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Pre-grant patent publication and cumulative innovation[☆]

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ABSTRACT

We examine the implications of pre-grant publication (PP) of patent applications in the context of a cumulative innovation model. We show that PP leads to fewer applications and fewer inventions, but it may raise the probability that new technologies will reach the product market and thereby enhances consumer surplus and possibly total welfare as well.

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1. Introduction

The two main objectives of patent systems are to encourage investments in R&D by granting inventors a temporary monopoly over the use of their inventions and to facilitate the dissemination of R&D knowledge. One aspect of patent systems that reflects the desire to balance these conflicting objectives is the requirement to publicly disclose pre-grant patent applications after 18 months from the date of application. This requirement, which is in place in practically every industrialized country (see Ragusa, 1992), implies that inventors may face the risk that their knowledge will be made public even if eventually their patent applications are rejected. Not surprisingly, opponents of this requirement argue that this risk may discourage innovations, especially by small independent inventors who lack the means to vigorously protect their intellectual property. A notable exception to the 18 months rule is the current U.S. patent system which allows applicants to keep their patent applications confidential until an actual patent is issued, provided that they do not seek patent protection in another country in which the 18 months rule applies.[1]

In this paper we examine the implications of pre-grant publication of patent applications in the context of a cumulative innovation model. In this model, two firms engage in an R&D process aimed at developing a new commercial technology. Our analysis begins when one of the two firms has managed to accumulate enough interim R&D knowledge to file for a patent.[2] We then examine what are the effects of pre-grant patent publication (PP) on the incentives of the leading firm to apply for a patent on its interim R&D knowledge, and on the R&D investments of the two firms which determine their likelihood to successfully develop the new commercial technology.

In principle, pre-grant patent publication (PP) may have two main effects: first, it creates a technical spillover because the lagging firm gets access to the leading firm's interim R&D knowledge when the

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[1] The Patent Reform Act of 2007 (H.R. 1908 and S.1145 of the 110th Congress) proposes to eliminate the exemption. Until the passage of the American Inventors Protection Act (AIPA) in 1999, all patent applications in the U.S. were kept confidential until a patent was actually granted. Since 1999, approximately 10% of all applicants opt-out of publication (FTC, 2005, p. 11).

[2] For instance, in the context of biotechnology, the interim R&D knowledge could represent a research tool like a cell line, chemical reagent, or antibody which is used in research but need not have an independent commercial value.

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Fig. 1. The sequence of events.

patent application is made public even if the application is eventually rejected. Second, PP may credibly reveal to the lagging firm that the leading firm is indeed leading and may also affect its beliefs about the extent of this lead. In this paper we focus on the first, technological spillover, effect of PP. This effect figures prominently in the public debate in the U.S. about PP.

We show that the implications of PP depend on the strength of patent protection, which depends in our model on two factors: (i) the likelihood that the patent office will grant the leading firm a patent on its interim R&D knowledge, and (ii) the likelihood that the patent will be upheld in court. PP matters however only if patent protection is strong or intermediate because under weak protection, the leading firm does not file for a patent even when patent applications are kept confidential. On the other hand, when patent protection is strong, the leading firm files for a patent even when a PP is in place. But since PP creates a technological spillover, it induces the leading firm to cut its R&D investment while inducing the lagging firm to invest more. When the cost of R&D is quadratic, PP raises the overall likelihood that the new technology will reach the product market, and hence it benefits consumers. If in addition the marginal cost of R&D is sufficiently large, then PP also raises social welfare (measured as the sum of the expected consumers' surplus and expected profits). On the other hand, PP hurts the leading firm and hence, weakens its incentives to accumulate interim R&D knowledge in the first place.

Things are more subtle when patent protection is intermediate. Now the leading firm files for a patent when patent applications are confidential but not when they are made public. Moreover, the effect of PP on the R&D investments depends on the likelihood that patents will be upheld in court: when this likelihood is large, PP induces the leading firm to cut its R&D investment while inducing the lagging firm to invest more. When the likelihood that patents will be upheld in court is small, PP has an ambiguous effect on the R&D investments. Nonetheless, when the cost of R&D is quadratic, PP still benefits consumers regardless of the likelihood that patents will be upheld in court. And, when the marginal cost of R&D is sufficiently large, PP enhances social welfare if patents are likely to be upheld in court, but it decreases social welfare otherwise.

The economic literature has already studied various aspects of patent laws, including the optimal length and breadth of patents (e.g., Nordhaus, 1969; Gilbert and Shapiro, 1990; Klemperer, 1990; Gallini, 1992; Chang, 1995; Green and Scotchmer, 1995; Matutes et al., 1996; O'Donoghue et al., 1998), priority rules such as "first to file" versus "first to invent" (e.g., Scotchmer and Green, 1990), novelty requirements (e.g., Scotchmer, 1996; Eswaran and Gallini, 1996; O'Donoghue, 1998), the optimal renewal of patents (Cornelli and Schankerman, 1999), and the optimal length of protection given to the first firm to discover interim R&D knowledge (Bloch and Markowitz, 1996). However, pre-grant patent publication has received very little attention in the economic literature. Given the continuing debate in the U.S. about the 18 months rule, it seems that a formal economic analysis of this issue is badly needed.

We are aware of only two papers that examine the implication of PP. Aoki and Prusa (1996) assume that PP reveals information about the quality choice of the first filer. They show that this information allows firms to coordinate their R&D investments and achieve a more collusive outcome. Unlike the current paper though, the decision to patent is not endogenous, filing for a patent does not create a technological spillover, and patenting does not allow the first filer to exclude its rival from the product market. Johnson and Popp (2003) examine citation analysis on all U.S. domestic patents from 1976 to 1996 and find that more "significant" patents (those that are subsequently cited more often) tend to take longer through the application process and hence are more likely to be affected by PP. Moreover, their analysis suggests that earlier disclosure should lead to faster diffusion of R&D knowledge. While faster diffusion benefits future inventors, it hurts the filing inventors and may therefore make them more reluctant to file for patents.

The rest of the paper is organized as follows: in Section 2 we describe the model and in Sections 3 and 4 we study the equilibrium under the PP and CF systems. In Section 5 we compare the two filing systems in terms of the equilibrium patenting and investment behavior of the two firms and use the results to examine the implications of PP for consumers' surplus and social welfare. We then consider the possibility that the two firms will engage in licensing in Section 6, and in Section 7 we examine the implications of PP for the firms' incentives to accumulate interim R&D knowledge. We conclude in Section 8. All proofs are in the Appendix A.

2. The model

Two firms engage in an R&D process aimed at developing a new commercial technology. Suppose that the R&D process has reached a critical point where one of the two firms, firm 1, has accumulated enough interim knowledge to apply for a patent. This knowledge represents, say, a research tool or some basic technology which lowers the cost of R&D in the rest of the R&D process. Although the patent (if granted) covers only the interim knowledge of firm 1, it nonetheless allows it to sue firm 2 for patent infringement if firm 2 eventually manages to develop the new technology. In most of the paper, we shall assume that when firm 1 holds a patent, it always sues firm 2 when the latter develops the new technology; this assumption can be justified on the grounds that firm 1 wishes to develop reputation for vigorously protecting its intellectual property. In Section 6 we shall relax this assumption and consider ex post licensing which takes place when firm 1 fails to develop the new technology while firm 2 succeeds.[3] The cost of applying for a patent is that some of firm 1's interim knowledge is spilled over to firm 2 either through the patent application (if it is made public), or through an actual patent (if and when it is granted).[4]

Given firm 1's patenting decision, but before the patent office makes a decision, the two firms decide how much to invest in the rest of the R&D process. The investment of each firm determines its eventual probability of success. We assume that the outcome of the R&D process is binary: each firm either succeeds to develop the new technology or it fails and develops nothing. Once the R&D process ends, the two firms compete in the product market. The sequence of events is summarized in Fig. 1.

[3] Another possibility is that firm 1 will license its interim R&D knowledge to firm 2 ex ante, before the outcome of the R&D process is decided. For analysis of this kind of licensing, see Spiegel (2008).

[4] This tradeoff is reminiscent of the tradeoff in Horstman et al. (1985), although the technological spillover in their model arises because patenting reveals to the lagging firm how profitable it would be to imitate the leading firm. For a related tradeoff, see Erkal (2005).

2.1. The filing system

We consider two filing systems: under a pre-grant patent publication system (PP system), the contents of patent applications are automatically published after a certain period of time from the application date (typically 18 months). Under a confidential filing system (CF system), patent applications are kept confidential until a patent is granted; if an application is rejected, then no information is revealed.

In practice, patent protection is imperfect both because patent applications are sometimes rejected by the patent office if they are not deemed sufficiently novel, useful, or non-obvious, and because actual patents are not always upheld in court.[5] We capture these imperfections by assuming that firm 1's patent application is approved with probability $\theta \in [0, 1]$, and if firm 1 sues firm 2 for patent infringement, then it wins in court with probability $\gamma \in [0, 1]$.[6] Throughout we treat θ and γ as exogenous parameters.[7]

2.2. The cost of R&D

Given firm 1's filing decision, but before the patent office decides whether to grant firm 1 a patent, firms 1 and 2 simultaneously choose how much to invest in the rest of the R&D process.[8] For analytical convenience, we shall assume that the two firms directly choose their probabilities of success, q^1 and q^2, and these choices determine their respective R&D cost functions, which are given by $C(q^1)$ and $\beta C(q^2)$, where $\beta > 1$ because firm 2 does not have full access to firm 1's interim knowledge. We assume that $C(\cdot)$ is twice continuously differentiable, increasing, and strictly convex, with $C'(0) = 0$.[9] The value of β depends on the degree of technological spillover which in turn depends on whether firm 1 applies for a patent and on which filing system is in place. We assume that the value of β is lowest and equals β_L if firm 1 applies for a patent and a PP system is in place; in that case, firm 2 gets access to firm 1's interim knowledge through firm 1's patent application. The value of β is intermediate and equals β_M if a patent is granted and a CF system is in place; firm 2 then gets access to firm 1's only through the patent itself. Finally, the value of β is largest and equals β_H if either firm 1 does not apply for a patent, or if it does but its patent application is rejected and a CF system is in place. In both cases, there is no technological spillover.[10]

We assume that the fact that firm 1's cost of R&D is lower is common knowledge. As mentioned in the Introduction, without this assumption, PP would not only create a technological spillover, but would also reveal to firm 2 that firm 1's cost is $C(q)$ and not higher. This will affect firm 1's incentive to file for a patent under the PP system. In the current paper, however, we wish to focus on the technological spillover effect and hence eliminate the effect of PP on firm 2's beliefs by adopting the common knowledge assumption.[11]

2.3. Competition in the product market

Once the R&D process ends, the two firms compete in the product market. Instead of assuming a specific type of product market competition, we simply assume that if only one firm succeeds to develop the new technology (this firm can be either firm 1 or 2), then the net present value of its profits is π_{yn} and the net present value of its rival's profits is π_{ny}. If both firms succeed to develop the new technology, then the net present value of their profits is π_{yy}, and if neither firm succeeds, the net present value of their profits is π_{nn}.[12] Throughout, we make the following assumptions:

A1. $\pi_{yn} > \pi_{yy} \ge \pi_{nn} \ge \pi_{ny}$.

