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February 2012

Online at https://mpra.ub.uni-muenchen.de/37033/
MPRA Paper No. 37033, posted 03 Mar 2012 19:17 UTC

In the Shadow of Giants*

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Abstract

Intellectual giants provide broad shoulders for subsequent inventors. Their unfinished inquiry, however, also casts shadow on the prospect of future research. This paper incorporates this shadow effect into a two-stage innovation process and shows that patenting the first-stage result (the basic invention) may enhance the second-stage innovation. It is optimal to reject patent protection to the basic invention only when this beneficial effect does not arise, and when it is essential to preserve the pioneering inventor's incentive to continue research activities.

Keywords: Cumulative Innovation, Patentable Subject Matter, Probabilistic Patents, Search, Shadow Effect.
JEL codes: K39, O31, O34.

*Previously circulated under the title "Understanding the Doctrine of Patentable Subject Matter." I would like to thank Vincenzo Denicolò, Doh-Shin Jeon, and Gerard Llobet for helpful conversation, as well as useful comments from participants to several conferences and seminars. All errors are mine. Comments are welcome.

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1 Introduction

"By standing on the shoulders of Giants," Sir Isaac Newton and generations of scholars saw further and more than their predecessors. This cumulative process of knowledge generation has been recognised as the foundation of modern economic analysis of innovation (Green and Scotchmer, 1995, Scotchmer, 1996, O'Donoghue, 1998, Denicolò, 2000, Bessen and Maskin, 2009). The unfinished pursuits of intellectual giants, however, leave a daunting task to follow. When evaluating the possibility to construct a necessary view to interpret probability,[1] Savage (1972, p. 61) cited the limited progress made by its two most prominent enthusiasts, J. M. Kenyes and R. Carnap, and suggested that:

> That these men express any doubt at all about the possibility of narrowing a personalistic view to the point where it becomes a necessary one, after such extensive and careful labor directed toward proving this possibility, speaks loudly for their integrity; at the same time it indicates that the task they have set themselves, if possible at all, is not a light one.

In another discipline, Farber (2010, p. 7) also expressed the same sort of doubts:

> The search for a foundational First Amendment "brick" has been unavailing so far. If so many thoughtful legal commentators have failed to identify *the* foundational value that supports a unified First Amendment theory, the prospects for future efforts may be dim.

In other words, when intellectual giants tumble or remain silent, their legacy may cast a shadow on future explorations.

This paper addresses the impacts of this "shadow effect" on innovation and patent policy. Section 2 introduces a simple innovation game where a pioneering inventor (she) and a follower (he) sequentially conduct research on an invention that may be impossible to achieve. The follower observes the pioneer's result and adjusts his own assessment of the successful probability accordingly. Since the two players pursue the same invention, the pioneer's failure sends a bad news to the follower. And a more devoted pioneer casts a darker shadow on the follower. In a simple way, this captures the negative information spill-over between inventors of different generations.

[1] According to Savage (1972), *"Necessary views hold that probability measures the extent to which one set of propositions, out of logical necessity and apart from human opinion, confirms the truth of another. They are generally regarded by their holders as extensions of logic, which tells when one set of propositions necessitates the truth of another."*

In section 3, I incorporate this shadow effect into a two-stage innovation process to discuss patent policy issues. Following the literature *à la* Green and Scotchmer (1995), I assume that the completion of the first stage is a pre-requisite to start the second stage. For the purpose of policy discussion, I refer to the first-stage invention as the abstract idea or basic invention, and the second-stage invention as the application. Only the pioneer participates in the first stage. At the second stage, the pioneer and follower sequentially engage in innovation activity as described in section 2. Hence the source of shadow effect is the pioneer's innovation effort at the second stage. Assume that the application is always patentable, and will always infringe on the abstract idea should the latter become patentable. I consider how patent rights of the abstract idea, or the basic patent, affect the overall innovation performance, the structure of the innovation market, and whether it is optimal to grant the basic patent.

A basic patent transfers the follower's innovation surplus to the pioneer. Consistent with the literature, this sharing effect encourages the pioneer to engage in basic research, but reduces both the pioneer's and follower's efforts at the second stage. Shadow effect, however, offsets this direct effect on the follower. The pioneer's lower second-stage effort restores the follower's confidence about the likelihood of success. When shadow effect outweighs sharing effect, the follower is more willing to conduct research after the abstract idea becomes patentable. The basic patent may improve the performance of both stages of innovation, and encourage decentralization of the innovation market, measured by the extent to which different inventions are created by different inventors. Shadow effect thus pictures a less gloomy role of the basic patent than previous literature predicted.

I then consider the optimality of the basic patent, a topic that is related to the debate of patentable subject matter in patent law. In light of the cumulative feature of innovation, the economic literature emphasises the importance of proper reward to early stage inventions, and focuses on how to adjust patent rights to latter inventions in order to balance R&D incentives across different stages in the innovation process.[2] Patent law, however, does not always enthusiastically embrace the strong protection to basic inventions. The Supreme Court of the United States has long held that "*[h]e who discovers a hitherto unknown phenomenon of nature has no claim to a monopoly of it which the law recognises. If there is to be invention from such a discovery, it must come from*

[2] See Scotchmer (2004) for a literature review. Bessen and Maskin (2009) argues that the patent system should be abolished in the cumulative innovation environment.

the application of the law of nature to a new and useful end."[3] Established in case law, the doctrine of patentable subject matter (henceforth, the DPSM) precludes the following from the realm of patent protection:[4]

> principles, laws of nature, mental processes, intellectual concepts, ideas, natural phenomena, mathematical formulae, methods of calculation, fundamental truths, original causes, motives, [and] the Pythagorean theorem. . . .

Applications of abstract ideas and principles, instead, can be patented, provided that they fulfill other patent law requirements.

To reconcile this discrepancy between economic theory and patent law (Eisenberg, 2000), I use the two-stage model to analyze when it is optimal to enable the DPSM and deny patent protection to the abstract idea in order to "promote the Progress of Science and useful Arts."[5] That is, to maximise the probability of finishing the two stages and inventing the application.[6] Previous analysis immediately provides a necessary condition: The DPSM is optimal only when the basic patent hampers subsequent innovation. The DPSM, therefore, cannot be the optimal policy when shadow effect dominates sharing effect.

Suppose that this necessary condition holds. The DPSM is more likely to be optimal when, at the *second* stage, the pioneer has better innovation capacity, while the follower is less likely to make the discovery. In this model, the patent policy has to balance not only incentives of different generations of inventors, but also those of the *same* inventor at different innovation stages. When the follower has a rather small probability to find the application (even without the threat of basic patent), there is little surplus to be transferred from the follower to the pioneer. The basic patent has

[3]Funk Bros. Seed Co. *vs.* Kalo Inoculand Co., 333 U.S. 127 (1948).

[4]*In re Bergy*, 596 F.2d 952, 201 U.S.P.Q. (BNA) 352 (C.C.P.A. 1979). See also Merges (1997). The European Patent Convention excludes the following from patentable inventions: (a) discoveries, scientific theories and mathematical methods; (b) aesthetic creations; (c) schemes, rules and methods for performing mental acts, playing games or doing business, and programs for computers; and (d) presentations of information (http://www.epo.org/patents/law/legal-texts/html/epc/1973/e/ar52.html).

[5]U.S. Constitution, Art I, sect. 8, cl. 8.

[6]For sure, one may find other justifications for the DPSM, such as the difficulty to enforce patent rights based on abstract ideas or mental process, or the somewhat ambiguous difference between "discovery" and "invention." In Gottschalk *vs.* Benson, 409 U.S. 63 (1972), the Supreme Court states that: "*It is conceded that one may not patent an idea. . . . The mathematical formula involved here has no substantial practical application except in connection with a digital computer, which means that if the judgment below is affirmed, the patent would wholly preempt the mathematical formula and in practical effect would be a patent on the algorithm itself.*" This argument could be analyzed as one with patent scope, i.e., whether to allow a patent with a very broad scope such that it covers all inventions using the algorithm.

limited incentive benefit on the first-stage innovation. On the other hand, the small research capacity of the follower also implies that the second-stage discovery largely depends on the pioneer's performance. When the pioneer can find the application with a significant probability, *provided that* she is willing to do so, the negative effect of the basic patent as an "intermediate reward" can be non-negligible. The DPSM then is justified as a way to preserve the pioneer's continuing efforts in research.

This finding implies that abstract ideas or basic inventions should not be patentable if engaging in fundamental research entails great first-mover advantage at subsequent research, while a new comer, lacking the experience at the earlier stage, faces a substantial obstacle to join the rank. But as the innovation process becomes more "democratic," i.e., as knowledge and research capacity disseminate and are no longer concentrated on a few "early stars," then it would be optimal to start patenting abstract ideas or early inventions. Alternatively, capacities possessed by the pioneer and follower may be different in kind. The pioneer may be good at perfecting the basic invention or better understanding its fundamental properties, and follower may be specialised in identifying uses of the basic invention and adapting it to specific contexts. The relative importance of these two capacities then depends on the phase of technological progress. To the extent that further understanding the basic scientific principles has priority in primitive technology fields, patent protection should only cover basic inventions or abstract ideas in mature fields.

My results also provide another interpretation of the shrinking application of the DPSM since the 1980s. Through a series of court decisions, particularly in computer software and biotechnology, the scope of patentable subject matters has drastically increased in the U.S. (Kuhn, 2007). Some commentators have warned that rapid expansions of patent protection would do more harm than good to the long-term development in these fields. And it is an often raised hypothesis that these industries could have done better had these basic patents been denied. Shadow effect nevertheless provides a theoretical argument to mitigate this concern.[7] Furthermore, if the optimal patent policy takes into account the concerns listed here, then there may be a reverse causality: abstract ideas should become patentable precisely when there is a better follower joining the development process.

Before concluding the paper in section 6, section 4 and 5 discuss some robustness issues as well as extensions. In section 4, I consider reputation concerns as alternative

[7] See, e.g., Merges (2007) for a discussion of these "unfulfilling" critics in the software industry.

incentives to conduct basic research, and licensing of basic patent, and argue that they do not change the main insight of the paper. In section 5, I let inventor pursue different applications whose *ex ante* existence probabilities are correlated. The pioneer's result, then, can be either "sunshine" or shadow to the follower. Giving the pioneer the patent rights provides her an incentive to "choose sunshine over shadow," namely, making an innovation decision that would lead to a optimistic rather than pessimistic follower. This generalised information spill-over again offers a beneficial effect of basic patent on subsequent research.[8]

The main contribution of this paper is to bring together shadow effect and patent policy. Previous works, e.g., Choi (1991) and Malueg and Tsutsui (1997), have introduced shadow effect into the paradigm of Poisson races in the form of uncertain hazard rates, but do not include patent policy in the analysis.[9] Choi (1991) puts hazard rate uncertainty at the first stage of a two-stage race, and illustrates how a rival's success boosts an inventor's confidence. This "If you can do that, why not me?" effect is the opposite of shadow effect, and I consider a similar "sunshine effect" in section 5. Malueg and Tsutsui (1997) characterises inventors' time paths of R&D investment in a one-stage race with hazard rate uncertainty. I put shadow effect at the second stage to study the role of the basic patent.[10]

The literature of patent policy, to the best of my knowledge, has not considered shadow effect. In addition, most studies either assume that early inventions always receive patent protection (Green and Scotchmer, 1995, Scotchmer, 1996, Denicolò, 2000), or give equal treatments to innovations at different stages (O'Donoghue, 1998). Matutes *et al.* (1996) and Kultti and Mittunen (2008) allow various levels of protection to the basic invention, including no protection, but conclude that some protection is always better. Harhoff *et al.* (2001) and Aoki and Nagaoka (2007) are the two ex-

[8]This result is obtained under payoff independence. Appendix B introduces payoff externality into this multiple-application setting.

[9]Shadow effect also appears in other topics in industrial organization. Mason and Välimäki (2011) analyzes a seller's pricing strategy under demand uncertainty, where the seller's pessimism grows as time passes without any sale. Bulow and Klemperer (2002) considers a common-value auction, where the winner's curse has the same flavor as shadow effect here. As they nicely put it: a larger audience in a seminar can yield fewer questions because of the concern that "if my question is so good, why hasn't someone else asked it?"

