invests in the R&D project if the following condition holds:

$$\theta\left[q(x_1)\frac{[1-F(x_1+x_2^*)]}{[1-F(x_1)]}B(X_R,X_E)+(1-q(x_1))(G-P)-x_2^*\right]\geq I.$$

Now, consider the left hand side of the above condition:

$$\begin{aligned}&\theta\left[q(x_1)\frac{[1-F(x_1+x_2^*)]}{[1-F(x_1)]}B(X_R,X_E)+(1-q(x_1))(G-P)-x_2^*\right]\\ \geq\ &\theta\left.\left[q(x_1)\frac{[1-F(x_1+x_2^*)]}{[1-F(x_1)]}B(X_R,X_E)+(1-q(x_1))(G-P)-x_2^*\right]\right|_{x_2=0}\\ =\ &\theta[q(x_1)B(X_R,X_E)+(1-q(x_1))(G-P)]\\ \geq\ &\theta[\alpha B+(1-\alpha)(G-P)].\end{aligned}$$

The first inequality comes from the fact that x_2^* is the optimum ex post search effort that maximizes the total expected payoff and the second inequality holds because $\alpha\geq q(x_1)\ \forall x_1$ and $(G-P)>(g-P)\geq B(X_R,X_E)\geq B$. Thus we get the sufficient condition for investment by the researcher as

$$\theta[\alpha B+(1-\alpha)(G-P)]\geq I.\quad\square$$

A.3. Proposition 1

Proof. We show that there are parameter values for which $X_R=X_E$. Recall that by Lemma 1, $x_2=X_E-x_1$ if $X_E>x_1$ and

$$\frac{[1-\alpha F(x_1)]}{-\alpha f(X_E)}\geq B\geq\frac{[1-\alpha F(x_1)]}{-\alpha f(X_E)}-\rho g\tag{11}$$

which is a non-empty range for all $\rho>0$.

When $x_2^*(x_1)=X_E-x_1$, innovator's payoff is given by

$$\begin{aligned}\Pi(x_1,x_2^*(x_1)) =\ &(1-\alpha)\theta(G-P)+\alpha\theta[1-F(X_E)](B+\rho g)\\ &-[1-\alpha F(x_1)](I+X_E-x_1)-x_1\end{aligned}$$

and

$$\Pi'(x_1,x_2^*(x_1)) = \alpha f(x_1)(I+\theta X_E-\theta x_1)-1+\theta[1-\alpha F(x_1)],$$
$$\Pi''(x_1,x_2^*(x_1)) = \alpha[(I+\theta X_E-\theta x_1)f'(x_1)-2\theta f(x_1)]<0.$$

Hence, the payoff is a concave function of x_1 when $x_2^*(x_1) = X_E - x_1$ and has a solution $x_1 \in [0, X_E]$ whenever $\Pi'(0, X_E) > 0$ and $\Pi'(X_E, 0) < 0$ which holds true if I is such that $\frac{1-\theta}{\alpha f(0)} - \theta X_E < I < \frac{1-\theta}{\alpha f(X_E)} + \frac{\theta F(X_E)}{f(X_E)}$. This is a non-empty range. The solution x_1^* does not depend on P. Hence we can always find P so that Eq. (11) holds for this solution. □

A.4. Proposition 2

Proof. By Lemma 1, we know that when $B \geq \frac{[1-\alpha F(x_1)]}{-\alpha f(x_1)} = \frac{-1}{q(x_1)\lambda(x_1)}$, then $x_2^* = 0$. There exists a large enough B so that this condition holds for all x_1, particularly for all $B \geq 0$. Or, a weaker sufficient condition is given by $B \geq \frac{-1}{\alpha\bar{\lambda}}$ where $\bar{\lambda} = \max_x \lambda(x)$, since $q(x_1) \leq \alpha$ and $\lambda(x_1) \leq \max \lambda(x)$. Therefore, for large enough B, we have $B \geq \frac{-1}{q(x_1)\lambda(x_1)}$ for all $x_1 \geq 0$. Hence, $x_2^*(x_1) = 0$ and the researcher's payoff in the range $x_1 < X_E$ becomes

$$\begin{aligned}\Pi(x_1, 0) = {} & \alpha\theta[(1-F(x_1))B + (1-F(X_E))\rho g] \\ & + (1-\alpha)\theta(G-P) - [1-\alpha F(x_1)]I - x_1.\end{aligned}$$