A2. $C'(1) > \max\{\pi_{yn} - \pi_{nn}, \pi_{yy} - \pi_{ny}\}$, and $C''(q) > \Pi$, where $\Pi \equiv \pi_{yn} + \pi_{ny} - \pi_{yy} - \pi_{nn}$ for all $q \in [0, 1]$.

Assumption A1 holds whenever the products of firms 1 and 2 are substitutes. Assumption A2 ensures that the best-response functions of firms 1 and 2 are well behaved. Moreover, the first part of Assumption A2 ensures that it is too costly to invest up to the point where developing the new technology becomes a sure thing, irrespective of whether the rival firm does or does not develop the new technology.

3. The pre-grant patent publication (PP) system

When firm 1 files for a patent under the PP system, it can prevent firm 2 from bringing the new technology to the product market (if firm 2 develops it) with probability $\gamma\theta$, which is the probability that a patent is granted and is upheld in court. Hence, $\gamma\theta$ reflects the effective patent protection that firm 1 enjoys. Recalling that the success probabilities of firms 1 and 2 are q^1 and q^2, the expected payoffs of the two firms are

$$\pi^1\left(q^1, q^2 | F\right) = q^1\left[q^2(1-\gamma\theta)\pi_{yy} + \left(1 - q^2(1-\gamma\theta)\right)\pi_{yn}\right] + \left(1-q^1\right)\left[q^2(1-\gamma\theta)\pi_{ny} + \left(1 - q^2(1-\gamma\theta)\right)\pi_{nn}\right] - C\left(q^1\right). \quad (1)$$

and

$$\pi^2\left(q^1, q^2 | F\right) = q^1\left[q^2(1-\gamma\theta)\pi_{yy} + \left(1 - q^2(1-\gamma\theta)\right)\pi_{ny}\right] + \left(1-q^1\right)\left[q^2(1-\gamma\theta)\pi_{yn} + \left(1 - q^2(1-\gamma\theta)\right)\pi_{nn}\right] - \beta_L C\left(q^2\right). \quad (2)$$

The first bracketed term in Eq. (1) is firm 1's payoff when it succeeds to develop the new technology. With probability $q^2(1-\gamma\theta)$, firm 2 also succeeds and is free to use the new technology in the

[5] In 2003, the grant rates were 59.9% at the EPO, 49.9% at the JPO, and 64% at the USPTO (USPTO, 2004, Table 4). Allison and Lemley (1998) find that out of the 300 final patent validity decisions by U.S. courts during the period 1989–1996, only 162 patents (54%) were held valid. In Japan, the original patent was upheld in only 23 out of the 51 patent infringement suits studied between April 2000 and January 2003 (45.1%) (Material prepared for 4th meeting of Subcommittee on Intellectual Property Disputes, Committee for Legal System Reform Headquarters for Promotion of Judicial Reform, Prime Minister's Office (January 31, 2003)).

[6] The assumption that patent protection is imperfect has also been made elsewhere. Meurer (1989), Anton and Yao (2003, 2004), and Choi (1998) assume that patents can be challenged in court and may be ruled as invalid, but the possibility that patent applications may be rejected plays no role in these papers. Kabla (1996) assumes that patent applications may be rejected, but does not consider the possibility that patents may not be upheld in court. Waterson (1990) and Crampes and Langinier (2002) assume that suing for patent infringement is costly so patentholders do not always sue imitators. Finally, Crampes and Langinier (1998) show that under certain conditions, firms may choose not to renew their patents in order to conceal favorable market information from potential entrants.

[7] According to the enablement doctrine of patent law, "claims ought to be bounded to a significant degree by what the disclosure enables, over and beyond prior art" (Merges and Nelson, 1994, p.10). Thus, in a more general model where firm 1 can choose the scope of its disclosure, the likelihood that a court will uphold firm 1's patent would be an endogenous variable.

[8] This timing reflects the fact that patent examination is typically a lengthy process: pendency time at USPTO was 26.7 months in 2003. Pendency times at EPO and JPO were 37.7 and 31.1 months respectively. (See USPTO, 2004 for details, including definition.)

[9] Given that $C(\cdot)$ is increasing, there is a 1.1 relationship between the probability of success and the cost of achieving it so it is equally possible to assume that the two firms choose how much to spend on R&D and these choices determine their respective probabilities of success.

[10] The assumption that $\beta_H > \beta_M > \beta_L$ is consistent with Mansfield et al. (1981) who estimate that the average ratio between the cost of imitating an existing technology ($\beta_L C(q)$ or $\beta_M C(q)$ in our model) and the cost of innovating it from scratch ($\beta_H C(q)$ in our model) is 0.65.

[11] For papers that study the effect of voluntary disclosure of R&D knowledge on the beliefs of rival firms, see for example Lichtman et al. (2000), Gordon (2004), Jansen (2008), and Gill (2008).

[12] To economize on notation we assume that the product market profits are symmetric: π_{yy}, π_{yn}, π_{ny}, and π_{nn} are the same for both firms. This assumption is not important however and none of our results depends on it.

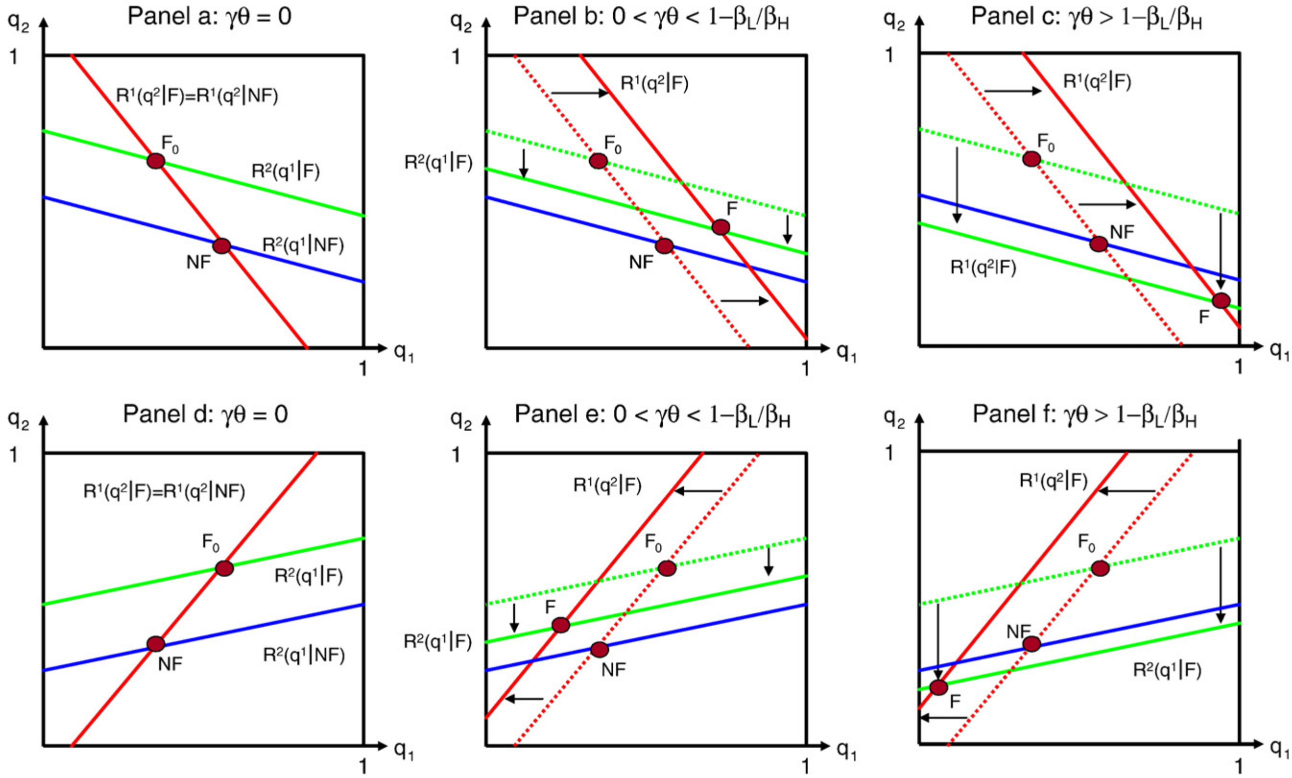

Fig. 2. The Nash equilibrium in the filling and the no-filling subgames and how it changes with increases in $\gamma\theta$.

product market, so firm 1's payoff is π_{yy}; with probability $1-q^2(1-\gamma\theta)$, firm 2 either fails or else it succeeds but it is prevented from using the new technology, so firm 1's payoff is π_{yn}. The second bracketed term in Eq. (1) represents the corresponding expressions when firm 1 fails to develop the new technology. The interpretation of Eq. (2) is similar. Firm 2's cost is $\beta_L C(q^2)$ because firm 2 gets access to firm 1's interim knowledge through firm 1's patent application.

Absent filing, firm 1 cannot prevent firm 2 from using the new technology if firm 2 develops it. Hence, the expected payoffs of the two firms are

$$\pi^1\left(q^1,q^2|NF\right) = q^1\left[q^2\pi_{yy} + \left(1-q^2\right)\pi_{yn}\right] + \left(1-q^1\right)\left[q^2\pi_{ny} + \left(1-q^2\right)\pi_{nn}\right] - C\left(q^1\right), \tag{3}$$

and

$$\pi^2\left(q^1,q^2|NF\right) = q^1\left[q^2\pi_{yy} + \left(1-q^2\right)\pi_{ny}\right] + \left(1-q^1\right)\left[q^2\pi_{yn} + \left(1-q^2\right)\pi_{nn}\right] - \beta_H C\left(q^2\right). \tag{4}$$

These expressions differ from the corresponding expressions in the filing subgame in two ways: first, the probability that firm 2 uses the new technology in the product market is now q^2 instead of $q^2(1-\gamma\theta)$. Second, absent filing, there is no technological spillover, so firm 2's cost of R&D is $\beta_H C(q^2)$ instead of $\beta_L C(q^2)$, where $\beta_H > \beta_L$.