[10]Since the focus of this paper is not the timing of innovation, I choose not to use the framework of Poisson race in order to illustrate the impact of patent policy in the simplest possible way. Nevertheless, in Appendix C, I sketch a two-stage Poisson race where both players can participate in both stages, and argue that the timing of the main analysis could be seen as a reduced-form from this model.

ceptions that obtain no protection as the optimal policy.[11] Keeping firms' research intensity constant, Harhoff *et al.* (2001) cautions that patenting basic inventions (gene in their model) may induce socially wasteful stockpile of basic inventions and delay applications. Aoki and Nagaoka (2007) allow firms to vary R&D efforts and is the most relevant paper on the issue of patentability.

Aoki and Nagaoka (2007) adopts the two-stage Poisson race framework of Denicolò (2000), where inventors have the same innovation technology and free entry characterises the equilibrium outcome. They show that granting the basic patent always reduces the second-stage innovation efforts, and it is desirable to do so when the cost at *either* stage is sufficiently high. The result that costly basic research justifies the basic patent is intuitive. On the other hand, high cost of application development renders basic research barely profitable under competition, and calls for patent protection to the basic invention in order to encourage entry in the first stage.[12] By contrast, I illustrate the beneficial effect of basic patent on subsequent innovation, due to shadow effect, and stress the asymmetry between inventors of different generations. I will also show that, when the first-stage innovation cost has uniform distribution, the optimality of the DPSM does not depend on the cost parameter (the support of the distribution) at this stage. In this regard, my analysis is complementary to the insight derived in Aoki and Nagaoka (2007).

Finally, the literature of multistage tournaments also emphasises a proper design to balance participants' efforts at different stages. Goltsman and Mukherjee (2008) considers the optimal rule to disclose intermediate result, and Gershkov and Perry (2009) considers whether to conduct a midterm review in the first place, as well as how to allocate the final prize according to the results at different stages. Both works share the same concern of this paper, namely, a policy that enhances the first-stage incentive

[11] A long and well established literature in the legal profession has devoted to the doctrine of patentable subject matter. Merges (1997) presents a textbook treatment. A partial list of recent articles includes Gruner (2007), Kuhn (2007), and Risch (2008).

[12] Aoki and Nagaoka (2007) addresses the issue as the utility requirement, which may be one of the legal bases of the DPSM. That is, an abstract idea is not patentable because it lacks "specific and substantial utility," i.e., it is not "useful for any particular practical purpose." (See USPTO, *Utility Examination Guidelines*, http://www.uspto.gov/web/menu/utility.pdf.) In Brenner *vs.* Manson, 383 U.S. 519 (1966), the Supreme Court ruled that the Manson patent is at a too preliminary stage to be protected by a patent, and stated that *"a patent is not a hunting license. It is not a reward for the search, but compensation for its successful conclusion."* The Court's reasoning, however, contains some flavor of patent scope: *"Unless and until a process is refined and developed to this point–where specific benefit exists in current available form–there is insufficient justification for permitting an applicant to engross what may prove to be a broad field."* Risch (2008) suggests to abolish the DPSM but reinvigorate the utility requirement to assess the patentability of each invention. In practice, the utility requirement is not strictly applied. Few patent applications are rejected for lack of utility.

(here, the basic patent as an intermediate reward) also dampens continuation efforts. My model, however, is not a tournament, because there may be no final prize (the second-stage invention). This feature is crucial to generate shadow effect, which, to my knowledge, is also lacking in the literature of tournaments.

2 Shadow Effect: An Illustration

In a nutshell, sequential research efforts and uncertain innovation prospect generate shadow effect. The latter element introduces learning into the innovation process, and the former creates a channel to learn. This section builds a simple model to capture shadow effect. Subsequent sections enrich the basic framework. Throughout the analysis, I use technology progress as the policy objective, namely, the expected level of new invention(s) achieved.[13]

Two inventors, a pioneer (she) and a follower (he), try to discover an invention. Both players are risk-neutral expected-payoff maximisers and protected by limited liability. For a reason that shall be clear later, let's call this invention an application. Innovation is modeled as a simple search process: After incurring a search cost, an inventor will find the application, as long as it exists. Players share a common *ex ante* belief that the application exists with probability $\alpha \in (0, 1]$, and the value of the application is $\pi > 0$. Denote the *ex ante* expected value as $v \equiv \alpha\pi$.

Before making the search decision, the pioneer learns her search cost c_P, which is distributed over $\mathbb{R}^+$ according to (twice differentiable) CDF $G_P(\cdot)$. Similarly, let c_F be the follower's search cost, and $G_F(\cdot)$ the (twice-differentiable) CDF. Both c_P and c_F are the inventor's private information, and distributed independently. The cost distribution captures an inventor's innovation capacity. A more capable inventor has a higher likelihood to get a lower search cost, and so, other things being equal, is more likely to search and make the discovery. I consider only cases where, from the *ex ante* point of view, there is some probability that an inventor will not incur the search cost even when she/he can grab the whole surplus v.

Innovation uncertainty ensues when $\alpha < 1$, and sequential innovation is introduced by the assumption that the pioneer searches before the follower (hence the two labels). I also assume that an inventor cannot commit to the search decision, nor ob-

[13]The U.S. Constitution instructs the Congress to design exclusive rights of limited terms to "promote the Progress of Sciences and useful Arts (Artical I, sect. 8, cl. 8). When there is under investment in innovation activities, this policy goal also coincides with social welfare concerns.

serve that of the other party. The follower only observes whether the pioneer has found the application or not, but not whether she has incurred the cost to search.

The game ends when the pioneer discovers the application. When the follower observes no discovery and believes that the pioneer searched with probability s_P, he updates the existence probability according to the Bayes' rule,

$$\frac{\alpha(1-s_P)}{1-\alpha+\alpha(1-s_P)} = \alpha \cdot \frac{1-s_P}{1-\alpha s_P} \equiv \alpha \cdot \delta. \tag{1}$$

In the denominator, $1-\alpha$ is the probability that the application does not exist, and $\alpha(1-s_P)$ the probability that the application exists but the pioneer did not search. Only the latter event appears in the numerator. The "belief discount" $\delta \leq 1$ measures how the pioneer's search activity s_P affects the follower's updated belief. Shadow effect occurs when uncertainty ($\alpha < 1$) meets an active pioneers ($s_P > 0$), so that the follower's updated belief is discounted by a factor $\delta < 1$ and strictly smaller than the *ex ante* level. Fixing $\alpha \in (0,1)$, a more intensive search by the pioneer (a higher s_P) casts a darker shadow on the follower: $\partial\delta/\partial s_P = -(1-\alpha)/(1-\alpha s_P)^2 < 0$.

Let's first derive inventors' optimal search strategy under the scenario of "winner-take-all," where the whole value π goes to the discoverer. In this case, the pioneer searches when the cost is lower than the *ex ante* expected value v, which occurs with probability $s_P^* \equiv G_P(v)$. The follower applies the discount factor $\delta^* \equiv \delta(s_P^*)$, and searches when the cost $c_F \leq \alpha \cdot \delta^* \cdot \pi = \delta^* \cdot v$, which occurs with probability $s_F^* \equiv G_F(\delta^* \cdot v)$. The total probability that some inventor will search is $S^* \equiv s_P^* + (1-s_P^*)s_F^*$, and the probability of discovering the application is $\alpha \cdot S^*$.

How to induce a higher S^* in a winner-take-all regime? When the winner's prize is a patent over the discovered invention, the policy maker may adjust the scope or length of patent protection to change the size of reward π (Scotchmer, 2004). Conventional wisdom holds that an increase in π (via, e.g., the expansion of patent scope or extension of patent terms) gives a direct boost to inventors' search incentives and should raise the overall S^*. Shadow effect, however, provides a countervailing force. A marginal change of π affects S^* by

$$\frac{dS^*}{d\pi} = \underbrace{(1-s_F^*)\frac{\partial s_P^*}{\partial \pi} + (1-s_P^*)\frac{\partial s_F^*}{\partial \pi}}_{\text{direct effect}} + \underbrace{(1-s_P^*)\frac{\partial s_F^*}{\partial \delta}\frac{\partial \delta^*}{\partial s_P}\frac{\partial s_P^*}{\partial \pi}}_{\text{shadow effect}}. \tag{2}$$

The direct effect, consisting of the first two terms, is strictly positive. The third term captures shadow effect and is non-positive. It shows how a change of s_P^*, induced by a change in π, affects s_F^* via the belief discount δ^*.

Let $\alpha < 1$ and consider the special case of uniform distribution: $c_i \sim UNIF[0, 1/K_i]$, $i \in \{P, F\}$. Let $K_P < 1$ and $K_F\delta^* < 1/v$ so that no inventor will search for sure. A higher K_i implies a better innovation capacity, for the inventor is more likely to have a lower search cost. After some calculation, the sign of $dS^*/d\pi$ is the same as

$$(1 - s_F^*)K_P + (1 - s_P^*)K_F \frac{\delta^* - s_P^*}{1 - \alpha s_P^*}. \tag{3}$$

For sufficiently high K_P such that $\delta^* < s_P^*$, the whole term becomes negative when K_F, and so s_F^*, is large enough. When this is true, the overall innovation efforts S^* can be raised by decreasing π, e.g., by reducing patent protection to the application.[14]

The dominance of shadow effect requires both a significant belief discount δ^* and an important contribution of s_F^* to the overall effort S^*. Intuitively, a better capacity of the pioneer (larger K_P) provides the necessary deep discount. Since the follower searches only when there is no discovery from the pioneer, the contribution of an increase in s_F^* is weighted by $1 - s_P^*$, the probably that the pioneer will not search. (Similarly, an increase in s_P^* deprives the follower of the search opportunity, and so its "net contributes" to S^* is weighted by $1 - s_F^*$.) High K_F thus reduces the importance of pioneer's search, and amplifies the impact s_F^* on S^*.

Proposition 1. *Suppose that the discoverer of the application receives the whole value π. A lower π may raise the overall search effort S^*.*

This simple exercise shows how shadow effect renders a seemingly straightforward policy evaluation nontrivial. It poses a trade-off between the two inventors' search incentives: when $\alpha < 1$, raising s_P causes a more pessimistic follower and thus discourages s_F. The next step is to apply this insight to the issue of patenting the basic invention.

3 Shadow Effect and the DPSM

I now extend the model to a two-stage innovation setting where the first stage aims to discover a basic invention, and the second stage to develop an application of the basic invention. The setting in the previous section is replicated at the second stage, and s_P and s_F now refer to the pioneer's and follower's second-stage search probability, respectively, with $S \equiv s_P + (1 - s_P)s_F$ as the overall search probability.

[14] It also reduces the typical deadweight loss associated with monopoly rights.

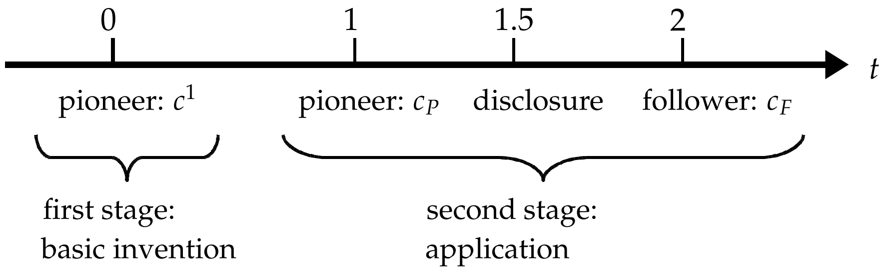

Figure 1: Two-stage innovation

I fix the size of π (and the thus the level of patent protection to the application), and assume that, for simplicity, the basic invention has no stand alone value. The basic invention, as a prerequisite to create the application, may be an abstract idea or scientific principle that requires further development efforts to generate any (economic) benefits. As in Matutes *et al.* (1996), I assume that only the pioneer can engage in the first stage. Innovation at this stage is also modeled as a search decision, but, without loss of generality, suppose that the basic invention exists for sure. The pioneer can discover the basic invention by incurring a search cost c^1, with is distributed according to CDF G^1. Figure 1 summarises the time sequence.[15] At time 1.5 of the second stage, I assume that, if the pioneer doesn't come up with the application (either because she doesn't search or because her search fails), the pioneer will disclose the basic invention so that the follower acquires necessary knowledge to search for the application. She will not, however, disclose whether she has incurred the cost, and so the follower's information structure remains the same as in the previous section. I postpone the discussion of disclosure as well as potential licensing issues to section 4.