Differentiating, we get

$$\Pi'(x_1, 0) = \alpha(I - \theta B)f(x_1) - 1.$$

If $B \geq \frac{I}{\theta}$, then the profit is decreasing in x_1 in the range $x_1 < X_E$ as well as in the range $x_1 \geq X_E$. Therefore profit is maximized at $x_1 = 0$. If $B < \frac{I}{\theta}$, then the profit is concave in the range $x_1 \leq X_E$. Therefore, its maximum in the range $x_1 \leq X_E$ is at $x_1 = 0$ if and only if

$$\Pi'(0, 0) = \alpha(I - \theta B)f(0) - 1 \leq 0$$

or,

$$B \geq \frac{\alpha\lambda(0)I - 1}{\alpha\theta\lambda(0)}.$$

Under these conditions, profit also decreases in the range $x_1 > X_E$ since the derivative close to X_E is negative from the left and it is even lower from the right.

To sum up, if

$$B \geq \max\left\{\frac{-1}{\alpha\bar{\lambda}}, \frac{\alpha\lambda(0)I - 1}{\alpha\theta\lambda(0)}\right\},$$

then $x_1^* = 0$ and $x_2^* = 0$. □

A.5. Proposition 3

Proof. Consider the profit function given in Eq. (7). Differentiating this function in each of its regions, we obtain

$$\frac{\partial\Pi(x_1, x_2^*(x_1))}{\partial x_1} = \begin{cases} \left[\begin{array}{c} -\alpha\theta(B+\rho g)f(x_1 + x_2^*)\left(1 + \frac{\partial x_2^*}{\partial x_1}\right) \\ + \alpha f(x_1)(I + \theta x_2^*) - (1-\alpha F(x_1))\theta\frac{\partial x_2^*}{\partial x_1} - 1 \end{array}\right] & \text{if} \quad X_R > X_E \\ \left[\begin{array}{c} -\alpha\theta B f(x_1 + x_2^*)\left(1 + \frac{\partial x_2^*}{\partial x_1}\right) \\ + \alpha f(x_1)(I + \theta x_2^*) - (1-\alpha F(x_1))\theta\frac{\partial x_2^*}{\partial x_1} - 1 \end{array}\right] & \text{if} \quad X_R < X_E \end{cases} \tag{12}$$

(i) Suppose $x_1^* = 0$ and $x_2^* > 0$. This implies that $x_1^* < X_E$ and $X_R = x_2^*$. Using Eq. (10) in Lemma 1 for the range $x_2^* > 0$, we have

$$x_2^*(0) = \begin{cases} f^{-1}\left(\frac{1}{-\alpha B}\right) < X_E, & \text{if} \quad \frac{1}{-\alpha f(0)} > B > \frac{1}{-\alpha f(X_E)}, \\ X_E, & \text{if} \quad \frac{1}{-\alpha f(X_E)} \geq B \geq \frac{1}{-\alpha f(X_E)} - \rho g, \\ f^{-1}\left(\frac{1}{-\alpha(B+\rho g)}\right) > X_E, & \text{if} \quad B < \frac{1}{-\alpha f(X_E)} - \rho g. \end{cases} \tag{13}$$

Substituting into Eq. (12), we get

$$\frac{\partial\Pi(0, x_2^*(0))}{\partial x_1} = \alpha f(0)(I + \theta x_2^*(0)) - (1-\theta).$$

Now, $x_1^* = 0$ implies that

$$\frac{\partial\Pi(0, x_2^*(0))}{\partial x_1} = \alpha f(0)(I + \theta x_2^*(0)) - (1-\theta) \leq 0 \tag{15}$$

which can hold true only if

$$I \leq \frac{(1-\theta)}{\alpha f(0)} - \theta x_2^*(0),$$

where $x_2^*(0)$ is given in Eq. (13). Hence, if I is large enough $\left(I \geq \frac{(1-\theta)}{\alpha\lambda(0)}\right)$, then $x_1^* = 0$ implies $x_2^* = 0$.