Let $R^1(q^2|F)$ and $R^2(q^1|F)$ be the best-response functions in the filing subgame; these functions are defined implicitly by $\frac{\partial\pi^1(q^1,q^2|F)}{\partial q^1} = 0$ and $\frac{\partial\pi^2(q^1,q^2|F)}{\partial q^2} = 0$. Similarly, the best-response functions in the no-filing subgame, $R^1(q^2|NF)$ and $R^2(q^1|NF)$, are defined implicitly by $\frac{\partial\pi^1(q^1,q^2|NF)}{\partial q^1} = 0$ and $\frac{\partial\pi^2(q^1,q^2|NF)}{\partial q^2} = 0$. Assumptions A1 and A2 ensure that the best-response functions in both subgames are well-defined and single-valued. The best-response functions are downward sloping in the (q^1, q^2) space (q^1 and q^2 are strategic substitutes) if $\Pi \equiv \pi_{yn} + \pi_{ny} - \pi_{yy} - \pi_{nn} > 0$ and are upward sloping (q^1 and q^2 are strategic complements) if $\Pi < 0$. To interpret Π, note that it can be written as $(\pi_{yn}-\pi_{nn})-(\pi_{yy}-\pi_{ny})$, where $\pi_{yn}-\pi_{nn}$ is the extra profits generated by the new technology when the rival fails to develop it, and $\pi_{yy}-\pi_{ny}$ is the corresponding extra profit when the rival succeeds. When $\Pi>0$, having the new technology is more profitable when the rival does not have it and conversely when $\Pi<0$.

The Nash equilibrium in the filing subgame, (q_F^1, q_F^2), is determined by the intersection of $R^1(q^2|F)$ and $R^2(q^1|F)$, while the Nash equilibrium in the no-filing subgame, (q_{NF}^1, q_{NF}^2), is determined by the intersection of $R^1(q^2|NF)$ and $R^2(q^1|NF)$. Assumptions A1 and A2 ensure that (q_F^1, q_F^2) and (q_{NF}^1, q_{NF}^2) are unique and lie inside the unit square (recall that q^1 and q^2 are probabilities and hence must be between 0 and 1).[13]

To see how the effective patent protection, $\gamma\theta$, affects the R&D investments, note that $\frac{\partial^2\pi^1(q^1,q^2|F)}{\partial q^1\partial(\gamma\theta)} = q^2\Pi$ and $\frac{\partial^2\pi^2(q^1,q^2|F)}{\partial q^2\partial(\gamma\theta)} = -[q^1(\pi_{yy}-\pi_{ny}) + (1-q^1)(\pi_{yn}-\pi_{nn})]$. Hence, when $\gamma\theta$ increases, $R^1(q^2|F)$ shifts outward if $\Pi>0$ (q^1 and q^2 are strategic substitutes) and inwards if $\Pi<0$ (q^1 and q^2 are strategic complements); by contrast, Assumption A1 ensures that $R^2(q^1|F)$ always shifts inward. As a result, q_F^1 increases with $\gamma\theta$ if $\Pi>0$ and decreases with $\gamma\theta$ if $\Pi<0$, while q_F^2 always decreases with $\gamma\theta$ irrespective of Π. Intuitively, as $\gamma\theta$ increases, firm 2 is less likely to bring the new technology to the product market and hence its marginal benefit from R&D falls; as a result firm 2 invests less. As for firm 1, note that its marginal benefit from R&D is a weighted average of $\pi_{yn}-\pi_{nn}$ and $\pi_{yy}-\pi_{ny}$. When $\gamma\theta$ increases, firm 1 is more likely to block firm 2 from using the new technology and hence its extra profits is more likely to be $\pi_{yn}-\pi_{nn}$ rather than $\pi_{yy}-\pi_{ny}$. This in turn boosts firm 1's incentive to invest if and only if $\pi_{yn}-\pi_{nn} > \pi_{yy}-\pi_{ny}$, i.e., if and only if $\Pi>0$.

Fig. 2 illustrates the equilibria in the filing and the no-filing subgames and shows how they are affected by $\gamma\theta$.[14] Panels a–c show

[13] The proof appears in a technical appendix which is available at www.tau.ac.il/~spiegel.

[14] For simplicity, we draw the best-response functions as straight lines even though in general this need not be the case. This however does not affect any of our conclusions.

the case where $\Pi>0$ (q^1 and q^2 are strategic substitutes) and Panels d–f show the case where $\Pi<0$ (q^1 and q^2 are strategic complements). Panels a and d show that in the extreme case where $\gamma\theta=0$ (firm 1 gets no patent protection), $R^1(q^2|F)=R^1(q^2|NF)$. On the other hand, given that $\beta_L>\beta_H$, the marginal cost of q^2 is lower in the filing subgame, so $R^2(q^1|F)>R^2(q^1|NF)$. Hence, the equilibrium point in the filing subgame, F_0, lies northwest of the equilibrium point in the no-filing subgame, NF, if $\Pi>0$ and northeast of NF if $\Pi<0$. As $\gamma\theta$ increases, $R^1(q^2|F)$ shifts to the right when $\Pi>0$ and to the left when $\Pi<0$. By contrast, $R^2(q^1|F)$ shifts down irrespective of Π. Panels b and e show that as a result, the equilibrium point in the filing subgame shifts southeast (southwest) from F_0 to F if $\Pi>0$ ($\Pi<0$). Panels c and f show that when $\gamma\theta\geq 1-\beta_L/\beta_H$, $R^2(q^1|F)$ drops below $R^2(q^1|NF)$, so F is attained southeast (southwest) of NF if $\Pi>0$ ($\Pi<0$). Notice that an increase in $\gamma\theta$ always leads to decrease in q_F^2, but leads to an increase in q_F^1 if $\Pi>0$ and a decrease in q_F^1 if $\Pi<0$.

Next let $\pi_F^1\equiv\pi^1(q_F^1, q_F^2|F)$ and $\pi_{NF}^1\equiv\pi^1(q_{NF}^1, q_{NF}^2|NF)$ be the Nash equilibrium payoffs of firm 1 in the filing and in the no-filing subgames, and define π_F^2 and π_{NF}^2 similarly. Then, we can prove the following result (the proof, along with all other proofs, is in the Appendix A):

Proposition 1. *(Firm 1's filing decision under the PP system.) There exists a unique critical value of $\gamma\theta$, denoted $\widehat{\gamma\theta}$, where $\widehat{\gamma\theta}\in(0,(1-\beta_L/\beta_H))$, such that $\pi_F^1 \gtreqless \pi_{NF}^1$ as $\gamma\theta \gtreqless \widehat{\gamma\theta}$.*

Proposition 1 implies that firm 1 files for a patent under the PP system if and only if the effective patent protection, $\gamma\theta$, exceeds a threshold level, $\widehat{\gamma\theta}$. Intuitively, firm 1 does not file for a patent when $\gamma\theta$ is small because then it loses some of its technological advantage, without enjoying much protection against imitation. As $\gamma\theta$ increases, patents receive stronger protection so filing becomes more attractive to firm 1. When $\gamma\theta > \widehat{\gamma\theta}$, firm 1's benefit from raising its chance to block firm 2 from using the new technology exceeds the associated loss of technological advantage and hence firm 1 files for a patent.

Proposition 1 also shows that the threshold $\widehat{\gamma\theta}$ is bounded from above by $1-\beta_L/\beta_H$. This implies that we should expect more patent applications when (i) β_L is high (PP creates a relatively small technological spillover so firm 1 does not lose much by filing for a patent), and (ii) β_H is low (firm 1's interim knowledge gives it only a small advantage over firm 2 and hence firm 1 has little to lose by filing).

4. Confidential filing (CF)

Absent filing, the expected payoffs of the two firms are still given by Eqs. (3) and (4) and hence the Nash equilibrium in the no-filing subgame continues to be (q_{NF}^1, q_{NF}^2). Moreover, firm 1's expected payoff when it files for a patent continues to be given by Eq. (1) because it can still prevent firm 2 from bringing the new technology to the product market with probability $\gamma\theta$, irrespective of whether its patent application is made public. Hence, the best-response function of firm 1 in the filing subgame remains $R^1(q^2|F)$, exactly as in the PP system.

The only difference between the PP and the CF systems is that now, firm 2's expected payoff in the filing subgame is no longer given by Eq. (2); instead it is given by

$$\begin{aligned}\bar{\pi}^2\left(q^1,q^2|F\right) &= q^1\left[q^2(1-\gamma\theta)\pi_{yy}+\left(1-q^2(1-\gamma\theta)\right)\pi_{ny}\right]\\ &\quad+\left(1-q^1\right)\left[q^2(1-\gamma\theta)\pi_{yn}+\left(1-q^2(1-\gamma\theta)\right)\pi_{nn}\right]-\beta_\theta C\left(q^2\right),\end{aligned}\tag{5}$$

where $\beta_\theta\equiv\theta\beta_M+(1-\theta)\beta_H$. This expression differs from Eq. (2) only in firm 2's cost of R&D, which is now higher and given by $\beta_\theta C(q^2)$ instead of $\beta_L C(q^2)$. The reason for this is that under the CF system, there is a technological spillover only when a patent is actually granted. This event occurs with probability θ; with probability $1-\theta$, firm 1's patent application is rejected and there is no spillover.

The best-response function of firm 2 in the filing subgame, $\bar{R}^2(q^1|F)$, is defined implicitly by $\frac{\partial\bar{\pi}^2(q^1,q^2|F)}{\partial q^2}=0$. Assumptions A1 and A2 ensure that it is well defined and single valued. Moreover, it is downward sloping in the (q^1,q^2) space (q^1 and q^2 are strategic substitutes) if $\Pi>0$ and upward sloping (q^1 and q^2 are strategic complements) if $\Pi<0$. A Nash equilibrium in the filing subgame, $(\bar{q}_F^1, \bar{q}_F^2)$, is determined by the intersection of $R^1(q^2|F)$ and $\bar{R}^2(q^1|F)$. Assumptions A1 and A2 ensure that $(\bar{q}_F^1, \bar{q}_F^2)$ is unique and lies inside the unit square.