Let $\theta \in [0, \overline{\theta}]$ be the probability that the application will infringe on the basic invention, with $\overline{\theta} < 1$.[16] Post infringement, the infringed party (i.e., the pioneer, the only inventor to engage in basic invention) receives the whole value π. The patent policy θ determines the division of surplus when the follower finds the application. The DPSM corresponds to the case of $\theta = 0$, namely when the basic invention is not patentable so that the discoverer can keep the whole π.

The policy objective, the overall probability to successfully develop the applica-

[15]See Appendix C for a justification of this timing in a standard two-stage Poisson race setting.

[16]I provide a justification for the upper bound later; see the discussion before Lemma 1. Alternatively, θ could be interpreted as the share of surplus that goes to the holder of basic patent. The upper bound $\overline{\theta} < 1$ then excludes the extreme case where the pioneering inventor has the full bargaining power.

tion, is now the probability that the pioneer searches at the first stage times the probability that the application is discovered at the second stage ($\alpha \cdot S$).[17] Absent any immediate return, the pioneer's first-stage search is motivated by her expected payoff at the second stage, denoted by u_P. At time 0, the pioneer discovers the basic invention when $c^1 \leq u_P$, which occurs with probability $G^1(u_P)$.

At the second stage, a policy θ changes the follower's innovation return to $(1-\theta)\pi$. The follower searches when $c_F \leq \alpha\delta(1-\theta)\pi = (1-\theta)\delta v$, which occurs with probability $s_F = G_F((1-\theta)\delta v)$. The pioneer, on the other hand, can either incur the cost and receive an expected search payoff $v - c_P$, or wait to share the follower's fruit, with an expected payoff $s_F\theta v$, namely, the probability s_F that the follower will search times the share θv via patent rights. Comparing the two options, the pioneer searches when $c_P \leq (1 - s_F\theta)v$, which occurs with probability $s_P = G_P((1 - s_F\theta)v)$.

Since players cannot observe the opponent's search strategy, a rational expectation equilibrium is sought at the second stage. In an equilibrium $(\hat{s}_P, \hat{s}_F)$, the two inventors' search strategy is consistent with each other:

$$\hat{s}_P = G_P((1 - \hat{s}_F\theta)v) \text{ and } \hat{s}_F = G_F((1-\theta)\hat{\delta}v), \text{ with } \hat{\delta} \equiv \delta(\hat{s}_P), \tag{4}$$

that is, the follower's belief is computed according to the pioneer's equilibrium search probability. The notation $(\hat{s}_P, \hat{s}_F)$ is reserved for an equilibrium under $\theta > 0$. The pioneer's expected payoff at the second stage is

$$\hat{u}_P = \int_0^{G_P^{-1}(\hat{s}_P)} (v - c_P)dG_P + (1 - \hat{s}_P)\hat{s}_F\theta v, \tag{5}$$

and the follower's expected payoff is

$$\hat{u}_F = \int_0^{G_F^{-1}(\hat{s}_F)} \left[(1-\theta)\hat{\delta}v - c\right] dG_F. \tag{6}$$

I exclude the values of θ such that $d\hat{s}_P/d\theta < 0$. By the following lemma, these θs correspond to a situation where both parties would want to negotiate to a lower θ. (See section 4 for more discussion about licensing.) Note that at $\theta = 1$, $\hat{s}_F = 0$ and so $d\hat{s}_P/d\theta > 0$, which in turn justifies the upper bound $\overline{\theta}$ being strictly smaller than one.

Lemma 1. *If $\theta > 0$ such that $d\hat{s}_P/d\theta \geq 0$, then $d\hat{u}_P/d\theta \leq 0$ and $d\hat{u}_F/d\theta < 0$.*

[17]I do not consider inducing duplicative discovery, i.e., encouraging the follower to search after the pioneer has found the application. It might be desirable for antitrust concerns to create competition, but is certainly at odd with the objective of protecting the basic invention.

When the basic invention is not patentable ($\theta = 0$), the second stage admits a unique equilibrium (s_P^*, s_F^*), as computed in section 2. Unique equilibrium is also obtained in the absence of shadow effect. When $\alpha = 1$ and so $\delta = 1$, the follower's search probability is not affected by $\hat{s}_P$. The patent policy θ pins down $\hat{s}_F$, which then determines the pioneer's search probability $\hat{s}_P$. Here higher θ always reduces $\hat{s}_F$, and thus the overall probability $\hat{S}$.

When $\theta > 0$ and $\alpha < 1$, s_P and s_F become strategic substitutes. Shadow effect introduces the same negative impact of s_P on s_F as in section 2. And higher s_F reduces s_P, for the pioneer can extract more surplus through patent rights. This mutual dependence may lead to multiple equilibria; section 4 present an example.

Despite the possibility of multiple equilibria, the basic patent always reduces the pioneer's incentive to continue to do research, $s_P^* > \hat{s}_P$ for all $\theta \in (0, \overline{\theta}]$. The assumption $\overline{\theta} < 1$ ensures that $\hat{s}_F > 0$ in any search equilibrium, and so $s_P^* = G_P(v) > \hat{s}_P = G_P((1 - \hat{s}_F\theta)v)$ for all $\theta \in (0, \overline{\theta}]$. For the follower, a lower search probability from the pioneer boosts his belief: $\hat{\delta} > \delta^*$, for $\hat{s}_P < s_P^*$. Shadow effect alleviates the negative effect of θ on the follower's search incentives. Whether $\hat{s}_F \gtrless s_F^*$, then, depends on $\hat{\delta}(1 - \theta) \gtrless \delta^*$. Shadow effect, again, may upset the conventional wisdom that the basic patent hinders subsequent research. It may happen that, for some $\theta > 0$, $\hat{S} = \hat{s}_P + (1 - \hat{s}_P)\hat{s}_F > S^*$.[18]

Consider again the example of uniform distributions, $c_i \sim UNIF[0, 1/K_i]$, $i \in \{P, F\}$. Let both K_P and K_F be strictly smaller than $1/v$, so that inventor will search for sure. In the proof of Proposition 3, I show that these cost distributions lead to a unique equilibrium at the second stage. Evaluate the policy impact at $\theta = 0$:

$$\begin{aligned}
\left.\frac{d\hat{S}}{d\theta}\right|_{\theta=0} &= (1 - s_F^*)\left.\frac{d\hat{s}_P}{d\theta}\right|_{\theta=0} + (1 - s_P^*)\left.\frac{d\hat{s}_F}{d\theta}\right|_{\theta=0} \\
&= -v\left\{(1 - s_F^*)s_F^*G_P' + (1 - s_P^*)\delta^*G_F' + (1 - s_P^*)s_F^*G_P'G_F'v\left.\frac{\partial\hat{\delta}}{\partial s_P}\right|_{s_P^*}\right\} \qquad (7) \\
&= -v\delta^*G_F'\left[1 - s_P^*s_F^*\left(1 + \frac{1 - \alpha}{1 - \alpha s_P^*}\right)\right],
\end{aligned}$$

[18]This result, for sure, requires a sufficiently strong shadow effect. Using human genome sequencing as the basic invention, Williams (2010) finds that (copyrights-based) intellectual property protection discouraged subsequent research. In her study, however, quick disclosure applies to the reference group, the genome sequenced by a public initiative (Human Genome Project). The so-called "Bermuda rules" required gene sequence information processed under the public project be submitted to the public online database GenBank within 24 hours of sequencing. Such a short time might prevent participants of the public project to develop a first-mover advantage in subsequent research. This empirical finding therefore could be interpreted as results with insignificant shadow effect.

which is positive when s_P^* and s_F^* are sufficiently large, and α sufficiently small. The requirements on s_P^* and s_F^* exhibit the same intuition as in section 2, and the requirements on α also contributes to a more important role of belief discount $\hat{\delta}$. In the extreme case of $\alpha = 1$, for instance, shadow effect disappears and $\hat{S} < S^*$ for all $\theta > 0$.

At the first stage, a higher expected payoff from the second stage raises the pioneer's incentive to search for the basic invention. Let u_P^* be the pioneer's second-stage payoff under $\theta = 0$. Compare it with $\hat{u}_P$, the payoff under $\theta > 0$:

$$\begin{aligned} u_P^* = \int_0^{G_P^{-1}(s_P^*)} (v - c_P) dG_P &= \int_0^{G_P^{-1}(\hat{s}_P)} (v - c_P) dG_P + \int_{G_P^{-1}(\hat{s}_P)}^{G_P^{-1}(s_P^*)} (v - c_P) dG_P \\ &< \int_0^{G_P^{-1}(\hat{s}_P)} (v - c_P) dG_P + \int_{G_P^{-1}(\hat{s}_P)}^{G_P^{-1}(s_P^*)} \hat{s}_F \theta v dG_P < \hat{u}_P, \end{aligned} \tag{8}$$

due to $s_P^* > \hat{s}_P$ and $\hat{c}_F > 0$, as well as the definition of $\hat{s}_P$. Consistent with previous studies, the DPSM ($\theta = 0$) imposes a cost of hampering basic invention.

Proposition 2. *(Effect of basic patent) Granting patent protection to the basic invention increases the pioneer's first-stage incentive, but reduces her incentive to continue at the second stage, for all $\theta \in (0, \overline{\theta}]$, $\hat{u}_P > u_P^*$ and $\hat{s}_P < s_P^*$. Due to shadow effect, its impacts on the follower's incentive and the second-stage performance are ambiguous, $s_F^* \gtrless \hat{s}_F$ and $S^* \gtrless \hat{S}$.*

Taking into account its overall impact, when is it optimal to impose the DPSM in order to promote technology progress? That is, when is $\theta = 0$ the solution to the program $\max_\theta \alpha G^1(\hat{u}_P)\hat{S}$? Fixing α, it is equivalent to finding conditions such that $G^1(u_P^*)S^* \geq G^1(\hat{u}_P)\hat{S}$ for all $\theta \in (0, \overline{\theta}]$.

According to Proposition 2, the DPSM reduces incentives at the first stage. If, at the second stage, $S^* < \hat{S}$ for some $\theta \in (0, \overline{\theta}]$, then the DPSM is dominated at both stages. A necessary condition for the DPSM to be optimal is that this policy facilitates second-stage innovation, namely, $\hat{S} < S^*$ for all $\theta \in (0, \overline{\theta}]$.

Suppose that this necessary condition holds. Consider a marginal change in θ:

$$\frac{dG^1(\hat{u}_P)\hat{S}}{d\theta} = \hat{S} G^{1'} (1 - \hat{s}_P) v \frac{d\theta \hat{s}_F}{d\theta} + G^1 \left[(1 - \hat{s}_F) \frac{d\hat{s}_P}{d\theta} + (1 - \hat{s}_P) \frac{d\hat{s}_F}{d\theta} \right]. \tag{9}$$

As discussed above, a basic patent encourages the first-stage innovation ($G^1(\hat{u}_P) > G^1(u_P^*)$) and changes the follower's innovation performance ($d\hat{s}_F / d\theta \gtrless 0$). This intermediate reward also *discourages* the pioneer from continuing to do research ($\hat{s}_P < s_P^*$). The cumulative innovation literature, such as Green and Scotchmer (1995), focuses on the trade-off between the first two forces, but overlooks the third decision, namely, the *same* inventor's innovation incentives across stages. If the negative impact on the pioneer's second-stage incentive dominates, then the basic invention should not be patentable in order to preserve her continuation efforts.

When $G'_P \neq 0$, the first-order condition is equivalent to

$$\left[(1-\hat{s}_F)G^1 - (1-\hat{s}_P)\hat{S}\frac{G^{1'}}{G'_P}\right]\frac{d\hat{s}_P}{d\theta} + (1-\hat{s}_P)G^1\frac{d\hat{s}_F}{d\theta}. \tag{10}$$

Since $d\hat{s}_P/d\theta < 0$, the whole term is negative when $d\hat{s}_F/d\theta \leq 0$ and

$$(1-\hat{s}_F)G^1 > (1-\hat{s}_P)\hat{S}\frac{G^{1'}}{G'_P}. \tag{11}$$

The first requirement holds when sharing effect dominates shadow effect in the follower's decision. The second requirement holds for a low $\hat{s}_F$ and a high $\hat{s}_P$, i.e., when innovation capacity at the second stage is located at the pioneer, but not the follower.