(ii) Suppose $x_1^* > 0$ and $x_2^* = 0$. This implies that $X_R = x_1^*$. Substitution into the first order condition and setting $\frac{\partial\Pi(x_1, x_2^*(x_1))}{\partial x_1} = 0$, we obtain

$$\begin{cases} -\alpha\theta(B+\rho g)f(x_1^*) + \alpha f(x_1^*)I - 1 = 0 & \text{if} \quad x_1^* \geq X_E \\ -\alpha\theta B f(x_1^*) + \alpha f(x_1^*)I - 1 = 0 & \text{if} \quad x_1^* < X_E \end{cases} \tag{14}$$

which implies

$$I = \begin{cases} \frac{1 + \alpha\theta(B+\rho g)f(x_1^*)}{\alpha f(x_1^*)} & \text{if} \quad x_1^* \geq X_E \\ \frac{1 + \alpha\theta B f(x_1^*)}{\alpha f(x_1^*)} & \text{if} \quad x_1^* < X_E \end{cases}$$

By Lemma 1 and the fact that $x_2^* = 0$, we have

$$\begin{cases} (B+\rho g) \geq \frac{[1-\alpha F(x_1^*)]}{-\alpha f(x_1^*)} & \text{if} \quad x_1^* \geq X_E \\ B \geq \frac{[1-\alpha F(x_1^*)]}{-\alpha f(x_1^*)} & \text{if} \quad x_1^* < X_E \end{cases}$$

and therefore it must be that

$$I \geq \frac{1 - \theta[1-\alpha F(x_1^*)]}{\alpha f(x_1^*)},$$

where x_1^* is derived from Eq. (14). Hence, if I is low enough $\left(I < \frac{(1-\theta)}{\alpha\lambda(0)}\right)$, then $x_2^* = 0$ implies $x_1^* = 0$. □

A.6. Proposition 4

Proof. Given fixed search efforts (x_1^*, x_2^*), payoff is higher the higher is the parameter ρ:

$$\frac{\partial\Pi(x_1^*, x_2^*, \rho)}{\partial\rho} = \alpha(1-F(x_1^*))\theta\left(\frac{1-F(X_R)}{1-F(x_1^*)}\frac{\partial B(X_R, X_E, \rho)}{\partial\rho}\right) > 0$$

because

$$\frac{\partial B(X_R, X_E, \rho)}{\partial \rho} = \begin{cases} F(X_E)g & \text{if} \quad X_R \geq X_E \\ (1-F(X_E))\dfrac{F(X_R)}{1-F(X_R)}g & \text{if} \quad X_R < X_E \end{cases}$$

and hence

$$\frac{\partial B(X_R, X_E, \rho)}{\partial \rho} \geq 0 \text{ if } g \geq 0.$$

Let $x_i^*(\rho)$ denote the optimal search efforts given ρ. Then for two correlation parameters $\rho_h > \rho_l$, we have

$$\Pi(x_1^*(\rho_h), x_2^*(\rho_h), \rho_h) \geq \Pi(x_1^*(\rho_l), x_2^*(\rho_l), \rho_h) \geq \Pi(x_1^*(\rho_l), x_2^*(\rho_l), \rho_l). \qquad \square$$

A.7. Propositions 5 and 6

Proof. In the assumed range of parameters, $x_2^*(x_1) = 0$ and thus

$$\Pi(x_1, 0) = (1-\alpha)[\theta(G-P)-I] + \alpha[1-F(x_1)][\theta B(x_1, X_E)-I]-x_1,$$

where,

$$B(x_1, X_E) = \begin{cases} B + \rho g & \text{if} \quad x_1 \geq X_E \\ B + \left(\dfrac{1-F(X_E)}{1-F(x_1)}\right)\rho g & \text{if} \quad x_1 < X_E \end{cases}.$$