To examine the effect of patent protection on the R&D investments, note from Eq. (5) that the likelihood that firm 1 gets a patent, θ, affects the filing subgame not only through the effective patent protection, $\gamma\theta$, but also through firm 2's cost of R&D. Hence, unlike the PP system, now γ and θ do not have the exact same effect on the equilibrium. We begin by noting that as θ increases, firm 2 is less likely to use the new technology in the product market, so its marginal benefit from R&D falls. But since firm 2 is also more likely to get access to firm 1's interim knowledge, its marginal cost of R&D falls as well. To examine the net effect, note that

$$\begin{aligned}\frac{\partial^2\bar{\pi}^2\left(q^1,q^2|F\right)}{\partial q^2\partial\theta} &= -\gamma\left[q^1\left(\pi_{yy}-\pi_{ny}\right)+\left(1-q^1\right)\left(\pi_{yn}-\pi_{nn}\right)\right]-(\beta_M-\beta_H)C'\left(q^2\right)\\ &= \frac{\beta_H}{\beta_\theta}\left[q^1\left(\pi_{yy}-\pi_{ny}\right)+\left(1-q^1\right)\left(\pi_{yn}-\pi_{nn}\right)\right]\left[\left(1-\frac{\beta_M}{\beta_H}\right)-\gamma\right],\end{aligned}$$

where the second equality follows by substituting for $C'(q^2)$ from the first order condition, $\frac{\partial\bar{\pi}^2(q^1,q^2|F)}{\partial q^2}=0$ and rearranging terms. Hence, when θ increases, $\bar{R}^2(q^1|F)$ shifts inward if $\gamma>1-\beta_M/\beta_H$ and outward if $\gamma<1-\beta_M/\beta_H$. As for firm 1, note that $\frac{\partial^2\pi^1(q^1,q^2|F)}{\partial q^1\partial\theta}=\gamma q^2\Pi$, so an increase in θ shifts $R^1(q^2|F)$ outward if $\Pi>0$ and inward if $\Pi<0$. Hence, when $\gamma>1-\beta_M/\beta_H$, the situation is similar to the PP case: $\bar{q}_F^1$ increases with θ if $\Pi>0$ and decreases if $\Pi<0$, while $\bar{q}_F^2$ always decreases with θ irrespective of Π. On the other hand, when $\gamma<1-\beta_M/\beta_H$, an increase in θ has an ambiguous effect on the R&D investments.

As for γ, its effect on the R&D investments is similar to the effect of $\gamma\theta$ under the PP system. That is, $\bar{q}_F^1$ increases with γ if $\Pi>0$ and decreases with γ if $\Pi<0$, while $\bar{q}_F^2$ always decreases with γ irrespective of Π. Using $\bar{\pi}_F^1\equiv\pi^1(\bar{q}_F^1, \bar{q}_F^2|F)$ and $\bar{\pi}_F^2\equiv\pi^2(\bar{q}_F^1, \bar{q}_F^2|F)$ to denote the equilibrium payoffs in the filing subgame, and recalling that as in Section 3, the equilibrium payoffs in the no-filing subgame are π_{NF}^1 and π_{NF}^2, we can prove the following result:

Proposition 2. *(Firm 1's filing decision under the CF system.) For each $\theta>0$, there exists a unique critical value of γ, denoted $\hat{\gamma}$, where $\hat{\gamma}\in(0,1-\beta_\theta/\beta_H)/\theta$, such that $\bar{\pi}_F^1 \gtreqless \pi_{NF}^1$ as $\gamma \gtreqless \hat{\gamma}$.*

Proposition 2 implies that given the likelihood of getting a patent, θ, firm 1 files for a patent under the CF system if and only if the likelihood that the patent will be upheld in court exceeds a threshold level, $\hat{\gamma}$, which is bounded from above by $(1-\beta_\theta/\beta_H)/\theta$.

5. The implications of PP for R&D, patenting, and welfare

Having examined the two filing systems in isolation, we now compare them in order to determine the impact of PP on firm 1's propensity to file for a patent on its interim knowledge, on the R&D investments of the two firms, and on consumer surplus and social welfare.

5.1. The effect of PP on patenting behavior and on the R&D investments

As a preliminary step, we begin by comparing the equilibrium R&D investments and expected payoffs under the two filing systems, assuming that firm 1 files for a patent (note however that firm 1 need not have the same propensity to file for a patent under the two systems). We do not need to make a similar comparison when firm 1 does not file for a patent since then PP is irrelevant.

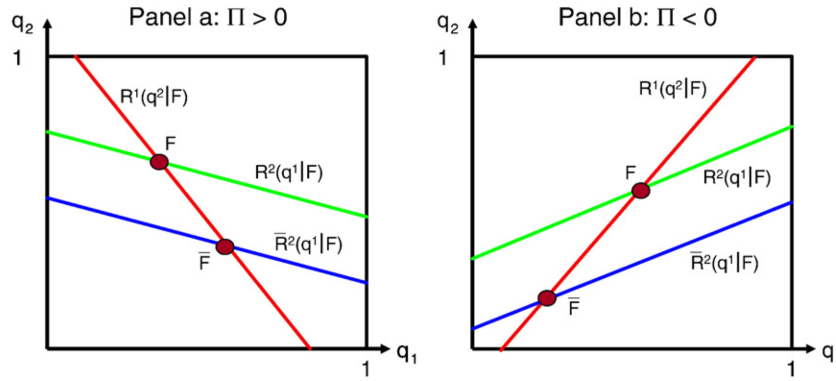

Fig. 3. Comparing the equilibrium in the filling subgame under the PP and the CF systems.

Lemma 1. *(Comparing the equilibrium investment levels and expected payoffs in the filing subgame under the two filing systems.) Suppose that firm 1 files for a patent under both systems. Then,*

(i) $q_F^2 > \bar{q}_{\bar{F}}^2$, $q_F^1 < \bar{q}_{\bar{F}}^1$ *if* $\Pi > 0$, *and* $q_F^1 > \bar{q}_{\bar{F}}^1$ *if* $\Pi < 0$,
(ii) $\pi_F^1 < \bar{\pi}_{\bar{F}}^1$, *and* $\pi_F^2 > \bar{\pi}_{\bar{F}}^2$ *if* $\Pi > 0$.

The intuition behind Lemma 1 is illustrated in Fig. 3. The expected marginal cost of firm 2 is higher under the CF system since then there is a technological spillover only if and when firm 1 gets a patent. Consequently, $\bar{R}^2(q^1|F)$ lies below $R^2(q^1|F)$. Since the best-response function of firm 1, $R^1(q^2|F)$, is the same under the two systems, the equilibrium point under PP, F, is attained northwest of the equilibrium point under CF, $\bar{F}$, if $\Pi > 0$ and northeast of $\bar{F}$ if $\Pi < 0$. Part (ii) of Lemma 1 shows that firm 1 is worse-off filing for a patent under PP; intuitively this is because PP creates a larger technological spillover than CF. Part (ii) of the lemma also shows that whenever $\Pi > 0$, firm 2 is better-off under PP. This is due not only to the larger technological spillover that firm 2 enjoys under PP, but also due to the fact that whenever $\Pi > 0$, firm 1 invests less in R&D and is therefore less likely to bring the new technology to the product market. When $\Pi < 0$, firm 1 invests more under PP so the overall effect of PP on firm 2 is ambiguous.

We are now ready to compare firm 1's propensity to file for a patent under the two systems.

Proposition 3. *(Firm 1's filing decision under the PP and CF filing systems.) Firm 1 does not file for a patent under both filing systems if* $\gamma \leq \hat{\gamma}$, files for a patent under both systems if $\gamma > \widehat{\gamma\theta}/\theta$, and files for a patent only under the CF system if $\hat{\gamma} < \gamma \leq \widehat{\gamma\theta}/\theta$.

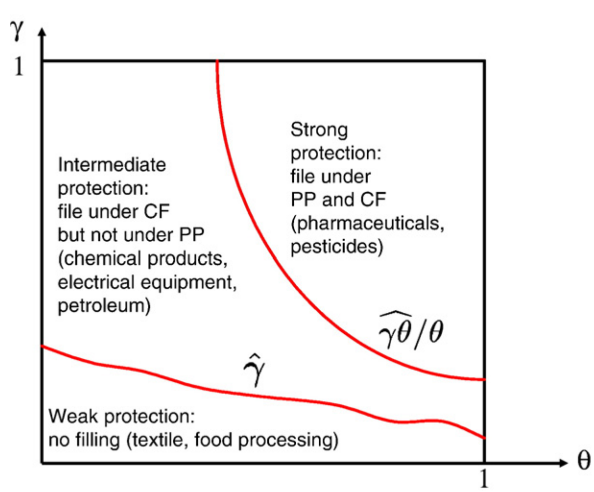

Fig. 4. Firm 1's filling decision under the PP and CF filling systems.

Proposition 3 is illustrated in Fig. 4 in the (θ, γ) space. When $\gamma \leq \hat{\gamma}$, patents receive weak protection since they are relatively hard to defend in court. Consequently, firm 1 does not file for a patent under neither filing system. Examples for industries with weak patent protection include some mature industries like textile, food processing, and fabricated metal products (Arundel and Kabla, 1998; Levin et al., 1987). When $\gamma > \widehat{\gamma\theta}/\theta$ patents receive strong protection since they are likely to be upheld in court; hence, firm 1 files for a patent under both filing systems. Examples for industries where patents are regarded as providing strong protection include pharmaceuticals, organic chemicals, and pesticides (Arundel and Kabla, 1998; Levin et al., 1987; Mansfield, 1986). Finally, when $\hat{\gamma} \leq \gamma \leq \widehat{\gamma\theta}/\theta$, patent protection is intermediate and firm 1 files for a patent only under the CF system. Industries where patents provide an intermediate protection (relative to alternatives such as, secrecy, securing a lead time advantage over rivals, learning curve advantages, and investment in sales or service efforts), include chemical products, relatively uncomplicated mechanical equipment, electrical equipment, and petroleum (Levin et al., 1987; Mansfield, 1986).

Proposition 3 has at least three important implications for PP which are now stated in the following corollaries. First, Proposition 3 implies that there are parameter values for which firm 1 files for a patent under the CF system but not under the PP system. Hence,

Corollary 1. *PP has an adverse effect on the propensity to file for patents.*

Corollary 1 suggests that PP may discourage the dissemination of R&D knowledge, contrary to what many proponents of this system argue.[15] The reason of course is that proponents of PP overlook the fact that PP has an adverse effect on the propensity to file for patents. This adverse effect of PP confirms Gilbert's (1994) intuition that "There is at least a theoretical potential for the publication of applications prior to the patent grants to have adverse incentive effects because of the potential for appropriation of the intellectual property when no patents are ever issued. To avoid appropriation of intellectual property, some investors who otherwise would apply for patents might rely instead on trade secrets protection." Proposition 3 qualifies

[15] For example, in a Congress hearing in February 1997, Rep. Howard Coble (then the chairman of the subcommittee on Courts and Intellectual Property) stated that PP "… will benefit American inventors, innovators, and society at large … by furthering the constitutional incentive to disseminate information regarding new technologies more rapidly …" Similarly, Rep. Sue W. Kelly, argued that "It's also an imperative that we have an 18-month publication of patent applications for all inventors …. How can we say that our businesses do not need to know about technology until actually a patent issues? We cannot in good conscious make such judgments because we neither know which technological inventions may be industry-critical, nor from whom or from what source such inventions will arise. Both statements appear in http://commdocs.house.gov/committees/judiciary/hju40523.000/hju40523_0f.htm.

this argument by suggesting that this adverse effect of PP pertains only to industries in which patent protection is intermediate.