To better understand the argument, consider special cost distributions. First let c_F take a two-point distribution, $c_F \in \{0, v+\varepsilon\}$, with $\varepsilon > 0$ and $\Pr(c_F = 0) = s_F \in (0,1)$. The follower's fixed capacity, $\hat{s}_F = s_F^* = s_F$, mutes shadow effect and ensures the necessary condition $S^* > \hat{S}$. This simplification illustrates how the follower's capacity s_F affects the trade-off between the pioneer's incentives at different stages.

Holding s_F constant, higher θ always raises the pioneer's first-stage incentives and reduces her second-stage incentives:

$$\frac{d\hat{u}_P}{d\theta} = (1-\hat{s}_P)s_F v > 0 \text{ and } \frac{d\hat{S}}{d\theta} = -(1-s_F)s_F v G'_P < 0. \tag{12}$$

Note that s_F appears in both terms. A more capable follower produces a higher surplus that can be transferred to the pioneer via patent rights, which gives the pioneer stronger incentives to discover the basic invention, but at the same time also allows her to save on her search activity at the second stage. Besides this common factor, the positive boost on $\hat{u}_P$ is also proportional to $1-\hat{s}_P$, the probability that the pioneer does not search for application, for only in this event could the surplus transfer occur. On the other hand, the negative impact on $\hat{S}$ is proportional to $1-s_F$, for a lower search effort from the pioneer has a more severe consequence when the follower is less likely to make the discovery. The DPSM may be optimal when the pioneer has significant search capacity (and so $\hat{s}_P$ is high for all $\theta \in [0,\overline{\theta}]$), but not the follower (and so s_F is small).

Let's further assume that c^1 and c_P take uniform distribution, $c^1 \sim UNIF[0, 1/K^1]$ and $c_P \sim UNIF[0, 1/K_P]$, where both K^1 and $K_P < 1/v$. With $d\hat{s}_P/d\theta < 0 = d\hat{s}_F/d\theta$, the DPSM becomes the optimal policy when condition (11) holds, or $[(1-s_F)\hat{u}_P - (1-\hat{s}_P)(\hat{S}/K_P)]K^1 > 0$, for all $\theta \geq 0$. By integration by parts and the optimal strategy $\hat{s}_P = K_P v(1-\theta s_F)$,

$$\begin{aligned}\hat{u}_P &= (v-c_P)G_P(c_P)|_0^{G_P^{-1}(\hat{s}_P)} + \int_0^{G_P^{-1}(\hat{s}_P)} G_P dc_P + (1-\hat{s}_P)s_F v\theta \\ &> \int_0^{G_P^{-1}(\hat{s}_P)} G_P dc_P = \frac{K_P}{2}\left[(1-\theta s_F)v\right]^2 = \frac{\hat{s}_P^2}{2K_P},\end{aligned} \tag{13}$$

and so

$$\begin{aligned}(1-s_F)K_P\hat{u}_P - (1-\hat{s}_P)\hat{S} &> (1-s_F)\frac{\hat{s}_P^2}{2} - (1-\hat{s}_P)[s_F + (1-s_F)\hat{s}_P] \\ &= (1-s_F)\hat{s}_P\left(\frac{3}{2}\hat{s}_P - 1\right) - s_F(1-\hat{s}_P).\end{aligned} \tag{14}$$

Note that $s_P^* = K_P v$ and so $\hat{s}_P = s_P^*(1-\theta s_F)$. When s_P^* increases and s_F reduces, this term becomes positive for all θ. Denying patent protection to the basic invention is more likely to be optimal when the pioneer's capacity of application search expands and that of the follower shrinks. The following proposition shows that this result holds when c_F also follows uniform distribution.[19]

Proposition 3. *The DPSM is not the optimal policy to promote the technology progress if there is some $\theta > 0$ such that $\hat{S} \geq S^*$.*

The DPSM is the optimal policy if the first-order condition (10) is negative for all $\theta \in [0, \overline{\theta}]$. When all search costs follow uniform distributions, the DPSM is optimal when K_P is sufficiently large and K_F sufficiently small.

The uniform distribution of c^1, the cost of basic innovation, brings about an interesting case: the optimal policy θ is independent of the cost parameter at this stage, K^1 here. Different from Aoki and Nagaoka (2007), within the class of uniform distributions, I can derive the optimality of the DPSM without referring to the difficulty of obtaining the basic invention.

[19]If, instead, the pioneer has a fixed and costless capacity s_P at the second stage, the optimal θ is determined according to the classical trade-off between different inventor's incentives at different stages. And the case of $s_P = 0$ corresponds to the standard model where different generations of innovations are conducted by different players. Let δ be the belief discount corresponding to s_P, which is also fixed; shadow effect also disappears. Higher θ always reduces second-stage incentives: $d\hat{S}/d\theta = (1-s_P)(d\hat{s}_F/d\theta) = -(1-s_P)G_F'\delta v$. The first-order condition has the same sign as $G^{1'}\hat{S}(\hat{s}_F - \theta\delta v G_F') - G^1\delta G_F'$. (Note that the expression (10) doesn't apply for $G_P' = 0$.) If both c^1 and c_F take uniform distributions, the sign is determined by $-2\theta s_P + (1-3\theta)(1-s_P)\hat{s}_F$, which is strictly positive at $\theta = 0$. The DPSM is not optimal.

4 Discussion

This section discusses implications and robustness issues.

☐ **Pioneer's first-mover advantage:** In light of Proposition 3, the DPSM should be imposed when the pioneer has superior ability at the subsequent research stage, but not the follower. The pioneer may acquire this advantage due to previous engagement in basic research, e.g.,through knowledge accumulation or learning-by-doing. The follower may not benefit from this knowledge accumulation either because the pioneer lacks incentives to help information dissemination and absorption, or because of the tacit nature and so the intrinsic difficulty to transfer knowledge among different inventors. The former may be addressed by the disclosure requirement in patent law. In this regard, the result here supports the conventional wisdom that the patent system should be designed to facilitate technology diffusion: The basic patent should not be issued when weak disclosure or enablement requirements significantly hampers other parties' ability to exploit the patented technology. The reason here, however, is to preserve the pioneer's incentive of continuation. The latter, on the other hand, depends on a late-comer's ability to assemble and digest necessary knowledge in order to effectively participate in the innovation process. To the extent that a nascent filed is characterised by the concentration of important knowledge or innovation capacity on a small number of key players, there may not be enough capable followers who can readily pursue the pioneer's research line, and the basic invention should not be patentable.

The second stage of the model can also be interpreted as commercialization. A party has better commercialization capacity when, for instance, she controls key physical assets that facilitate the design and marketing of the basic invention. The previous assumption that the second-stage result is patentable then is replaced by the protection of tangible property. The condition identified in Proposition 3 implies that the optimal patent policy hinges on the degree of vertical integration: the basic invention should not be patentable when the upstream pioneer extends her dominance to the downstream stage of commercialization.

☐ **Research grant and academic kudos:** Basic research is often funded by research grants, and reputation or recognition from the scientific community ("kudos") may provide strong incentive for academic researchers (Gans *et al.*, 2010).[20] These alternative incentive mechanisms avoid the negative sharing effect on the follower. However, they may trigger severe shadow effect and be inferior to the patent system.

Suppose that the pioneer receives a reward $R > 0$ after completing the first-stage innovation. This reward does not affect the second-stage decisions. Consider two cases. First, let R be a policy instrument (e.g., research grant) that is also controlled by the patent authority (e.g., the Congress). In possession of two instruments, the policy maker can set the patent policy θ to address the second-stage performance, and adjust incentives at the first stage with research grant R. This separation, however, does not necessarily vindicate the DPSM. When $\hat{S} > S^*$ for some θ, it is still optimal to issue the basic patent.

Next, suppose that R is not controlled by the patent authority. It may be reputation-based (scientific kudos, citations), or research grant provided by another agency (e.g., National Science Foundation or National Institutes of Health in the U.S.) or private organizations (e.g., the Nobel Prize). The policy maker then chooses the patent policy θ taking as given the "extra" boost for basic innovation. Again, patent protection to the basic invention is optimal if it benefits the second stage.

Suppose that patent protection always hurts the second stage, $\hat{S} < S^*$ for all $\theta > 0$. It is optimal to impose the DPSM if, for all $\theta > 0$

$$[G^1(R + u_P^*)/G^1(R + \hat{u}_P)] > (\hat{S}/S^*), \tag{15}$$

where $\hat{u}_P$ and $\hat{S}$ are computed at the the corresponding θ. When the left-hand side is increasing in R, as in the case of uniform distribution, higher R moves the optimal patent policy towards the DPSM.

Proposition 4. *(Alternative rewards to basic invention) When shadow effect give rises to the beneficial effect of the basic patent on the second-stage innovation, the DPSM is not optimal regardless of the introduction of non-patent reward R.*

□ **Policy package:** In the end of section 2, the parameter π is interpreted as patent protection the application receives. Applying this interpretation to the framework of

[20]Reputation or similar concerns (such as a Nobel Prize) may also provide strong incentives to disclose basic invention in the absence of patent protection. Scientists may also prefer more challenging tasks (Sauermann and Cohen, 2007, Owan and Nagaoka, 2008), namely, there is an intrinsic (psychological) reward that is decreasing in the belief that the application can be found. Although shadow effect is weakened by such reward, previous results hold as long as its magnitude is not too large.

section 3, the patent authority may tackle the two-stage incentives problem with a policy package (θ, π). Interestingly, $\partial\hat{S}/\partial\theta > 0$ at $\theta = 0$ implies $\partial\hat{S}/\partial\pi < 0$ at $\theta = 0$. The same shadow effect that provides the basic patent with a benefit at the second stage also ensures a similar benefit by slightly reducing patent protection to the application. One might conjecture that, if, for reasons not considered here, the policy maker would like to keep the basic invention unpatentable, then it may be beneficial to reduce the protection to the application as well. The answer to this question, which involves first-stage incentives, as well as the complete characterization of optimal policy are left for future research.

Proposition 5. *Evaluating at $\theta = 0$, $\partial\hat{S}/\partial\theta > 0$ implies $\partial\hat{S}/\partial\pi < 0$.*

□ **Licensing and information disclosure:** Two issues in the previous model may prompt licensing. First, excessive protection to the basic invention may be detrimental to both the pioneer and follower. Second, the follower is interested in the pioneer's private information at time 1, namely, what the pioneer has learned about α according to her search activity. Let's consider these two issues in turn.[21] Limited liability constrains the licensing space to revenue-sharing rules (royalty terms) between the two parties. Let $l \in [0, 1]$ be the portion of π transferred from the follower to the pioneer, when the former discovers the application. The patent policy θ determines the two parties' outside option during negotiation.

An extreme example of excessive patent protection is $\theta = 1$, whereby the follower does not search at all. Lemma 1 gives a more general condition, namely, $d\hat{s}_P/d\theta \geq 0$, that implies that both parties benefit from a lower θ. The policy space $[0, \overline{\theta}]$, with $\overline{\theta} < 1$, can also be seen as the values of θ that are "licensing-proof," and will prevail after taking into account of licensing. [22]

For the second issue, the pioneer's private information allows the follower to either save search cost (when the pioneer fails), or restore his search incentives (when the pioneer does not search). A failed pioneer (at the second stage) has no interest in the follower's innovation activity, for she knows that the follower won't succeed,

[21] I do not consider licensing to disclose the basic invention. When the basic invention is patentable, the pioneer benefits from the follower's search activity. When $\theta = 0$, disclosure does not harm the pioneer, and she may decide to publish it for reputation concerns. Appendix C discusses the disclosure decision in a two-stage Poisson race model.