In an interior solution with $0 < x_1 < X_E$, the following first order condition must hold:

$$\Pi'(x_1, 0) = -\alpha f(x_1)(\theta B - I) - 1.$$

In an interior solution with $x_1 > X_E$, the following first order condition must hold:

$$\Pi'(x_1, 0) = -\alpha f(x_1)[\theta(B + \rho g) - I] - 1.$$

Implicitly differentiating $\Pi'(x_1^*, 0)$ with respect to any parameter η and using the second order condition, we find that

$$sign\left(\frac{dx_1^*}{d\eta}\right) = sign\left(\frac{\partial \Pi'(x_1^*, 0)}{\partial \eta}\right).$$

We now differentiate with respect to each of the parameters in the range $0 < x_1^* < X_E$:

$$\frac{\partial \Pi'(x_1^*, 0)}{\partial I} = \alpha f(x_1^*) > 0.$$

$$\frac{\partial \Pi'(x_1^*, 0)}{\partial \alpha} = f(x_1^*)(I - \theta B) = \frac{1}{\alpha} > 0.$$

$$\frac{\partial \Pi'(x_1^*, 0)}{\partial P} = \alpha\theta f(x_1^*) > 0.$$

$$\frac{\partial \Pi'(x_1^*, 0)}{\partial X_E} = \alpha f(x_1^*)\theta(1-\rho) f(X_E) g > 0.$$

$$\frac{\partial \Pi'(x_1^*, 0)}{\partial g} = -\alpha\theta f(x_1^*)(1-\rho)(1-F(X_E)) < 0.$$

Similar derivatives confirm these results when $x_1^* > X_E$.

The effect of ρ depends on the optimal level of search:

$$\frac{\partial \Pi'(x_1^*, 0)}{\partial \rho} = \begin{cases} -\alpha\theta f(x_1^*) F(X_E) g < 0 & \text{if} \quad x_1^* > X_E \\ \alpha\theta f(x_1^*)(1-F(X_E)) g > 0 & \text{if} \quad x_1^* < X_E \end{cases}. \qquad \square$$

A.8. Lemma 3 and its proof

Lemma 3. *When* $B > 0$, *then*

$$\frac{dp(X_R(\rho), X_E, \rho)}{d\rho} < 0.$$

Proof. We have shown that

$$p(X_R, X_E) = \begin{cases} (1-\rho)F(X_E) & \text{if} \quad X_R \geq X_E \\ \dfrac{\rho(F(X_E)-F(X_R)) + (1-\rho)(1-F(X_R))F(X_E)}{(1-F(X_R))} & \text{if} \quad X_R < X_E \end{cases}.$$

Differentiating in each range, we find that

$$\frac{dp(X_R(\rho), X_E, \rho)}{d\rho} = \begin{cases} -F(X_E) & \text{if} \quad X_R \geq X_E \\ -\dfrac{(1-F(X_E))}{(1-F(X_R))}\left[F(X_R) + \rho\dfrac{f(X_R)}{(1-F(X_R))}\dfrac{dX_R}{d\rho}\right] & \text{if} \quad X_R < X_E \end{cases}.$$

When $B > 0$, then $x_2^* = 0$. In Proposition 5, we established that in this case, when $x_1^* < X_E$, search increases with correlation, $\frac{dx_1}{d\rho} > 0$. Under the conditions of this lemma, $X_R = x_1^*$, hence $\frac{dX_R}{d\rho} > 0$ and therefore $\frac{dp(X_R(\rho), X_E, \rho)}{d\rho} < 0$. $\square$

A.9. Proposition 7

Proof. Assume that $\rho = 0$, i.e., innovator's search process is independent of examiner's search process. Assume an exponential search technology which is more efficient after the innovation, i.e., the search technology for ex ante search is given by $F_s(x_1) = 1 - e^{-\lambda_s x_1}$ and for novelty search is given by $F_n(\widetilde{x_1} + x_2) = 1 - e^{-\lambda_n(\widetilde{x_1} + x_2)}$, where $\lambda_s < \lambda_n$ and $\widetilde{x_1} = F_n^{-1}[F_s(x_1)] = \frac{\lambda_s}{\lambda_n} x_1$.