Corollary 2. *When patent protection is strong, PP leads to an increase in* q^2 *and a decrease (increase) in* q^1 *if* $\Pi>0$ ($\Pi<0$). *When patent protection is intermediate and* $\gamma\theta \geq 1-\frac{\beta_\theta}{\beta_H}$, *PP leads to a decrease in* q^2 *and an increase (decrease) in* q^1 *if* $\Pi>0$ ($\Pi<0$). *If* $\gamma\theta < 1-\frac{\beta_\theta}{\beta_H}$, *then PP has an ambiguous effect on* q^1 *and* q^2.

Tepperman (2002) studies the effect of Canada's 1989 Patent Act reform that led to a switch from a confidential filing system with a first-to-invent priority rule to a PP system with a first-to-file priority rule on the behavior of 84 Canadian firms from various industries. He finds that on average, firms have increased their R&D spending following the reform. Corollary 2 shows that on a theoretical ground, PP has an ambiguous effect on investments in R&D. Tepperman also finds that following the reform, firms have increased their patenting intensity. Although this finding is inconsistent with Corollary 1, one should bear in mind that Tepperman examines the combined effect of a switch from CF to PP and from first-to-invent to first-to-file, whereas we only examine the effect of a switch from CF to PP.[16]

Corollary 3. *PP hurts firm 1 when patent protection is strong or intermediate but it may benefit firm 2.*

When patent protection is weak, firm 1 does not file for a patent so PP is irrelevant. When patent protection is strong, firm 1 files for a patent under both systems, but PP hurts it because it leads to a larger technological spillover. PP also hurts firm 1 when patent protection is intermediate, because then firm 1 chooses to file for a patent only under the CF system. Since π^1_{NF} is the same under the PP and CF systems, it follows from revealed preferences that firm 1's choice to file under the CF system means that it must be better-off than under the PP system. Putnam (1997) estimates that PP is associated with a \$479 decrease in the mean value of patents. In our model, firm 1's loss is even larger since Putnam's estimate is conditional on a patent being granted, while we examine the impact of PP on the unconditional expected profit of firm 1.

In the context of our model, it is natural to assume that small inventors will mainly play the role of firm 1, because they often lack the capacity and resources needed to absorb the technological spillovers generated by other firms. Corollary 3 may then explain why the main opposition for adopting a PP system in the U.S. came from small and independent inventors, while the main support for PP came from large corporations.

5.2. The implications of PP for consumer surplus and social welfare

In this section, we study the implications of the technological spillover effect of PP on consumers' surplus and social welfare. Our analysis is done from an ex post point of view since at this point we still have not examined the implications of PP for the incentive of the two firms to accumulate interim R&D knowledge.

Let s_{yy} be the net present value of consumer surplus when both firms develop the new technology, and define s_{yn} and s_{nn} similarly for the cases where only one firm, and when neither firm develop it. The corresponding social welfare is given by the sum of consumer surplus and firms' profits, so $w_{yy}=s_{yy}+2\pi_{yy}$, $w_{yn}=s_{yn}+\pi_{yn}+\pi_{ny}$, and $w_{nn}=s_{nn}+2\pi_{nn}$. Since the comparison between consumer surplus and social welfare under the two filing systems is in general very complex, we shall impose the following assumption:

A3. $C(q)=rq^2/2$, where $r>\Pi$.

[16] Scotchmer and Green (1990) show that firms have stronger incentives to invest in R&D and to file for patents under the first-to-file rule than under the first-to-patent rule. This result can explain Tepperman's findings.

Given Assumption A3, it is straightforward to show that the equilibrium levels of investment in the filing subgame under the PP system are

$$q^1_F=\frac{\left(\pi_{yn}-\pi_{nn}\right)\left(r\beta_L-(1-\gamma\theta)^2\Pi\right)}{r^2\beta_L-(1-\gamma\theta)^2\Pi^2},\quad q^2_F=\frac{\left(\pi_{yn}-\pi_{nn}\right)(1-\gamma\theta)(r-\Pi)}{r^2\beta_L-(1-\gamma\theta)^2\Pi^2}. \tag{6}$$

The corresponding levels of investment under the CF system, $\bar q^1_F$ and $\bar q^2_F$, are similar except that β_θ replaces β_L. In the no-fling subgame, the equilibrium levels of investment, q^1_{NF} and q^2_{NF}, are also given by Eq. (6), with $\theta=0$ and with β_H replacing β_L. By Assumption A3, $r>\Pi$; together with the assumption that $\beta_\theta\geq\beta_L>1\geq1-\gamma\theta$, this ensures that the equilibrium investment levels are all strictly between 0 and 1.

Substituting the equilibrium levels of investment into Eqs. (1) and (5) and recalling from Propositions 1 and 2 that $\widehat{\gamma\theta}$ is implicitly defined by $\pi^1_F=\pi^1_{NF}$ and $\hat\gamma$ is implicitly defined by $\bar\pi^1_F=\pi^1_{NF}$, we can establish the following result:

Lemma 2. Given Assumption A3, patent protection is:

(i) strong if $\gamma\geq\widehat{\gamma\theta}/\theta\equiv\frac{1-\sqrt{\beta_L/\beta_H}}{\theta}$,
(ii) intermediate if $\hat\gamma\equiv\frac{1-\sqrt{\beta_\theta/\beta_H}}{\theta}\leq\gamma<\frac{1-\sqrt{\beta_L/\beta_H}}{\theta}$,
(iii) weak if $\gamma<\frac{1-\sqrt{\beta_\theta/\beta_H}}{\theta}$.

In addition to Assumption A3, we also make the following assumptions:

A4. $s_{yy}\geq s_{yn}\geq s_{nn}$, $s_{yy}-s_{yn}\geq s_{yn}-s_{nn}>\pi_{nn}-\pi_{ny}$.

A5. $w_{yy}\geq w_{yn}\geq w_{nm}$.

Assumption A4 implies that the net present value of consumer surplus is increasing with the number of firms that use the new technology at an increasing rate. It also implies that the welfare gain to consumers when only one firm uses the new technology outweighs the associated loss to the firm that does not use the new technology. Assumption A5 implies that social welfare is increasing with the number of firms that use the new technology. Both assumptions hold in a broad class of oligopoly models; for instance, when the new technology is cost reducing, Assumptions A4 and A5 hold in the Cournot model with homogeneous products and a linear demand and in the Bertrand model with linear cost functions.

5.2.1. Expected consumers' surplus

Holding firm 1's interim R&D knowledge constant across the two filing systems, the ex-post expected consumer surplus under both systems when firm 1 files for a patent is,

$$\begin{aligned}S\left(q^1,q^2|F\right)&=q^1q^2(1-\gamma\theta)s_{yy}+\left(1-q^1\right)\left(1-q^2(1-\gamma\theta)\right)s_{nn}\\&\quad+\left[q^1\left(1-q^2(1-\gamma\theta)\right)+\left(1-q^1\right)q^2(1-\gamma\theta)\right]s_{yn}.\end{aligned} \tag{7}$$

Likewise, the ex-post expected consumer surplus under both systems absent filing is given by,

$$S\left(q^1,q^2|NF\right)=q^1q^2s_{yy}+\left(1-q^1\right)\left(1-q^2\right)s_{nn}+\left[q^1\left(1-q^2\right)+\left(1-q^1\right)q^2\right]s_{yn}. \tag{8}$$

Let $S_F\equiv S(q^1_F,\ q^2_F|F)$ be the equilibrium expected value of consumer surplus under the PP system when there is filing, and define $\bar S_F\equiv S(\bar q^1_F,\bar q^2_F|F)$ similarly for the CF system. When firm 1 does not file for a patent, PP plays no role and the equilibrium expected value of consumer surplus under both filing systems is given by $S_{NF}\equiv S(q^1_{NF},q^2_{NF}|NF)$.

When patent protection is strong, firm 1 files for a patent under both systems. Hence, we need to compare S_F and $\bar{S}_F$. Substituting for q_F^1 and q_F^2 from Eqs. (6) into (7) yields

$$S_F = s_{nn} + \frac{\left(\pi_{yn}-\pi_{nn}\right)^2(1-\gamma\theta)^2(r-\Pi)\left(r\beta_L-(1-\gamma\theta)^2\Pi\right)s}{(r^2\beta_L-(1-\gamma\theta)^2\Pi^2)^2} + \frac{\left(\pi_{yn}-\pi_{nn}\right)\left(r\beta_L+(1-\gamma\theta)^2(r-2\Pi)\right)\left(s_{yn}-s_{nn}\right)}{r^2\beta_L-(1-\gamma\theta)^2\Pi^2}, \tag{9}$$

where $s \equiv s_{yy}+s_{nn}-2s_{yn}>0$ by Assumption A4. The expression for $\bar{S}_F$ is identical, except that β_θ replaces β_L.

In the intermediate protection case, firm 1 files for a patent under the CF system but not under the PP system. Therefore, we need to compare $\bar{S}_F$ and S_{NF}, where S_{NF} is also given by Eq. (9) when it is evaluated at $\gamma\theta=0$ and with β_H replacing β_L.