[22] Under uniform distributions, for example, $d\hat{s}_P/d\theta \geq 0$ for all $\theta \geq 1/2$. For this issue, the exact timing of licensing, namely, whether the negotiation occurs before or after the pioneer has made her second-stage search decision, does not matter. In both cases, the pioneer's licensing payoff is proportional to $\theta \cdot \hat{s}_F$.

either. By contrast, a pioneer who didn't search at the second stage will want to get a stake, *and* give her private information to the follower in order to raise the latter's incentives. Breaking the failed pioneer's indifference in different manners generates different information transmission outcomes. This indifference, however, is not robust to a modification that introduces mistakes in pioneer's search.[23]

Suppose that, even if the pioneer incurs c_P to search, there is some probability $\varepsilon \in (0, 1)$ that she won't find an existing application. The pioneer's failure, then, is still a bad news, but not as desperate as before. Her updated belief about the existence of the application is $\alpha^{\varepsilon} = \varepsilon\alpha/(1 - \alpha + \varepsilon\alpha) \in (0, \alpha)$. Given licensing term l, the pioneer's expected licensing income is $\alpha^P G_F(\tilde{\alpha}^l(1-l)\pi)l\pi$, where $\alpha^P \in \{\alpha, \alpha^{\varepsilon}\}$ is the pioneer's "type", and $\tilde{\alpha}^l$ is the follower's updated belief according to the licensing outcome, transmitted through the contractual term l. Both types of pioneer aim to maximise $G_F(\tilde{\alpha}^l(1-l)\pi)$. There is an equilibrium in the licensing negotiation subgame where the pioneer's strategy does not depend on her private information, and the follower learns nothing. The qualitative feature of shadow effect is retained.[24]

□ **Structure of innovation market:** In a two-stage homogeneous Poisson race where inventors possess identical research capacity, the pioneer in Aoki and Nagaoka (2007), i.e., the first inventor to finish the first race, will exert her patent rights to block opponents' entry into the second race.[25] The pioneer does not benefit from others' innovation capacity. The basic patent generates a monopoly at the second stage, and increases the concentration of the innovation market, as measured by the extent to which different inventions are created by different inventors, given completion of both stages.

In my model, by contrast, the pioneer uses the basic patent to extract surplus from the follower. Conditional on discovery, the probability that the follow discovers is $[(1 - \hat{s}_P)\hat{s}_F]/\hat{S}$ under $\theta > 0$, which is greater than the probability under the DPSM,

[23] When the true level of c_P is the pioneer's private information and whether she has spent this cost is non-verifiable, it is unclear which patent policy tool could be used to induce the pioneer to disclose this information. Since patents are public records, whenever the identity of following inventors are unknown *ex ante*, it may be difficult to enforce patent rights whose disclosure helps others to *not* conducting innovation.

[24] Relaxing the limited liability constraint, the follower may be able to purchase the pioneer's private information with cash. But in general the optimal licensing term is no more a surplus-sharing rule. I do not pursue this question here.

[25] Aoki and Nagaoka (2007) considers a two-point policy space, the basic invention is either not patentable or infringed for sure, and uses social welfare as the policy objective, which consists of inventors' profit and a social benefit of the application not accrued to inventors.

$[(1-s_P^*)s_F^*]/S^*$ if $s_P^*(1-\hat{s}_P)\hat{s}_F > \hat{s}_P(1-s_P^*)s_F^*$. Since $s_P^* > \hat{s}_P$, as long as $\hat{s}_F/s_F^*$ is not too small, the basic patent helps the decentralization of innovation activities. And since shadow effect mitigates the negative impact of θ on $\hat{s}_F$, it reinforces the disintegration caused by the patent policy.

□ **Multiple equilibria at the second stage:** Mutual dependence of $\hat{s}_P$ and $\hat{s}_F$, induced by basic patent ($\theta > 0$) and shadow effect ($\alpha < 1$), may generate multiple equilibria at the second innovation stage. Along the equilibrium path, higher $\hat{s}_P$ reduces the follower's search intensity $\hat{s}_F$ via a lower belief discount factor $\hat{\delta}$. The reduction in $\hat{s}_F$ in turn justifies the initial increase in $\hat{s}_P$. By the same token, expecting a higher search probability from the follower, the pioneer will lower her search effort, whereby causes a higher updated belief and so higher incentive to search by the follower.

Two-point cost distributions provide the simplest example. For $i \in \{P, F\}$, let $c_i \in \{k_i, v+\varepsilon\}$, with $v \geq k_i \geq 0$ and $\varepsilon > 0$, and the probability of low search cost is $\Pr(c_i = k_i) = s_i \in (0,1)$. Inventor $i \in \{P, F\}$ does not incur the high cost $v+\varepsilon$, and searches at most with probability s_i. For $(0, s_F)$ to be an equilibrium, the pioneer must prefer to wait and let the follower search, $k_P > v(1-s_F\theta)$; and, given that the pioneer does not search, the follower has belief discount $\hat{\delta} = 1$ and is willing to search when $k_F \leq v(1-\theta)$. For $(s_P, 0)$ to be an equilibrium, the pioneer will search when she knows that the follow won't, for $k_P \leq v$; and the follower, holding belief discount $\hat{\delta} = (1-s_P)/(1-\alpha s_P)$, will not search when $k_F > (1-\theta)\hat{\delta}v$. If all these conditions hold, then both $(s_P, 0)$ and $(0, s_F)$ are equilibria at the second stage.

Multiple equilibria presents the possibility of inefficient allocation of search activity. Let $s_P = s_F = s \in (0,1)$ but $k_P \neq k_F$, and assume that both $(0, s)$ and $(s, 0)$ are both equilibria. The total search probability is the same, $\hat{S} = s$, but search cost is smaller in one equilibrium than in the other. When $k_P > k_F$, the equilibrium where only the follower searches is more cost-efficient.

Lastly, let $s_F > s_P$. The DPSM leads to unique equilibrium $(s_P, 0)$, with $S^* = s_P$. But when multiple equilibria $(s_P, 0)$ and $(0, s_F)$ ensue under some $\theta > 0$, the total search probability is $\hat{S} = s_F > S^*$ in the equilibrium $(0, s_F)$. When the "good" equilibrium prevails, the basic patent boosts the second-stage innovation performance and encourages market disintegration, $(1-s_P^*)s_F^*/S^* = 0 < (1-\hat{s}_P)\hat{s}_F/\hat{S} = 1$.

□ **Patent policy and joint surplus:** The DPSM does not maximise the two inventor's joint surplus. Raising θ slightly above zero only exerts a negative impact on the follower's payoff $\hat{u}_F$. This negative effect, however, is offset by a positive impact on the pioneering inventor's payoff $\hat{u}_P$. Protecting the basic invention with some patent rights therefor benefit the innovation sector as a whole.

Proposition 6. *The DPSM does not maximise the joint surplus of the two inventors.*

5 Multiple Applications: Shadow and Sunshine

Since "There falls no shadow where there shines no sun (Hilaire Belloc, poet)," this section considers more general information spill-over, where the pioneer's search outcome may be a good (sunshine) or bad news (shadow) to the follower. Very often researchers have different ideas about how to apply a basic invention (Murray *et al.*, 2009). Let the pioneer and follower pursue different applications, but maintain the assumptions that the pioneer moves before the follower, and that the follower only observes whether the pioneer has come up with her application or not. Inventors will disclose the discovered application (in order to, for instance, receive patent protection). I focus on the application search stage, but also consider the impact of basic patent θ. For simplicity, let each application generate a return $\pi > 0$ (Appendix B considers payoff externality). The pioneer gets a payoff 2π when the follower's application infringes on the pioneer's patent.

Denote $a_P = 1$ ($a_P = 0$) as the event where the pioneer's application exists (does not exist, respectively); similarly for $a_F \in \{0, 1\}$. To generate information spill-over, a_P should provide information about a_F. Suppose that the follower's application has *ex ante* existence probability $\Pr(a_F = 1) = \alpha_F \in (0, 1]$. For both $a_F \in \{0, 1\}$,

$$\Pr(a_P = a_F | a_F) = \rho \in [0, 1], \tag{16}$$

i.e., the existence or not of pioneer's application coincides with that of the follower's with probability ρ. A "signal" $a_P = 1$ is generated, and the pioneer's application exists with *ex ante* probability $\alpha_P \equiv \alpha_F \cdot \rho + (1 - \alpha_F)(1 - \rho)$. By Bayes' rule, when learning $a_P = 1$, the updated assessment about the follower's application is $(\alpha \cdot \rho)/\alpha_P$; and when observing $a_P = 0$, the updated belief is $[\alpha_F(1 - \rho)]/(1 - \alpha_P)$. Denote $\delta^+ \equiv \rho/\alpha_P$ and $\delta^- \equiv (1 - \rho)/(1 - \alpha_P)$. When $\rho = 1/2$, $\delta^+ = 1 = \delta^-$, learning a_P provides no information about a_F. When $\rho > 1/2$, the two applications' existence probability are positively correlated, with $\delta^+ > 1 > \delta^-$: observing $a_P = 1$ ($a_P = 0$) raises (reduces, respectively) the updated belief about a_F. The reverse is true for $\rho < 1/2$.

The follower, however, only observes $a_P = 1$, but not $a_P = 0$. As before, no application from the pioneer also includes the possibility that she did not search at all. Given the pioneer's search probability $\hat{s}_P$, the follower's updated belief is

$$\frac{(1-\hat{s}_P)\alpha_F + \hat{s}_P\alpha_F(1-\rho)}{(1-\hat{s}_P) + \hat{s}_P(1-\alpha_P)} = \alpha_F \frac{1-\hat{s}_P\rho}{1-\hat{s}_P\alpha_P}. \tag{17}$$

Let $\hat{\delta}^- \equiv (1-\hat{s}_P\rho)/(1-\hat{s}_P\alpha_P)$. When $\hat{s}_P \to 1$ ($\hat{s}_P \to 0$), $\hat{\delta}^- \to \delta^-$ ($\hat{\delta}^- \to 1$, respectively). The pioneer's inaction dilutes the information content of this event.

Denote $v_i \equiv \alpha_i \cdot \pi$, $i \in \{P, F\}$. The follower exerts probability to search $\hat{s}_F^+ = G_F((1-\theta)\delta^+ v_F)$ when observing that the pioneer has found her application, and $\hat{s}_F^- = G_F((1-\theta)\hat{\delta}^- v_F)$ otherwise. Higher θ always reduces $\hat{s}_F^+$. But, similar to previous analysis, patent policy exerts two effects on $\hat{s}_F^-$: a direct negative effect, and an indirect, belief effect via $\hat{\delta}^-$.

For the pioneer, not searching generates an expected licensing income, $\alpha_F \hat{s}_F^- \theta\pi$, and the payoff from incurring c_P to search is

$$\begin{aligned} &-c_P + \alpha_P\left\{\alpha_F\delta^+\hat{s}_F^+[\theta\cdot 2\pi + (1-\theta)\pi] + (1-\alpha_F\delta^+\hat{s}_F^+)\pi\right\} + (1-\alpha_P)\alpha_F\delta^-\hat{s}_F^-\theta\pi \\ =&-c_P + v_P + \rho v_F\theta(\hat{s}_F^+ - \hat{s}_F^-) + \hat{s}_F^-\theta v_F. \end{aligned} \tag{18}$$

The pioneer fails with probability $1-\alpha_P$, and will update her belief about the follower's application according to δ^-. With probability α_P, the pioneer successfully develops her application, and the payoff depends on the follower's outcome as well as the resolution of patent dispute. The pioneer searches when

$$c_P \leq v_P + \rho v_F\theta(\hat{s}_F^+ - \hat{s}_F^-), \tag{19}$$

which determines the search probability $\hat{s}_P$. Since $\hat{s}_F^+$ is uniquely determined by the patent policy θ, a rational expectation equilibrium is characterised by a mutually consistent pair $\hat{s}_P$ and $\hat{s}_F^-$.

Here the pioneer can no longer "delegate" her search to the follower. Hence patent policy θ does not alter the impact of v_P on $\hat{s}_P$. The impact of θ hinges on which action, searching or not, generates a higher licensing income from the follower. Not searching leads to the belief discount $\hat{\delta}^-$ and induces the follower to search with probability $\hat{s}_F^-$. If the pioneer searches, she may succeed with a probability, which then changes the follower's belief to δ^+ and search probability to $\hat{s}_F^+$. The difference in follower's search behavior, $\hat{s}_F^+ - \hat{s}_F^-$, determines how patent policy affects the pioneer's search incentives. In the absence of information spill-over, $\rho = 1/2$ and so $\hat{\delta}^- = \delta^+ = 1$ for all $\hat{s}_P$, the follower exerts the same search effort, $\hat{s}_F^+ = \hat{s}_F^-$. The basic patent does not affect the pioneer's search incentives, $\hat{s}_P = G_P(v_P)$ for all θ, but only has a negative impact on the follower.