We first derive the optimal search efforts. We show that, in this set-up, for parameter values satisfying the investment condition (6), the payoff maximizing search intensities by the researcher are given by:

1. *if* $I > \left(\frac{\lambda_n - \lambda_s\theta}{\alpha\lambda_s\lambda_n}\right)$, *then*

$$\begin{cases} x_1^* = \dfrac{1}{\lambda_s}\ln\left[\dfrac{\alpha\lambda_s(\theta + \lambda_n I + \lambda_n\theta\overline{x_2})}{\lambda_n - \theta(1-\alpha)\lambda_s}\right], x_2^* = \overline{x_2}, & \text{if} \quad -\dfrac{1 + (1-\alpha)\lambda_s I}{\lambda_n - \theta(1-\alpha)\lambda_s} > B, \\ x_1^* = \dfrac{1}{\lambda_s}\ln[\alpha\lambda_s(I - \theta B)], x_2^* = 0, & \text{if} \quad \dfrac{\alpha\lambda_s I - 1}{\alpha\lambda_s\theta} > B \geq -\dfrac{1 + (1-\alpha)\lambda_s I}{\lambda_n - \theta(1-\alpha)\lambda_s}, \\ x_1^* = 0, x_2^* = 0, & \text{if} \quad B \geq \dfrac{\alpha\lambda_s I - 1}{\alpha\lambda_s\theta}; \end{cases}$$

2. *if* $I \leq \left(\frac{\lambda_n - \lambda_s\theta}{\alpha\lambda_s\lambda_n}\right)$, *then*

$$\begin{cases} x_1^* = \dfrac{1}{\lambda_s}\ln\left[\dfrac{\alpha\lambda_s(\theta + \lambda_n I + \lambda_n\theta\overline{x_2})}{\lambda_n - \theta(1-\alpha)\lambda_s}\right], x_2^* = \overline{x_2}, & \text{if} \quad -\dfrac{1}{\alpha\lambda_n}e^{\frac{(\lambda_n - \lambda_s\theta) - \alpha\lambda_s\lambda_n I}{\alpha\lambda_s\theta}} > B, \\ x_1^* = 0, x_2^* = \dfrac{1}{\lambda_n}\ln[-\alpha\lambda_n B], & \text{if} \quad -\dfrac{1}{\alpha\lambda_n} > B \geq -\dfrac{1}{\alpha\lambda_n}e^{\frac{(\lambda_n - \lambda_s\theta) - \alpha\lambda_s\lambda_n I}{\alpha\lambda_s\theta}}, \\ x_1^* = 0, x_2^* = 0, & \text{if} \quad B \geq -\dfrac{1}{\alpha\lambda_n}, \end{cases}$$

where $B = [(1 - F_E(X_E))g - P]$ *and* $\overline{x_2}$ *is the unique solution to*

$$x_2 = \frac{1}{\lambda_n}\ln\left[\frac{-B\{\lambda_n - \theta(1-\alpha)\lambda_s\}}{1 + (1-\alpha)\lambda_s(I + \theta x_2)}\right].$$

To derive these search efforts, we use the optimal novelty search x_2 as we derived in Lemma 1, and consider the optimal choice of x_1

given $x_2^*(x_1)$ that maximize the researcher's payoff as given in Eq. (7). From Lemma 1, we know that