Proposition 4. *(The effect of PP on consumers.) Suppose that* Assumptions A3 and A4 *hold and patent protection is intermediate or strong, i.e., $\gamma \geq \hat{\gamma}$ (otherwise PP is irrelevant). Then PP enhances consumer surplus. Moreover, when patent protection is intermediate, the increase in consumer surplus due to PP is larger when γ is larger.*

Intuitively, in the strong protection case ($\gamma \geq \frac{1-\sqrt{\beta_L/\beta_H}}{\theta}$), firm 1 files for a patent under both filing systems. As Lemma 1 shows, PP induces both firms to invest more if $\Pi<0$, so consumers are better-off as the new technology is more likely to reach the product market. When $\Pi>0$, PP induces firm 2 to invest more and induces firm 1 to invest less. Given Assumption A3, the former effect dominates, so once again consumers are better-off under PP. Things are more subtle when patent protection is intermediate ($\frac{1-\sqrt{\beta_\theta/\beta_H}}{\theta} \leq \gamma < \frac{1-\sqrt{\beta_L/\beta_H}}{\theta}$), because then firm 1 files for a patent only under the CF system. As γ increases, patents are more likely to be upheld in court, so firm 1 is more likely to block firm 2 from using the new technology in the product market; hence, consumer surplus under the CF system, $\bar{S}_F$, decreases with γ. Under the PP system, firm 1 does not file for a patent, so the resulting consumer surplus, S_{NF}, is independent of γ. Noting that $\bar{S}_F=S_{NF}$ when $\gamma=\left(1-\sqrt{\beta_\theta/\beta_H}\right)/\theta$, it follows that $S_{NF}>\bar{S}_F$, and moreover, $S_{NF}-\bar{S}_F$ is increasing with γ.

5.2.2. Expected social welfare

Holding firm 1's interim R&D knowledge constant across the two filing systems, the (ex post) expected social welfare when firm 1 files for a patent is $W_F=S_F+\pi_F^1+\pi_F^2$ under the PP system, and $\bar{W}_F=\bar{S}_F+\bar{\pi}_F^1+\bar{\pi}_F^2$ under the CF system. When firm 1 does not file for a patent, the (ex-post) expected social welfare is $W_{NF}=S_{NF}+\pi_{NF}^1+\pi_{NF}^2$. When patent protection is strong, firm 1 files for a patent under both systems, so the equilibrium expected social welfare is W_F under PP and $\bar{W}_F$ under CF. Given Assumption A3 and using Eqs. (1), (2), (6), and (9),

$$W_F = w_{nn} + \frac{\left(\pi_{yn}-\pi_{nn}\right)^2(1-\gamma\theta)^2(r-\Pi)\left(r\beta_L-(1-\gamma\theta)^2\Pi\right)s}{(r^2\beta_L-(1-\gamma\theta)^2\Pi^2)^2} + \frac{\left(\pi_{yn}-\pi_{nn}\right)\left(r\beta_L+(1-\gamma\theta)^2(r-2\Pi)\right)\left(s_{yn}-s_{nn}+\pi_{ny}-\pi_{nn}\right)}{r^2\beta_L-(1-\gamma\theta)^2\Pi^2} + \frac{\left(\pi_{yn}-\pi_{nn}\right)^2 r\left(\left(r\beta_L-(1-\gamma\theta)^2\Pi\right)^2+\beta_L(1-\gamma\theta)^2(r-\Pi)^2\right)}{2(r^2\beta_L-(1-\gamma\theta)^2\Pi^2)^2}. \tag{10}$$

The expression for $\bar{W}_F$ is identical except that β_θ replaces β_L.

In the intermediate protection case, firm 1 files for a patent only under the CF system, so the equilibrium expected social welfare is $\bar{W}_F$ under CF and W_{NF} under PP, where W_{NF} is identical to W_F except that $\gamma\theta=0$ and β_H replaces β_L.

Proposition 5. *(The welfare implications of PP.) Suppose that* Assumptions A3–A5 *hold and let*

$$\hat{r}(\beta) \equiv \frac{\Pi\left(Y^2+\sqrt{\beta}Y+\beta-(1-\gamma\theta)^2\right)}{\sqrt{\beta}Y}, \quad Y \equiv \left(\sqrt{\beta}-(1-\gamma\theta)\right)^{\frac{2}{3}}\left(\sqrt{\beta}+(1-\gamma\theta)\right)^{\frac{1}{3}}.$$

Then,

(i) *a sufficient condition for PP to enhance ex-post expected welfare when patent protection is strong is $r>\hat{r}(\beta_\theta)$*
(ii) *a sufficient condition for PP to enhance (lower) ex-post expected welfare when patent protection is intermediate is $r>\hat{r}(\beta_\theta)$ and $\gamma<(>)\frac{\beta_H-\beta_M}{\beta_H+\beta_\theta}$; moreover, when these conditions hold, the welfare gain (loss) from to PP is larger (smaller) the larger is γ.*

Proposition 5 reveals that the welfare effect of PP depends on r, which measures the slope of the marginal cost of R&D. Intuitively, the R&D cost functions are convex; hence, all else equal, a more even allocation of investments between the two firms generates an efficiency gain which increases with r. When patent protection is intermediate, things also depend on γ, which is the likelihood that firm 1's patent is upheld in court. As γ increases, firm 2 becomes less likely to use the new technology and this lowers expected social welfare under the CF system, where firm 1 files for a patent. Under PP, 1 does not file for a patent so there is no similar negative effect.

5.3. The timing of PP

In countries that have already adopted the PP system, patent applications are published at 18 months from the filing date (Ragusa, 1992). We now examine the impact of the timing of publication on social welfare. To this end, we shall assume that an earlier PP leads to a drop in β_L by generating a larger technological spillover when firm 1 files for a patent.

Proposition 6. *(The effect of cutting the time between the filing date and the publication date.) Suppose that* Assumptions A3–A5 hold. *Then, as β_L falls (publication is made earlier), there are fewer patent applications under the PP system, but so long as $r \geq \hat{r}(\beta_L)$, the welfare gain from PP, conditional on filing for a patent, grows larger.*

Proposition 6 shows that earlier publication of patent applications has mixed welfare effects: on the one hand, it increases the cost of patenting, so less R&D knowledge is disseminated. On the other hand, conditional on patents being filed, the welfare gain from PP increases at least when the cost of R&D is sufficiently convex (note that this is also the condition for PP to be socially desirable). These results are in line with Bloch and Markowitz (1996) who study the effect of delays in the mandatory disclosure of interim R&D knowledge on the incentives to invest in a multi-stage R&D race. They find that shorter disclosure delays weaken the incentives to accumulate interim R&D knowledge, but conditional on an initial discovery being made, shorter disclosure delays enhance welfare by decreasing the expected time of discovering the final commercial product.

6. Ex post licensing

So far we have assumed that when firm 1 holds a patent, it always sues firm 2 for patent infringement when firm 2 develops the new technology. In this section we relax this assumption. Assuming that $\pi_{yn}+\pi_{ny}>2\pi_{yy}$, firm 1 will continue to sue firm 2 for patent infringement when both firms manage to develop the new technology because the joint payoff when firm 1 wins in court, $\pi_{yn}+\pi_{ny}$, exceeds the joint payoff when firm 1 does not sue, $2\pi_{yy}$.[17]

Things are different however when firm 1 fails to develop the new technology, while firm 2 succeeds. In that case firm 1 can issue firm 2 an (ex post) license, which ensures that it will not sue firm 2; in return, firm 2 pays firm 1 a license fee. The resulting joint payoff of the two firms is then $\pi_{yn}+\pi_{ny}$. Without ex post licensing, firm 1 sues firm 2 and with probability γ it wins in court and prevents firm 2 from using the new technology. The resulting joint payoff of the two firms is then $2\pi_{nn}$. With probability $1-\gamma$, firm 2 wins in court and is then free to use the new technology, so the joint payoff of the two firms is $\pi_{yn}+\pi_{ny}$, exactly as in the case of ex post licensing. Comparing the joint payoff of the two firms under ex post licensing, $\pi_{yn}+\pi_{ny}$, with their joint payoff absent ex post licensing, $2\gamma\pi_{nn}+(1-\gamma)(\pi_{yn}+\pi_{ny})$, reveals that ex post licensing is efficient and generates an expected surplus of $\gamma(\pi_{yn}+\pi_{ny}-2\pi_{nn})$.

To examine the implications of ex post licensing, suppose that firms 1 and 2 divide the expected surplus from ex post licensing, $\gamma(\pi_{yn}+\pi_{ny}-2\pi_{nn})$, between them in proportions α and $1-\alpha$. Moreover, note that ex post licensing matters only when firm 1 files for a patent, a patent is granted, firm 1 fails to develop the new technology, and firm 2 succeeds. The probability of this event is $\theta(1-q^1)q^2$. Hence, ex post licensing increases the expected payoffs of firms 1 and 2 in the filing subgame by

$$\Delta\pi^1\left(q^1,q^2|F\right)=\theta\left(1-q^1\right)q^2\alpha\gamma\left(\pi_{yn}+\pi_{ny}-2\pi_{nn}\right),$$

and

$$\Delta\pi^2\left(q^1,q^2|F\right)=\theta\left(1-q^1\right)q^2(1-\alpha)\gamma\left(\pi_{yn}+\pi_{ny}-2\pi_{nn}\right).$$

Two observations are now immediate. First, $\Delta\pi^1(q^1,q^2|F)>0$, so ex post licensing has a direct positive effect on firm 1's payoff when it files for a patent. Second, $\Delta\pi^1(q^1,q^2|F)$ falls with q^1, while $\Delta\pi^2(q^1,q^2|F)$ increases with q^2, so the best-response function of firm 1 in the filing subgame (under both PP and CF) shifts inward, while the best-response function of firm 2 shifts outward. Since $\pi_{yn}+\pi_{ny}>2\pi_{yy}>\pi_{yy}+\pi_{nn}$, the best-response functions of the two firms are strategic substitutes ($\Pi>0$). Consequently, ex post licensing induces firm 1 to invest less in R&D in the filing subgame, and it induces firm 2 to invest more. Since this indirect effect lowers the equilibrium profit of firm 1 in the filing subgame, the overall effect of ex post licensing on firm 1's incentive to file for a patent is in general ambiguous. Nonetheless, given that the direct and indirect effects of ex post licensing on firm 1's payoff are the same under the PP and CF systems, ex post licensing does not affect the main qualitative conclusions of our analysis.

7. The incentives to accumulate interim R&D knowledge

Up to this point, we have focused on the implications of PP after firm 1 has already accumulated enough interim knowledge to file for a patent. In this section we ask how PP affects the firms' incentives to accumulate interim R&D knowledge in the first place. To this end, let B denote the difference between the expected profits of firm 1 (the leading firm) and firm 2 (the lagging firm). We argue that the filing system that leads to a higher B, provides a stronger incentive to accumulate interim R&D knowledge. As before, we only need to study the strong and intermediate protection cases because PP is irrelevant when patent protection is weak.