When the existence probabilities are positively correlated ($\rho > 1/2$), the follower's search probabilities exhibit $\hat{s}_F^+ > \hat{s}_F^-$, for $\delta^+ > 1 > \hat{\delta}^-$ for all θ and $\hat{s}_P$. No discovery from the pioneer still casts shadow on the follower's endeavor, but the appearance of pioneer's application will "brighten" the follower's prospect. The pioneer's stake in the follower's search raises her incentive, with the intention to send the follower to the "bright" path and exerts $\hat{s}_F^+$.[26] For all $\theta > 0$, $\hat{s}_P = G_P(v_P + \rho\theta v_F(\hat{s}_F^+ - \hat{s}_F^-)) > G_P(v_P)$. Higher search probability, however, further weakens the follower's search probability $\hat{s}_F^-$, due to a shadow discount that is decreasing in $\hat{s}_P$: $\partial\hat{\delta}^-/\partial\hat{s}_P = -[(1-\alpha_F)(2\rho - 1)]/(1-\hat{s}_P\alpha_P)^2 < 0$.

When $\rho \in (0, 1/2)$, the two applications' existence probability are negatively correlated. Shadow and sunshine project at the opposite events: The pioneer's discovery is a bad news for the follower while silence is a good news, and $\hat{s}_F^+ < \hat{s}_F^-$ follows $\delta^+ < 1 < \hat{\delta}^-$. The basic patent reduces the pioneer's search incentive, $G_P(v_P + \rho\theta v_F(\hat{s}_F^+ - \hat{s}_F^-)) < G_P(v_P)$ for all $\theta \in (0,1)$. Since now $\partial\hat{\delta}^-/\partial\hat{s}_P > 0$, a reduction in $\hat{s}_P$ again further reduces $\hat{s}_F^-$.

An interesting case occurs for $\rho = 0$, and so $\alpha_P = 1 - \alpha_F$, i.e., the two applications do not co-exist: Patent policy θ does not change the pioneer's search decision, which is fixed at $\hat{s}_P = G_P(v_P)$. This is because the pioneer's search decision does not affect licensing income. If the pioneer does not search, she expects the follower's application to exist with probability α_F, and the follower to exert search probability $\hat{s}_F^-$. When the pioneer searches, licensing payment may accrue only when her own search fails, which occurs with probability $1 - \alpha_P = \alpha_F$. The follower's search probability in this event is also $\hat{s}_F^-$. Patent policy θ only negatively affects the follower.

To sum up, when inventors pursue different applications, the basic patent always reduces the follower's incentives, $\hat{s}_F^+$ and $\hat{s}_F^-$. Information spill-over, nevertheless, provides positive impacts that work through *the pioneer* here. First, the basic patent induces higher search probability from the pioneer under positive correlation. Second, the pioneer's incentive to "select sunshine over shadow," caused by $\theta > 0$, further mitigates the negative impact on the follower. The *ex ante* probability that the

[26] Since the follower does not observe $\hat{s}_P$, the pioneer cannot act as a Stackelberg leader and intentionally choose her search probability to manipulate the follower's belief.

follower will develop his application,

$$\alpha_P \hat{s}_P \alpha_F \delta^+ \hat{s}_F^+ + (1-\alpha_P \hat{s}_P)\alpha_F \hat{\delta}^- \hat{s}_F^- = \alpha_F \left[\rho \hat{s}_P \hat{s}_F^+ + (1-\rho \hat{s}_P)\hat{s}_F^-\right], \tag{20}$$

contains a weighted average between $\hat{s}_F^+$ and $\hat{s}_F^-$. When $\rho > 1/2$, $\hat{s}_F^+ > \hat{s}_F^-$. Setting $\theta > 0$ reduces both $\hat{s}_F^+$ and $\hat{s}_F^-$, but at the same time raises $\hat{s}_P$, and so puts more weight on the high search probability end. Similarly, when $0 < \rho < 1/2$, $\hat{s}_F^+ < \hat{s}_F^-$, and the smaller $\hat{s}_P$ induced by $\theta > 0$ moves the weighted average toward $\hat{s}_F^-$.[27] Except for perfectly negative correlation, the introduction of information spill-over uncovers an incentive effect that would be missing otherwise.

Proposition 7. When inventors pursue different applications and there is payoff independence, rewarding the pioneer with patent rights discourages the follower's application search, but may raise or reduce the pioneer's incentive to develop her application.

6 Conclusion

In this paper, I analyzed how the basic patent affects the cumulative innovation process in the presence of shadow effect, namely, the dimer prospect of future research given previous failed attempts. Shadow effect gives the basic patent a more friendly role to subsequent innovation and helps disintegration of the innovation market. To justify the DPSM, i.e., to reject patent protection to the basic invention, therefore, requires weak shadow effect. The DPSM may be the optimal policy to induce the pioneering inventor's continuation efforts.

For future research, it would be interesting to check the empirical validation of the predictions derived the shadow effect, for instance, the one concerning the concentration of the innovation market. An empirical support of shadow effect would invite us to re-evaluate policy recommendations from economic theory and take into account the more subtle role (basic) patents play in innovation, as demonstrated in this paper.

Concerning patent policy, the sufficient condition of the optimality of the DPSM is derived under specific cost distributions. It would be important to test its robustness in more general settings. Since research capacity (cost distribution here) may not be

[27] Murray *et al.* (2009) provides empirical results that more research paths were explored after the relaxation of (patent-backed) restrictions on the use and distribution of genetically engineered mice, which are used as research tools. They do not distinguish between pioneers and followers. (The latter group might roughly be identified as scientists not working for DuPont, the owner of patents under study.) To the extent that most researchers belong to the second category, their findings are consistent with the result here.

easily identified, future work should also develop other fundamental elements that are easier for policy-makers to apply.

A few issues deserve more attentions: multiple pioneers at the first-stage innovation as in Denicolò (2000) and Aoki and Nagaoka (2007); secrecy protection to the basic invention; and the optimal combination of the DPSM with other policy instruments, to name a few. A better understanding of the doctrine of the patentable subject matter would advance our knowledge on the optimal design of the patent system. This paper constitutes an early step.

Appendix

A Proofs

□ Lemma 1

Proof. Suppose

$$\frac{d\hat{s}_P}{d\theta} = -G_P' v \frac{d(\theta \hat{s}_F)}{d\theta} \geq 0, \tag{21}$$

which requires $d(\theta\hat{s}_F)/d\theta \leq 0$. By the envelope theorem,

$$\frac{d\hat{u}_P}{d\theta} = (1-\hat{s}_P)v\frac{d(\theta\hat{s}_F)}{d\theta} \leq 0 \text{ and } \frac{d\hat{u}_F}{d\theta} = \hat{s}_F v\left[-\hat{\delta} + (1-\theta)\frac{\partial\hat{\delta}}{\partial s_P}\frac{d\hat{s}_P}{d\theta}\right] < 0, \tag{22}$$

where $\partial\hat{\delta}/\partial s_P \leq 0$ for all $\alpha \in [0,1]$. *Q.E.D.*

□ Proposition 3

Proof. When $G_P' \neq 0$, the expression (10) can be obtained by rewriting $d(\theta\hat{s}_F)/d\theta$ as a function of $d\hat{s}_P/d\theta$. Differentiate $\hat{s}_P$ and $\hat{s}_F$, and let $\hat{\delta}' \equiv \partial\hat{\delta}/\partial s_P$:

$$d\hat{s}_P + \theta v G_P' d\hat{s}_F = -\hat{s}_F v G_P' d\theta \tag{23}$$

$$-(1-\theta)\hat{\delta}' v G_F' d\hat{s}_P + d\hat{s}_F = -\hat{\delta} v G_F' d\theta. \tag{24}$$

By Cramer's rule,

$$\frac{d\hat{s}_P}{d\theta} = -\frac{vG_P'}{\triangle}(\hat{s}_F - \theta\hat{\delta}vG_F') \text{ and } \frac{d\hat{s}_F}{d\theta} = -\frac{vG_F'}{\triangle}\left[\hat{\delta} + (1-\theta)\hat{\delta}'\hat{s}_F v G_P'\right], \tag{25}$$

where $\triangle = 1 + \theta(1-\theta)\hat{\delta}' v^2 G'_P G'_F$. For small shadow effect, $\hat{\delta}' \to 0$, $\triangle > 0$ and $d\hat{s}_F / d\theta < 0$.[28]

Let $c^1 \sim UNIF[0, 1/K^1]$ and $c_i \sim UNIF[0, 1/K_i]$, $i \in \{P, F\}$. When both K_P and $K_F < 1/v$, there is unique equilibrium at the second stage. Expressing $\hat{s}_F$ in terms of $\hat{s}_P$ (via $\hat{\delta}$), a solution of the following equation corresponds to a search equilibrium:

$$\hat{s}_P = G_P\left((1 - \theta G_F((1-\theta)\hat{\delta}v))v\right) = K_P v \left[1 - \theta(1-\theta)\frac{1-\hat{s}_P}{1-\alpha\hat{s}_P}K_F v\right]. \tag{26}$$

By $K_F v < 1$, the right-hand side is strictly positive. Since $K_P v < 1$, for all $\theta \in (0,1)$, $\hat{s}_P = 1$ is not a solution, and in equilibrium $1 - \alpha\hat{s}_P > 0$. An equilibrium is a solution of the following quadratic equation:

$$\alpha\hat{s}_P^2 - \{1 + K_P v[\alpha - \theta(1-\theta)K_F v]\}\hat{s}_P + K_P v[1 - \theta(1-\theta)K_F v] = 0. \tag{27}$$

Let $\mathbf{B} = 1 + K_P v[\alpha - \theta(1-\theta)K_F v]$ and $\mathbf{C} = K_P v[1 - \theta(1-\theta)K_F v]$. Note that $\mathbf{C} < 1$. The determinant is strictly positive, for $\mathbf{B}^2 - 4\alpha\mathbf{C}$ equals to

$$\{1 - K_P v[\alpha + \theta(1-\theta)K_F v]\}^2 + 4\alpha\theta(1-\theta)K_P v K_F v(1 - K_P v) > 0. \tag{28}$$

Since $\mathbf{B} > \sqrt{\mathbf{B}^2 - 4\alpha\mathbf{C}}$, both roots are positive. The root $(\mathbf{B} - \sqrt{\mathbf{B}^2 - 4\alpha\mathbf{C}})/(2\alpha)$ is the unique solution if

$$\frac{\mathbf{B} - \sqrt{\mathbf{B}^2 - 4\alpha\mathbf{C}}}{2\alpha} < 1 < \frac{\mathbf{B} + \sqrt{\mathbf{B}^2 - 4\alpha\mathbf{C}}}{2\alpha}, \tag{29}$$

or, equivalently, $\sqrt{\mathbf{B}^2 - 4\alpha\mathbf{C}} > \max\{\mathbf{B} - 2\alpha, 2\alpha - \mathbf{B}\}$. When $\mathbf{B} > 2\alpha$, it suffices to check $\sqrt{\mathbf{B}^2 - 4\alpha\mathbf{C}} > \mathbf{B} - 2\alpha$, or,

$$\mathbf{B}^2 - 4\alpha\mathbf{C} > \mathbf{B}^2 - 4\alpha\mathbf{B} + 4\alpha^2 \Rightarrow \mathbf{B} > \mathbf{C} + \alpha \Rightarrow 1 - \alpha > K_P v(1-\alpha), \tag{30}$$

which holds for $K_P v < 1$. Similar for the case of $\mathbf{B} \leq 2\alpha$.

Under uniform distributions,

$$\triangle = 1 - \theta(1-\theta)K_P v K_F v \frac{1-\alpha}{(1-\alpha\hat{s}_P)^2} = 1 - \frac{(1-\alpha)\theta s_P^* \hat{s}_F}{(1-\alpha\hat{s}_P)(1-\hat{s}_P)}, \tag{31}$$

for $s_P^* = K_P v$ and $\hat{s}_F = K_F v(1-\theta)\hat{\delta}$. By $\hat{s}_P = K_P v(1 - \theta\hat{s}_F) = s_P^*(1 - \theta\hat{s}_F)$,

$$(1-\alpha\hat{s}_P)(1-\hat{s}_P) = (1-\alpha\hat{s}_P)(1 - s_P^* + \theta s_P^*\hat{s}_F) > (1-\alpha\hat{s}_P)\theta s_P^*\hat{s}_F > (1-\alpha)\theta s_P^*\hat{s}_F. \tag{32}$$

[28]On the $\hat{s}_P - \hat{s}_F$ plane, a stable equilibrium $(\hat{s}_P, \hat{s}_F)$ guarantees $\triangle > 0$ for it requires that the pioneer's reaction curve have a larger slope (in absolute value) than the follower's reaction curve.