$$x_2^*(x_1) = \begin{cases} f_n^{-1}\left(\dfrac{[1-\alpha F_n(\widetilde{x}_1)]}{-\alpha B}\right)-\widetilde{x}_1, & \text{if} \quad B<\dfrac{[1-\alpha F_n(\widetilde{x}_1)]}{-\alpha f_n(\widetilde{x}_1)}, \\ 0, & \text{if} \quad B\geq\dfrac{[1-\alpha F_n(\widetilde{x}_1)]}{-\alpha f_n(\widetilde{x}_1)}. \end{cases}$$
$$= \begin{cases} \dfrac{1}{\lambda_n} ln\left[\dfrac{-\alpha\lambda_n B}{[(1-\alpha)e^{\lambda_s x_1}+\alpha]}\right], & \text{if} \quad B<\dfrac{(1-\alpha)e^{\lambda_s x_1}+\alpha}{-\alpha\lambda_n}, \\ 0, & \text{if} \quad B\geq\dfrac{(1-\alpha)e^{\lambda_s x_1}+\alpha}{-\alpha\lambda_n}. \end{cases} \tag{15}$$

Maximizing the expected payoff from early state of the art search given by Eq. (7), we get the first order condition as

$$-\alpha\theta Bf_n(\widetilde{x}_1+x_2^*)\left(\frac{\lambda_s}{\lambda_n}+\frac{dx_2^*}{dx_1}\right)-\theta[1-\alpha F_s(x_1)]\frac{dx_2^*}{dx_1}+\alpha f_s(x_1)(I+\theta x_2^*)-1=0. \tag{16}$$

Therefore, when x_2^* is interior, then substituting Eq. (15) into Eq. (16), we get that

$$-\theta[1-\alpha F_s(x_1)]\frac{dx_2^*}{dx_1}+\theta[1-\alpha F_s(x_1)]\left(\frac{\lambda_s}{\lambda_n}+\frac{dx_2^*}{dx_1}\right)+\alpha f_s(x_1)(I+\theta x_2^*)=1$$
$$\text{or, } \theta\frac{\lambda_s}{\lambda_n}[1-\alpha F_s(x_1)]+\alpha f_s(x_1)(I+\theta x_2^*)=1$$
$$\text{or, } \theta(1-\alpha)\frac{\lambda_s}{\lambda_n}+\alpha\lambda_s e^{-\lambda_s x_1}\left(I+\theta x_2^*+\frac{\theta}{\lambda_n}\right)=1$$
$$\text{or, } \frac{\alpha\lambda_s\left(I+\theta\overline{x_2}+\frac{\theta}{\lambda_n}\right)}{1-\theta(1-\alpha)\frac{\lambda_s}{\lambda_n}}=e^{\lambda_s x_1}$$

where (using Eq. (15)) $\overline{x_2}$ is the unique solution to

$$x_2=\frac{1}{\lambda_n}\ln\left[\frac{-\lambda_n B\left\{1-\theta(1-\alpha)\frac{\lambda_s}{\lambda_n}\right\}}{1+(1-\alpha)\lambda_s(I+\theta x_2)}\right].$$

Similarly, when $x_2^*=0$, then substituting Eq. (15) into Eq. (16), we get the first order condition as

$$-\alpha\theta Bf_n(\widetilde{x}_1)\frac{\lambda_s}{\lambda_n}+\alpha f_s(x_1)I-1=0$$
$$\text{or, } \alpha\lambda_s e^{-\lambda_s x_1}(I-\theta B)=1.$$

Therefore,

$$x_1^*=\frac{1}{\lambda_s}ln[\alpha\lambda_s(I-\theta B)]>0 \text{ and } x_2^*=0 \text{ if } \alpha\lambda_s(I-\theta B)>1.$$

Combining all the above, we obtain the optimal search efforts as stated earlier.

Now, from the optimal solutions listed above (or the first order conditions), it is easy to find the comparative static results (all results are weak, e.g. rises could mean rise or remain unchanged):

1. as I increases, x_1^* rises, x_2^* falls, but $(x_1^*+x_2^*)$ rises;
2. as B increases, i.e., as g rises or P falls or X_E falls, we have lower x_1^* and x_2^*;
3. as α increases, both x_1^* and x_2^* rise. □

A.10. Proposition 8

Proof. Using the social parameter values $\hat{g}$, $\hat{P}$ and $X_E=0$, we see that $B=(g-P)>(\hat{g}-\hat{P})=\hat{B}$. In Proposition 7, we have seen that as B increases, the search efforts by the researcher, both before investment and after investment but before filing for a patent, decrease. Since $\hat{B}<B$, we can conclude that the researcher under-invests in prior art search than the socially optimal level. □