[17] The assumption that $\pi_{yn}+\pi_{ny}>2\pi_{yy}$ holds trivially when firms 1 and 2 are Bertrand competitors with linear cost functions and the new technology is cost-reducing, because then $\pi_{yn}>0=\pi_{yy}=\pi_{nn}=\pi_{ny}$. Likewise, this assumption holds when firms 1 and 2 are Cournot competitors with linear demand and cost functions and the new technology is sufficiently cost reducing. To illustrate, suppose that the inverse demand function is $P=A-x_1-x_2$, where x_i is the output of firm $i=1$, 2, and let firm i's marginal cost be 0 if it develops the new technology and $k<A/2$ otherwise. Then, $\pi_{yn}=(A+k)^2/9$, $\pi_{yy}=A^2/9$, $\pi_{nn}=(A-k)^2/9$, and $\pi_{ny}=(A-2k)^2/9$, so $\pi_{yn}+\pi_{ny}>2\pi_{yy}$ provided that $k>2A/5$.

In the strong protection case, firm 1 files for a patent under both filing systems, so $B=B_F\equiv\pi_F^1-\pi_F^2$ under the PP system, and $B=\bar{B}_F\equiv\bar{\pi}_F^1-\bar{\pi}_F^2$ under the CF system. Hence, the effect of PP depends on the sign of $B_F-\bar{B}_F$. By Lemma 1, when $\Pi>0$, then $\pi_F^1<\bar{\pi}_F^1$ and $\pi_F^2>\bar{\pi}_F^2$, so it is clear that $B_F<\bar{B}_F$. When $\Pi<0$, the relationship between π_F^2 and $\bar{\pi}_F^2$ is in general ambiguous. To examine the sign of $B_F-\bar{B}_F$, we therefore impose Assumption A3. Using Eqs. (1), (2), and (6),

$$B_F=\frac{\left(\pi_{yn}-\pi_{nn}\right)\left(\pi_{yn}+\pi_{nn}-2\pi_{ny}\right)r\left(\beta_L-(1-\gamma\theta)^2\right)}{2\left(r^2\beta_L-(1-\gamma\theta)^2\Pi^2\right)}. \tag{11}$$

$\bar{B}_F$ is given by the same expression except that β_θ replaces β_L.

When protection is intermediate, PP induces firm 1 to stop filing for a patent, so $B=B_{NF}\equiv\pi_{NF}^1-\pi_{NF}^2$. Under CF, firm 1 continues to file for a patent, so as before, $B=\bar{B}_F$. The effect of PP, then, depends on the sign of $B_{NF}-\bar{B}_F$, where B_{NF} is given by Eq. (11) with β_H replacing β_L and with $\theta=0$.

Proposition 7. *(The effect of PP on the incentives to accumulate interim R&D knowledge.) Given* Assumption A3, *PP weakens the incentive to accumulate R&D knowledge both when patent protection is strong and when it is intermediate. The negative effect of PP on the incentive to accumulate interim R&D knowledge decreases with θ when patent protection is strong but increases with γ when patent protection is intermediate.*

Proposition 7 supports the concern that PP might discourage investments in R&D. Given the importance of R&D knowledge, this adverse effect of PP should be given a serious consideration. In addition, the proposition shows that as patents become more likely to be upheld in court, this drawback of PP becomes less significant if patent protection is strong, but more significant if patent protection is intermediate. The reason for this difference is that when protection is strong, firm 1 files for a patent under both filing systems. As patents become more likely to be upheld in court, PP is less detrimental to firm 1 and less beneficial to firm 2, so its negative effect on the incentive to accumulate interim knowledge diminishes. When patent protection is intermediate, firm 1 does not file for a patent under the PP system, so γ does not affect the incentive to invest. But, since an increase in γ boosts the incentive to invest under the CF system, the detrimental effect of PP on the incentive to invest (i.e., the difference between B_{NF} and $\bar{B}_F$) increases.

8. Conclusion

We have studied a cumulative innovation model in which one firm has accumulated interim R&D knowledge and needs to decide whether or not to apply for a patent. The benefit from applying is that if a patent is granted, the firm can sue its rival for patent infringement in case the rival successfully develops a new commercial technology. Applying for a patent is costly however because it creates a technological spillover which diminishes the technological advantage of the applicant. This spillover is larger under a PP system because then the rival gets access to the applicant's knowledge through the patent application (even if eventually the application is turned down) rather than through the actual patent (if and when it is granted). Our analysis focuses on the implications of this spillover effect.

Our results suggest that PP discourages patent applications in industries in which patent protection is intermediate and may weaken the incentives to invent. At the same time, holding the number of inventions fixed, PP may raise the likelihood that new technologies will reach the product market and may therefore benefit consumers and may also enhance social welfare.

Although our model is quite general (we do not assume a particular type of competition in the product market, we do not need to distinguish between product and process inventions, and we derive many of the results without assuming a particular functional form for the R&D cost functions), it is clear that further analysis is needed before we have a good understanding of the implications of PP. In what follows we briefly mention three possible extensions. First, in a dynamic model of R&D in which firms continuously accumulate interim R&D knowledge, firms need to decide not only whether to apply for a patent but also when to do it. Filing early is risky because the application is less likely to be accepted; on the other hand, an early filing contains less knowledge and hence leads to a smaller technological spillover. Applying early can also play a defensive role because the firm is not only able to sue rivals earlier, but can also preempt rivals from getting their own patent. This ensures that the firm will not be sued for patent infringement by rivals.

Second, it is possible to extend our analysis by allowing firm 1 to strategically decide how much interim knowledge to include in its patent application: including more knowledge increases the probability that a patent will be granted but also increases the degree of technological spillover.

Third, when firms have private information regarding the extent of their interim R&D knowledge (or even the fact that they are trying to develop the new technology), PP reveals this information to rivals earlier and for sure. This will obviously affect the incentives to file. Moreover, firms may be tempted to abuse the PP system and file for a patent in order to fool their rivals into believing that they are ahead in the race. At the same time, PP may eliminate "submarine" patents, by giving firms a due warning about patent applications which are in the pipeline.[18]

Appendix A

Following are Lemma A1, and the proofs of Lemmas 1–2, Propositions 1–7, and Corollaries 2–3.

Lemma A1. *The effect of patent protection on the equilibrium R&D investments under the two filing systems*:

(i) $\frac{\partial q_F^2}{\partial(\gamma\theta)} < 0$ *while the sign of* $\frac{\partial q_F^1}{\partial(\gamma\theta)}$ *is equal to the sign of* Π. *Moreover,* $q_F^2 > q_{NF}^2$ *when* $\gamma\theta = 0$ *and conversely when* $\gamma\theta = 1 - \beta_L/\beta_H$.

(ii) $\frac{\partial \bar{q}_F^2}{\partial\gamma} < 0$ *while the sign of* $\frac{\partial \bar{q}_F^1}{\partial\gamma}$ *is equal to the sign of* Π. *Moreover,* $\bar{q}_F^2 > q_{NF}^2$ *when* $\gamma = 0$ *and conversely when* $\gamma = (1 - \beta_\theta/\beta_H)/\theta$.

Proof of Lemma A1.

(i) The Nash equilibrium in the filing subgame is implicitly defined by the equations $\frac{\partial\pi^1(q^1,q^2|F)}{\partial q^1} = 0$ and $\frac{\partial\pi^2(q^1,q^2|F)}{\partial q^2} = 0$. Differentiating this system with respect to $\gamma\theta$ yields:

$$\frac{\partial q_F^1}{\partial(\gamma\theta)} = \frac{\Pi\left[(1-\gamma\theta)\left[q_F^1\left(\pi_{yy}-\pi_{ny}\right) + \left(1-q_F^1\right)\left(\pi_{yn}-\pi_{nn}\right)\right] + \beta_L q_F^2 C''\left(q_F^2\right)\right]}{\beta_L C''(q_F^1)C''(q_F^2) - \Pi^2(1-\gamma\theta)^2},$$

and

$$\frac{\partial q_F^2}{\partial(\gamma\theta)} = \frac{-\Pi^2(1-\gamma\theta)q_F^2 - \left[q_F^1\left(\pi_{yy}-\pi_{ny}\right) + \left(1-q_F^1\right)\left(\pi_{yn}-\pi_{nn}\right)\right]C''\left(q_F^1\right)}{\beta_L C''(q_F^1)C''(q_F^2) - \Pi^2(1-\gamma\theta)^2},$$

where $\Pi \equiv \pi_{yn} + \pi_{ny} - \pi_{yy} - \pi_{nn}$. By Assumption A2, $C''(q_F^1)C''(q_F^2) > \Pi^2$; together with the fact that $\beta_L > 1$, it follows that the denominator in both expressions is strictly positive. Hence, $\frac{\partial q_F^2}{\partial(\gamma\theta)} < 0$ while the sign of $\frac{\partial q_F^1}{\partial(\gamma\theta)}$ is equal to the sign of Π.

To compare q_F^2 and q_{NF}^2, suppose first that $\gamma\theta = 0$. Then, Eqs. (1) and (3) coincide, so $R^1(q^2|F) = R^1(q^2|NF)$. On the other hand, since $\beta_L < \beta_H$, it follows that $R^2(q^1|F) > R^2(q^1|NF)$ for all q^1. Hence, $q_F^2 > q_{NF}^2$ (this is true irrespective or whether $\Pi > 0$ or $\Pi < 0$). Next, suppose that $\gamma\theta = 1 - \beta_L/\beta_H$. Then, it is easy to verify that $\frac{\partial\pi^2(q^1,q^2|F)}{\partial q^2} = 0$ implies $\frac{\partial\pi^2(q^1,q^2|NF)}{\partial q^2} = 0$, so $R^2(q^1|F) = R^2(q^1|NF)$. By contrast, $\frac{\partial^2\pi^1(q^1,q^2|F)}{\partial q^1\partial(\gamma\theta)} = q^2\Pi$, so $R^1(q^2|F) > R^1(q^2|NF)$ if $\Pi > 0$ and $R^1(q^2|F) < R^1(q^2|NF)$ if $\Pi < 0$. Recalling that the best-response functions are downward sloping when $\Pi > 0$ and upward sloping when $\Pi < 0$, it follows that $q_F^2 < q_{NF}^2$.

(ii) The proof is similar to the proof of part (i), except that β_θ replaces β_L and γ replaces $\theta\gamma$. □

Proof of Proposition 1. By Eq. (3), π_{NF}^1 is independent of γ and θ. Using the envelope theorem,

$$\frac{\partial\pi_F^1}{\partial(\gamma\theta)} = -q_F^2\left[q_F^1\left(\pi_{yy}-\pi_{yn}\right) + \left(1-q_F^1\right)\left(\pi_{ny}-\pi_{nn}\right)\right] + \frac{\partial\pi_F^1}{\partial q^2}\frac{\partial q_F^2}{\partial(\gamma\theta)}. \tag{12}$$

Assumption A1 ensures that the bracketed expression and $\partial\pi_F^1/\partial q^2$ are negative. Since $\partial q_F^2/\partial(\gamma\theta) < 0$, it follows that $\partial\pi_F^1/\partial(\theta\gamma) > 0$.