The denominator $\triangle > 0$. Given so,

$$\frac{d\hat{s}_P}{d\theta} = -\frac{K_P v K_F v}{\triangle}\hat{\delta}(1-2\theta), \tag{33}$$

which is strictly negative for all $\theta < 1/2$; and

$$\frac{d\hat{s}_F}{d\theta} = -\frac{K_F v}{\triangle}\hat{\delta}\left[1 - \frac{(1-\theta)(1-\alpha)}{(1-\hat{s}_P)(1-\alpha\hat{s}_P)^2}\hat{s}_F K_P v\right] = -\frac{K_F v}{\triangle}\left[1 - \frac{(1-\alpha)(1-\theta)^2 s_P^*}{(1-\alpha\hat{s}_P)^3}K_F v\right]. \tag{34}$$

If K_F is sufficiently small, e.g. if $K_F v < (1-\alpha s_P^*)^3/[(1-\alpha)s_P^*]$, this term is also negative. In this case, it suffices to check the expression (11), or $(1-\hat{s}_F)\hat{u}_P K_P > (1-\hat{s}_P)\hat{S}$.

Expressed in term of $\hat{s}_F$,

$$\hat{S} = \hat{s}_F + (1-\hat{s}_F)(1-\theta\hat{s}_F)K_P v = s_P^*\left[1 + x\hat{s}_F - (1-\hat{s}_F)y\right], \tag{35}$$

and

$$\hat{u}_P = \theta\hat{s}_F v + \frac{s_P^{*2}}{2K_P}(1-\theta\hat{s}_F)^2 = \frac{s_P^{*2}}{2K_P}\left(1 + 2xy + y^2\right), \tag{36}$$

where $x \equiv (1/s_P^*) - 1 > 0$ and $y \equiv \theta\hat{s}_F$. The sufficient condition becomes

$$\begin{aligned} &(1-\hat{s}_F)\frac{s_P^{*2}}{2}(1+2xy+y^2) > s_P^{*2}(x+y)[1 + x\hat{s}_F - (1-\hat{s}_F)y] \\ \Leftrightarrow &(1-\hat{s}_F)[1 + y(4x+3y)] > 2(x+y)(1+x\hat{s}_F). \end{aligned} \tag{37}$$

This condition holds when both x and $\hat{s}_F$ are sufficiently small. The former requires a sufficiently large K_P (and so s_P^*), and the latter a sufficiently small K_F. *Q.E.D.*

□ Proposition 5

Proof. By the proof of Proposition 3, suppose that

$$\frac{\partial\hat{S}}{\partial\theta}\Big|_{\theta=0} = -v\left[(1-s_F^*)s_F^* G_P' + (1-s_P^*)\delta^* G_F' + (1-s_P^*)s_F^*\delta^{*'} G_P' G_F' v\right] > 0, \tag{38}$$

which implies that $1 - s_F^* + (1-s_P^*)\delta^{*'} G_F' v < 0$. The comparative statics result with respect to π is

$$\frac{\partial\hat{s}_P}{\partial\pi} = \frac{\alpha G_P'}{\triangle}\left[1 - \theta\hat{s}_F - \theta(1-\theta)\hat{\delta} v G_F'\right] \text{ and } \frac{\partial\hat{s}_F}{\partial\pi} = (1-\theta)\frac{\alpha G_F'}{\triangle}\left[\hat{\delta} + (1-\theta\hat{s}_F)\hat{\delta}' G_P' v\right], \tag{39}$$

where $\triangle$ is defined in the proof of Proposition 3. Evaluating at $\theta = 0$,

$$\begin{aligned} \frac{\partial\hat{S}}{\partial\pi}\Big|_{\theta=0} =&\alpha\left[(1-s_F^*)G_P' + (1-s_P^*)\delta^* G_F' + (1-s_P^*)\delta^{*'} G_P' G_F' v\right] \\ =&\alpha\Big\{(1-s_F^*)s_F^* G_P' + (1-s_P^*)\delta^* G_F' + (1-s_P^*)s_F^*\delta^{*'} G_P' G_F' v \\ &+ (1-s_F^*)G_P'[1 - s_F^* + (1-s_P^*)\delta^{*'} G_F' v]\Big\}, \end{aligned} \tag{40}$$

must also be strictly negative. *Q.E.D.*

□ **Proposition 6**

Proof. The joint surplus from the *ex ante* point of view is

$$U = \int_0^{\hat{u}_P} (\hat{u}_P - c^1) dG^1 + G^1(\hat{u}_P)(1 - \alpha \hat{s}_P)\hat{u}_F. \tag{41}$$

The follower receives $\hat{u}_F$ only when the basic invention is created and the pioneer does not come up with the application. The impact of the policy θ is

$$\frac{dU}{d\theta} = G^1(\hat{u}_P)\frac{d\hat{u}_P}{d\theta} + (1-\alpha\hat{s}_P)G^{1'}(\hat{u}_P)\hat{u}_F\frac{d\hat{u}_P}{d\theta} - G^1(\hat{u}_P)\left[\alpha\hat{u}_F\frac{d\hat{s}_P}{d\theta} - (1-\alpha\hat{s}_P)\frac{d\hat{u}_F}{d\theta}\right], \tag{42}$$

where $d\hat{u}_P/d\theta$ and $d\hat{u}_F/d\theta$ can be found in the proof of Lemma 1. At $\theta = 0$, $d\hat{u}_P/d\theta = (1 - s_P^*)s_F^* v > 0$. Using the comparative static results in the proof of Proposition 3, $\triangle = 1$ and $d\hat{s}_P/d\theta = -s_F^* v G_P' < 0$. The only negative term in $dU/d\theta$ occurs in $d\hat{u}_F/d\theta$, namely, $-G^1(u_P^*)(1 - s_P^*)s_F^* v$. It is exactly offset by the first term in $dU/d\theta$. Therefore, $dU/d\theta > 0$ at $\theta = 0$. *Q.E.D.*

B Multiple Applications with Correlated Payoffs

This appendix introduces payoff externality into the multiple-application setting in section 5. Assume symmetric payoffs. When there is one application, the payoff is $\pi > 0$. If two applications are developed and put into use, then each generates a payoff $\gamma\pi$, where $\gamma \geq 0$. When $\gamma > 1$ ($\gamma < 1$), the two applications are complements (substitutes), for one's appearance raises (reduces, respectively) the value of the other. Payoff externality introduces another use of patent rights: the pioneer can grant a license and grab the full joint surplus $2\gamma\pi$, or block the use of the follower's application, with a payoff π.[29] Let $b = \max\{2\gamma, 1\} \geq 1$. The pioneer grants a license when $b = 2\gamma$, but blocks the follower's application when $b = 1$.

Payoff externality only changes the follower's search probability when observing the pioneer's application, which is now $\hat{s}_F^+ = G_F((1-\theta)\delta^+\gamma v_F)$. In the other event, his search probability is still $\hat{s}_F^- = G_F((1-\theta)\hat{\delta}^- v_F)$. The pioneer's payoff from not searching is still $\alpha_F \hat{s}_F^- \theta\pi$, and the payoff from incurring c_P to search is now

$$\begin{aligned} & - c_P + \alpha_P \left\{\alpha_F\delta^+\hat{s}_F^+[\theta b\pi + (1-\theta)\gamma\pi] + (1-\alpha_F\delta^+\hat{s}_F^+)\pi\right\} + (1-\alpha_P)\alpha_F\delta^-\hat{s}_F^-\theta\pi \\ = & - c_P + v_P + \rho v_F\left\{\theta[\hat{s}_F^+(b-\gamma) - \hat{s}_F^-] - (1-\gamma)\hat{s}_F^+\right\} + \hat{s}_F^-\theta v_F. \end{aligned} \tag{43}$$

[29] The pioneer also obtains π if she allows the follower's application to be used, and at the same time shuts down her own application. Although the pioneer always offers a license in this case, the final market outcome is the same, namely, only one application is put in use. I ignore this scenario.

When both players develop the applications, patent protection improves the pioneer's payoff by $(b-\gamma)\pi$. The pioneer searches when

$$c_P \leq v_P + \rho v_F \left\{\theta[\hat{s}_F^+(b-\gamma) - \hat{s}_F^-] - (1-\gamma)\hat{s}_F^+\right\}, \tag{44}$$

which determines the search probability $\hat{s}_P$. Payoff externality exerts a directly effect on the pioneer's search incentive, with a magnitude proportional to the follower's search probability $\hat{s}_F^+$. Under payoff complementarity ($\gamma > 1$), a higher probability that the follower will search and come up with an application raises the pioneer's incentive to do so; the reverse is true for payoff substitutability ($\gamma < 1$).

Absent information spill-over ($\rho = 1/2$), the effect of patent protection on the pioneer crucially depends on the type of payoff externality. When $\gamma > 1$, $\hat{s}_F^+ > \hat{s}_F^-$, and $\hat{s}_F^+(b-\gamma) = \gamma\hat{s}_F^+ > \hat{s}_F^-$, setting $\theta > 0$ increases the pioneer's search incentive relative to $\theta = 0$. The reverse is true for $\gamma < 1$, whether $b = 2\gamma$ or 1.

Adding payoff externality to information spill-over distorts the pioneer's search decision in two ways: the impact of $\hat{s}_F^+$ has to be weighted by $b - \gamma \gtrless 1$, and the relative size of $\hat{s}_F^+$ and $\hat{s}_F^-$ now also depends on γ. The two forces go in the same direction when $\gamma > 1$ and $\rho > 1/2$, or when $\gamma < 1$ and $\rho \in (0, 1/2)$. In the former case, $\delta^+ \cdot \gamma > \hat{\delta}^-$ for all $\hat{s}_P$, and so $(b-\gamma)\hat{s}_F^+ = \gamma\hat{s}_F^+ > \hat{s}_F^-$. The basic patent raises the pioneer's search incentives, and reduces the follower's search incentives $\hat{s}_F^+$ and $\hat{s}_F^-$. In the latter case, $\delta^+ \cdot \gamma < \hat{\delta^-}$ for all $\hat{s}_P$, and so $(b-\gamma)\hat{s}_F^+ < \hat{s}_F^+ < \hat{s}_F^-$. The basic patent reduces both players' search incentives (recall that by $\rho < 1/2$, $\hat{s}_F^-$ is increasing in $\hat{s}_P$).

The two forces go in opposite directions in the remaining cases, with $\gamma \cdot \delta^+ \gtrless \hat{\delta}^-$. Consider only extreme cases where payoff externality dominates. When $\rho \in (0, 1/2)$, let $\gamma > \alpha_P/[\rho \cdot (1-\alpha_P)]$, such that $\gamma \cdot \delta^+ > \hat{\delta}^-$. Patent protection $\theta > 0$ raises $\hat{s}_P$ and reduces both $\hat{s}_F^+$ and $\hat{s}_F^-$. When $\rho > 1/2$, let $\gamma < [(1-\rho)\alpha_P]/\rho$, such that $\gamma \cdot \delta^+ < \hat{\delta}^-$. Patent protection $\theta > 0$ reduces $\hat{s}_P$ and $\hat{s}_F^+$, but, via $\hat{\delta}^-$, there is a positive effect that works against direct negative effect on $\hat{s}_F^-$. Note that the previous analysis in section 2 is equivalent to the case of $\rho = 1$ and $\gamma = 0$.

Perfectly negative correlation still causes the pioneer's search decision $\hat{s}_P = G_P(v_P)$ for all θ and γ. Payoff externality ($\gamma \neq 1$) matters only when two applications could both be developed, and so is irrelevant due to mutual exclusivity. ■

C Two-stage Race and Disclosure of Basic Invention

The fixed sequence of moves in the main analysis can be seen as a reduced form of a two-stage Poisson race. This appendix sketches such a model. The idea is to introduce exogenous delay in the disclosure process, so that a follower has to account for the time lapses between when he learns the basic invention and when the pioneer actually made the discovery.