A.11. Proposition 9

Proof. The innovator never has an incentive not to disclose results of novelty search, or else she would have been better off not to have searched. Suppose the innovator has searched for prior art before innovation and revealed invalidating prior art. Pursuing a bad path and applying for a patent (not disclosing the invalidating prior art references) yields payoff $(B-I_m)$. If $B>I_m$, and if when both paths where found to be bad, pursuing a bad path and not disclosing is better than not pursuing any path. If $B<I_m$, pursing a bad path is inferior to not investing, hence if invalidating prior art is revealed, the innovator does not pursue that path. Therefore, no non-disclosure issue arises. □

A.12. Proposition 10

Proof. Suppose $0<B<I_m$, then $x_{2i}^*=0$ for $i\in\{1, 2\}$. Therefore the payoff from the ex ante search $\Pi(x_1, x_{21}, x_{22})$ is given by

$$\Pi(x_1,0,0)=(1-\alpha_1)[\theta(G-P)-I]+\alpha_1[1-F_s(x_1)](\theta B-I)$$
$$+\alpha_1 F_s(x_1)[(1-\alpha_2)[\theta(G-P)-I]+\alpha_2[1-F_s(x_1)](\theta B-I)]-x_1$$

Differentiating the payoff with respect to x_1, we get

$$\Pi'(x_1,0,0)=\alpha_1(1-\alpha_2)\theta f_s(x_1)[G-(1-F_E(X_E))g]$$
$$+2\alpha_1\alpha_2 f_s(x_1)F_s(x_1)(I-\theta B)-1.$$

Assume that we are in a range with interior solution $x_1^*>0$. Then we have

$$sign\left(\frac{dx_1}{d\eta}\right)=sign\left(\frac{\partial\Pi'(x_1,0,0)}{\partial\eta}\right)$$

Differentiating with respect to each of the parameters, we get the following:

$$\frac{\partial\Pi'(x_1^*,0,0)}{\partial I}=2\alpha_1\alpha_2 f_s(x_1^*)F_s(x_1^*)>0.$$
$$\frac{\partial\Pi'(x_1^*,0,0)}{\partial\alpha_1}=(1-\alpha_2)\theta f_s(x_1^*)[G-(1-F_E(X_E))g]+2\alpha_2 f_s(x_1^*)F_s(x_1^*)(I-\theta B)$$
$$=\frac{1}{\alpha_1}>0.$$
$$\frac{\partial\Pi'(x_1^*,0,0)}{\partial\alpha_2}=-\alpha_1\theta f_s(x_1^*)[G-(1-F_E(X_E))g]+2\alpha_1 f_s(x_1^*)F_s(x_1^*)(I-\theta B)$$
$$=\frac{1}{\alpha_2}[1-\alpha_1\theta f_s(x_1^*)[G-(1-F_E(X_E))g]]\lesseqgtr 0.$$
$$\frac{\partial\Pi'(x_1^*,0,0)}{\partial G}=\alpha_1(1-\alpha_2)\theta f_s(x_1^*)>0.$$
$$\frac{\partial\Pi'(x_1^*,0,0)}{\partial g}=-\alpha_1(1-\alpha_2)\theta f_s(x_1^*)(1-F_E(X_E))-2\alpha_1\alpha_2\theta f_s(x_1^*)F_s(x_1^*)(1-F_E(X_E))$$
$$<0.$$
$$\frac{\partial\Pi'(x_1^*,0,0)}{\partial P}=2\alpha_1\alpha_2\theta f_s(x_1^*)F_s(x_1^*)>0.$$
$$\frac{\partial\Pi'(x_1^*,0,0)}{\partial X_E}=\alpha_1(1-\alpha_2)\theta f_s(x_1^*)f_E(X_E)g+2\alpha_1\alpha_2\theta f_s(x_1^*)F_s(x_1^*)f_E(X_E)g>0.$$

□

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