Time runs continuously from zero to infinity. Two inventors, A (she) and B (he), face a two-stage Poisson race from the beginning. The hazard rate at each stage is the same for both inventors, and the arrival dates are independently distributed. Previous innovation decision corresponds to the decision of entering a stage at a fixed, once-and-for-all (but *ex ante* random) cost. The basic invention (the first-stage invention) has a strictly positive hazard rate, but no stand-alone value. The application (the second-stage invention) delivers a benefit $\pi > 0$, but has a strictly positive hazard rate $\lambda > 0$ only with probability α. Let $r \geq 0$ be the common interest rate.[30]

An inventor decides whether to enter the second stage after learning the basic invention, either by own discovery or through disclosure by the other inventor. After discovering the basic invention, an inventor may disclose it via academic publication or patent application. For simplicity, I consider the two routes separately. Both processes involve delay from submission to publication: in most jurisdictions, most patent applications are published 18 months after filing; and the referring process of academic journals may require a non-negligible amount of time.[31]

These delays lead to sequential search at the second stage. Suppose that, say, only A enters the first stage. Inventor B needs the knowledge input from A to enter the second stage, and his decision is made with the information that A may have already started the race. Shadow effect ensues.[32] On the other hand, when both inventors enter the first stage, simultaneous discovery is precluded in Poisson race. Disclosure by

[30] Bag and Dasgupta (1995) considers inventors' disclosure decision in a two-stage Poisson race with shadow effect, but does not include patent policy or reputation concerns. Note that the assumption of common hazard rates is not crucial here. Shadow effect, or, more generally, information spill-over exists as long as the two inventors' hazard rates are correlated.

[31] In the case of online publishing, e.g., working papers, the delay may refer to the (random) amount of time from the point the work is uploaded to the point it is searched and read by other researches.

[32] If A is allowed to delay her second-stage decision, it only complicates the Bayesian updating formula, but does not change the qualitative result.

one inventor also reveals to the other some information about the sequence of actions, i.e., who had moved to the second stage. If an inventor adopts only pure strategy, namely, the time from discovery of basic invention to submission for publication is deterministic, then the opponent, when learning the basic invention from the publication, can perfectly figure out how much time has lapsed since the first inventor's second-stage decision. Through Bayesian updating again comes shadow effect.

The rest of the section uses a simple case to show how reputation concerns and patent reward, respectively, induces the equilibrium behavior of immediate submission. Assume that the actions of submitting for publication and incurring cost to enter the race are not observable to one's opponent. Only the first submission is published and only the first submitter receives the (patent or reputation) reward.[33] The winner of the disclosure game does not know whether there is a second submission, i.e., whether there is independent (but later) discovery of the basic invention. Either the second submitter (if any) withdraws the patent application after knowing the same invention has been patented, or the journal editor rejects identical result that has already been published. To simplify the analysis, consider fixed capacity at the second stage, i.e., both inventors have a two-point cost distribution at the second stage, $c_i^2 \in \{0, \pi + \varepsilon\}$, where $\varepsilon > 0$ and $\Pr(c_i^2 = 0) = s_i$, $i \in \{A, B\}$. An inventor enters the second stage if and only if the cost is zero.

Assume that inventor B adopts the strategy of immediate submission after discovering the basic invention. I derive the conditions under which A will not postpone submission when B is not in the first-stage race. Competition for the first-stage prize reduces the incentive to postpone submission. The same conditions therefore ensure immediate submission when B also enters the first stage. The proof of Proposition 8 confirms this point.

First, consider a reputation reward $R > 0$ to the first inventor that publishes the basic invention on a journal.[34] Let $\triangle_R > 0$ be the delay in the academic publication. Suppose that inventor A discovers the basic invention at time t and B does not enter the first stage. If inventor A submits at time $t + d$, with $d \geq 0$, then inventor B enters the second stage at time $t + d + \triangle_R$ with probability s_B. If inventor A decides to stay off the second stage, her expected payoff is $R \cdot e^{-r(d+\triangle_R)}$ at the value of time-t; she has no incentive to hold off. If inventor A enters the second stage, her expected payoff (at

[33] The first-to-file system is almost universally adopted, and the U.S. will join the ranks in 2013.

[34] See Merton (1973) for a discussion of priority as rewards in doing science.

the time-t value) is

$$
\begin{aligned}
&Re^{-r(d+\triangle_R)} + \int_0^{d+\triangle_R} \lambda\alpha\pi e^{-(\lambda+r)t}dt + s_B \int_{d+\triangle_R}^{\infty} \lambda\alpha\pi e^{-(2\lambda+r)t}dt \\
&+ (1-s_B)\int_{d+\triangle_R}^{\infty} \lambda\alpha\pi e^{-(\lambda+r)t}dt \\
=&R\cdot e^{-r(d+\triangle_R)} + \lambda v\left\{\eta_1(0) + s_B[\eta_2(d+\triangle_R) - \eta_1(d+\triangle_R)]\right\},
\end{aligned}
\tag{45}
$$

where $v \equiv \alpha\pi$, $\eta_1(T) = \int_T^{\infty} e^{-(\lambda+r)t}dt$, and $\eta_2(T) = \int_T^{\infty} e^{-(2\lambda+r)t}dt$. A marginal increase in d changes the payoff by

$$
-e^{-r(d+\triangle_R)}\left[rR + s_B\lambda v\left(e^{-2\lambda(d+\triangle_R)} - e^{-\lambda(d+\triangle_R)}\right)\right], \tag{46}
$$

which is strictly negative for all $d \geq 0$ if $rR > s_B\lambda v e^{-\lambda\triangle_R}$.

Next, let's set $R = 0$ and consider how patent policy $\theta > 0$ induces immediate submission. Let $\triangle_\theta > 0$ be the delay in patent application. When B does not enter the first stage, inventor A's payoff from entering the second stage (at time t) and filing patent protection at time $t+d$ is

$$
\lambda v\left\{\eta_1(0) + s_B[(1+\theta)\eta_2(d+\triangle_\theta) - \eta_1(d+\triangle_\theta)]\right\}. \tag{47}
$$

The first-order condition to determine the optimal d has the same sign as

$$
-(1+\theta)e^{-(2\lambda+r)(d+\triangle_\theta)} + e^{-(\lambda+r)(d+\triangle_\theta)}, \tag{48}
$$

and the second-order condition has the same sign as

$$
(2\lambda+r)(1+\theta)e^{-(2\lambda+r)(d+\triangle_\theta)} - (\lambda+r)e^{-(\lambda+r)(d+\triangle_\theta)}. \tag{49}
$$

If the first-order condition becomes zero, by $\lambda > 0$ the second-order condition must be strictly positive. The optimal d must be a corner solution, namely, either zero or infinity. For $d = 0$ to be the (unique) solution, we must have $(1+\theta)\eta_2(\triangle_\theta) > \eta_1(\triangle_\theta)$, or, equivalently,

$$
(1+\theta)\frac{\lambda+r}{2\lambda+r} > e^{(\lambda+r)\triangle_\theta}, \tag{50}
$$

which requires a sufficiently large θ, and a sufficiently *small* $\triangle_\theta$. This condition also ensures that inventor A will indeed enter the second race. Her expected payoff from staying off the race and collecting licensing payment from inventor B is $\lambda v s_B\theta\eta_1(\triangle_\theta)$, strictly smaller than the payoff from participating.

Proposition 8. When $rR > s_i \lambda v e^{-\lambda \triangle_R}$, $i \in \{A, B\}$, the reputation reward R induces immediate submission for publication.

When condition (50) holds, the patent reward θ induces immediate submission.

Proof. Suppose that A discovers the basic invention at time t, and there is no publication yet. When B also participates in the first stage, immediate submission by A does not guarantee her the reward. Delay in publication creates a window $[t - \triangle_i, t)$, $j \in \{R, \theta\}$, during which B's submission won't be observed at time t. But if A further postpones and submits at time $t + d$, she will lose when B submits during $[t, t + d)$. Postponing delivers no benefit to an inventor that stays off the second stage. Suppose that A enters the second stage. Since a follower enters when the cost is zero, we can ignore the event where B's discovery time lies between $t - \triangle_j$ and t, $i \in \{R, \theta\}$.[35] Let $f(\tau)$ and $F(\tau)$ be the pdf and CDF of inventor B's first-stage arrival time τ. By the memoryless property, there are the same as conditional distributions that B has not discovered the basic invention at time t.

In the case of reputation reward, inventor A's payoff of submitting at time $t + d$ is

$$\begin{aligned}
&\lambda v \int_t^{t+d} [\eta_1(0) + s_B(\eta_2(\tau - t) - \eta_1(\tau - t))] f d\tau \\
&+ \int_{t+d}^{t+d+\triangle_R} \left\{ R e^{-r(d+\triangle_R)} + \lambda v [\eta_1(0) + s_B(\eta_2(\tau - t) - \eta_1(\tau - t))] \right\} f d\tau \\
&+ \int_{t+d+\triangle_R}^{\infty} \left\{ R e^{-r(d+\triangle_R)} + \lambda v [\eta_1(0) + s_B(\eta_2(d + \triangle_R) - \eta_1(d + \triangle_R))] \right\} f d\tau.
\end{aligned} \tag{51}$$

The first-order condition to determine the optimal d is

$$\begin{aligned}
&- f(d + \triangle_R) R e^{-r(d+\triangle_R)} - [F(t + d + \triangle_R) - F(t + d)] r R e^{-r(d+\triangle_R)} \\
&- [1 - F(t + d + \triangle_R)] e^{-r(d+\triangle_R)} \left\{ rR + s_B \lambda v \left[e^{-2\lambda(d+\triangle_R)} - e^{-\lambda(d+\triangle_R)} \right] \right\}.
\end{aligned} \tag{52}$$

The condition $rR > s_B \lambda v e^{-\lambda \triangle_R}$ also guarantees that A will not postpone.

In the case of patent reward, inventor A's payoff is λv times

$$\begin{aligned}
&\int_t^{t+d} (1 - \theta) \{\eta_1(0) + s_B[\eta_2(\tau - t) - \eta_1(\tau - t)]\} f d\tau \\
&+ \int_{t+d}^{t+d+\triangle_\theta} \{\eta_1(0) + s_B[(1 + \theta)\eta_2(\tau - t) - \eta_1(\tau - t)]\} f d\tau \\
&+ \int_{t+d+\triangle_\theta}^{\infty} \{\eta_1(0) + s_B[(1 + \theta)\eta_2(d + \triangle_\theta) - \eta_1(d + \triangle_\theta)]\} f d\tau.
\end{aligned} \tag{53}$$

[35] With more general cost distribution, shadow effect will affect inventor A's entry decision for this range, namely, A has to consider the event where she becomes the follower.

The first-order condition contains two parts:

$$\begin{aligned} &- \theta f(t+d)\left\{\eta_1(0) + s_B[2\eta_2(d) - \eta_1(d)]\right\} \\ &- [1 - F(t+d+\triangle_\theta)]s_B[(1+\theta)e^{-(2\lambda+r)(d+\triangle_\theta)} - e^{-(\lambda+r)(d+\triangle_\theta)}]. \end{aligned} \tag{54}$$

The second part reflects the same concern as in the case where inventor B learns from A's disclosure, but now it only occurs with a probably, when B's first-stage arrival time is later than $t + d + \triangle_\theta$. The first part reflects the effect of losing the patent rights to B, which is always negative for $\eta_1(d) \le \eta_1(0)$ for all $d \ge 0$. Again, competition provides stronger incentive of earlier disclosure. *Q.E.D.*

Notice the opposite requirements on $\triangle_R$ and $\triangle_\theta$ to induce immediate submission. The reputation reward aims to compensate for A's loss of giving away the basic invention and a lower winning probability at the second stage due to B's participation. A longer delay in publication (higher $\triangle_R$) partially offsets the damage of disclosure, and makes the condition more likely to hold. By contrast, the patent reward mitigates A's loss by transferring part of B's return to A. Inventor A's decision is either to hold off submission indefinitely (in order to keep the monopoly status at the second stage), or to facilitate entry of B and extract licensing payment. A lower $\triangle_\theta$ induces earlier entry and makes the stake in B more valuable, and thus reduces the amount of patent reward necessary for immediate submission. ■

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