To prove the existence of $\widehat{\gamma\theta} \in (0, 1 - \beta_L/\beta_H)$, such that $\pi_F^1 \gtreqless \pi_{NF}^1$ as $\gamma\theta \gtreqless \widehat{\gamma\theta}$, note that $\widehat{\gamma\theta}$ is defined implicitly $\pi_F^1 = \pi_{NF}^1$. Since π_F^1 increases with $\gamma\theta$, whereas π_{NF}^1 is independent of $\gamma\theta$, it suffices to show that $\pi_F^1 < \pi_{NF}^1$ if $\gamma\theta = 0$ and conversely if $\gamma\theta = 1 - \beta_L/\beta_H$. If $\gamma\theta = 0$, Eqs. (1) and (3) imply that $\pi^1(q^1, q^2|F) = \pi^1(q^1, q^2|NF)$. Consequently,

$$\pi_F^1 < \pi^1\left(q_F^1, q_{NF}^2|F\right) = \pi^1\left(q_F^1, q_{NF}^2|NF\right) \le \pi_{NF}^1,$$

where the strict inequality follows because $\partial\pi^1(q^1, q^2|F)/\partial q^2 < 0$ and since Lemma A1 states that $q_F^2 > q_{NF}^2$ when $\gamma\theta = 0$, and the weak inequality is implied by revealed preferences (i.e., the definition of q_{NF}^1). Next, suppose that $\gamma\theta = 1 - \beta_L/\beta_H$. Then by Lemma A1, $q_F^2 < q_{NF}^2$. Using Eqs. (1) and (3) and Assumption A1, it is easy to show that $\pi^1(q^1, q^2|F) > \pi^1(q^1, q^2|NF)$ for all $\gamma\theta > 0$. Hence,

$$\pi_F^1 \ge \pi^1\left(q_{NF}^1, q_F^2|F\right) > \pi^1\left(q_{NF}^1, q_F^2|NF\right) > \pi_{NF}^1,$$

where the weak inequality is implied by revealed preferences and the second strict inequality follows because $\partial\pi^1(q^1, q^2|F)/\partial q^2 < 0$ and since $q_F^2 < q^2{}_{NF}$. □

Proof of Proposition 2. To prove the existence of $\hat{\gamma} \in (0, 1 - \beta_\theta/\beta_H)/\theta$, note that $\hat{\gamma}$ is defined implicitly $\bar{\pi}_F^1 = \pi_{NF}^1$. The proofs that $\bar{\pi}_F^1$ increases with γ and that $\bar{\pi}_F^1 < \pi_{NF}^1$ is similar to the proof of Proposition 1. Since π_{NF}^1 is independent of γ, it suffices to show that $\bar{\pi}_F^1 > \pi_{NF}^1$ if $\gamma = (1 - \beta_\theta/\beta_H)/\theta$. To this end, recall from Lemma A1 that $\bar{q}_F^2 < q_{NF}^2$ and recall from the proof of Proposition 1 that $\pi^1(q^1, q^2|F) > \pi^1(q^1, q^2|NF)$ for all $\gamma\theta > 0$. Consequently,

$$\bar{\pi}_F^1 \ge \bar{\pi}^1\left(q_{NF}^1, \bar{q}_F^2|F\right) > \pi^1\left(q_{NF}^1, \bar{q}_F^2|NF\right) > \pi_{NF}^1,$$

where the weak inequality is implied by revealed preferences and the second strict inequality follows because $\partial\pi^1(q^1, q^2|F)/\partial q^2 < 0$ and $\bar{q}_F^2 < q_{NF}^2$. □

Proof of Lemma 1.

(i) Follows immediately from Fig. 3.

(ii) Since $q_F^2 > \bar{q}_F^2$ and noting that $\partial\pi^1(q^1, q^2|F)/\partial q^2 < 0$,

$$\pi_F^1 < \pi^1\left(q_F^1, \bar{q}_F^2|F\right) \le \bar{\pi}_F^1,$$

where the weak inequality follows by revealed preferences.
As for firm 2, note that if $\Pi > 0$, then $q_F^1 < \bar{q}_F^1$. Together with the fact that $\partial\pi^2(q^1, q^2|F)/\partial q^1 < 0$, it follows that $\pi^2(q_F^1, \cdot|F) > \pi^2(\bar{q}_F^1, \cdot|F)$. Hence,

$$\pi_F^2 \ge \pi^2\left(q_F^1, \bar{q}_F^2|F\right) > \pi^2\left(\bar{q}_F^1, \bar{q}_F^2|F\right) > \bar{\pi}_F^2,$$

[18] Submarine patents refer to patent applications which are intentionally delayed by the applicants until a similar idea is commercialized by someone else, at which point the application is completed and entitles the patentholder to collect royalties. A case in point are the patents that were issued in the 1980s and the 1990s to Jerome Lemelson for bar code-scanning and "machine vision" technologies which he first filed for in 1954 and 1956. According to a story published in the *American Lawyer* in May 1993, Lemelson collected $500 million in royalties from manufacturers who inadvertently infringed on his patents.

where the weak inequality follows from revealed preferences and the second strict inequality follows from Eqs. (2) and (4) by noting that $\beta_\theta > \beta_L$. □

Proof of Proposition 3. By Propositions 1 and 2, firm 1 files for a patent under the PP system if $\gamma > \widehat{\gamma\theta}/\theta$ and under the CF system if $\gamma > \hat{\gamma}$, where $\widehat{\gamma\theta}/\theta$ is defined implicitly by $\pi_F^1 = \pi_{NF}^1$ and $\hat{\gamma}$ is defined implicitly by $\bar{\pi}_F^1 = \pi_{NF}^1$. Since Propositions 1 and 2 show that $\frac{\partial \pi_F^1}{\partial \gamma}, \frac{\partial \bar{\pi}_F^1}{\partial \gamma} < 0$ and since $\pi_F^1 < \bar{\pi}_F^1$ by Lemma 1, it follows that $\hat{\gamma} < \gamma \le \widehat{\gamma\theta}/\theta$. □

Proof of Corollary 2. When patent protection is strong, firm 1 files for a patent under both systems. The effect of PP on the R&D investments follows in this case from part (i) of Lemma 1. When patent protection is intermediate, firm 1 files for a patent only under the CF system. The R&D investment levels are then q_{NF}^1 and q_{NF}^2 under PP and $\bar{q}_F^1$ and $\bar{q}_F^2$ under CF. To compare these levels of investment, note that from Eqs. (4) and (5) that $R^2(q^1|NF)$ and $\bar{R}^2(q^1|F)$, respectively are implicitly defined by

$$\frac{\partial \pi^2\left(q^1,q^2|NF\right)}{\partial q^2} = \left[q^1\left(\pi_{yy}-\pi_{ny}\right) + \left(1-q^1\right)\left(\pi_{yn}-\pi_{nn}\right)\right] - \beta_H C'\left(q^2\right) = 0,$$

and

$$\frac{\partial \bar{\pi}^2\left(q^1,q^2|F\right)}{\partial q^2} = (1-\gamma\theta)\left[q^1\left(\pi_{yy}-\pi_{ny}\right) + \left(1-q^1\right)\left(\pi_{yn}-\pi_{nn}\right)\right] - \beta_\theta C'\left(q^2\right) = 0.$$

Substituting from the $\frac{\partial \pi^2(q^1,q^2|NF)}{\partial q^2} = 0$ into $\frac{\partial \bar{\pi}^2(q^1,q^2|F)}{\partial q^2}$ and rearranging terms,

$$\frac{\partial \bar{\pi}^2\left(q^1,q^2|F\right)}{\partial q^2} = \left[\left(1-\frac{\beta_\theta}{\beta_H}\right) - \gamma\theta\right]\beta_H C'\left(q^2\right).$$

If $\gamma\theta \ge 1 - \frac{\beta_\theta}{\beta_H}$, then, evaluated at $q^2 = R^2(q^1|NF)$, $\frac{\partial \bar{\pi}^2(q^1,q^2|F)}{\partial q^2} \le 0$, implying that $\bar{R}^2(q^1|F) \le R^2(q^1|NF)$. If $\Pi > 0$, then $R^1(q^2|F) > \bar{R}^1(q^2|NF)$ and since the best-response functions are downward sloping, $\bar{q}_F^1 > q_{NF}^2$ and $\bar{q}_F^2 > q_{NF}^2$. If $\Pi < 0$, then $R^1(q^2|F) < R^1(q^2|NF)$ and since the best-response functions are upward sloping, $\bar{q}_F^1 < q_{NF}^2$ and $\bar{q}_F^2 < q_{NF}^2$. If $\gamma\theta < 1 - \frac{\beta_\theta}{\beta_H}$, then, $\bar{R}^2(q^1|F) > R^2(q^1|NF)$ and hence the relationship between q_{NF}^1 and q_{NF}^2 and $\bar{q}_F^1$ and $\bar{q}_F^2$ is ambiguous. □

Proof of Corollary 3. The reason why PP hurts firm 1 is explained in the text following the proposition. To see that PP may benefit firm 2, suppose first that patent protection is strong. Then firm 1 files for a patent under both systems. Since $\beta_\theta > \beta_L$, it follows from Eqs. (2) and (4) that $\pi^2(q^1,q^2|F) > \bar{\pi}^2(q^1, q^2|F)$. Panel a of Fig. 3 shows that when $\Pi > 0$, $q_F^1 < \bar{q}_F^1$. Given that $\partial \pi^2(q^1,q^2|F)/\partial q^1 < 0$, this implies in turn that $\pi^2(q_F^1,\cdot|F) > \pi^2(\bar{q}_F^1,\cdot|F)$. Hence,

$$\pi_F^2 \ge \pi^2\left(q_F^1, \bar{q}_F^2|F\right) > \pi^2\left(\bar{q}_F^1, \bar{q}_F^2|F\right) > \bar{\pi}_F^2,$$

where the weak inequality follows from revealed preferences.

If patent protection is intermediate, then firm 1 files for a patent only under the CF system. Hence, we need to show that cases exist in which $\bar{\pi}_F^2 < \pi_{NF}^2$. Using Eqs. (4) and (5),

$$\pi^2\left(\bar{q}_F^1, \bar{q}_F^2|NF\right) - \bar{\pi}_F^2 = \theta\gamma\bar{q}_F^2\left[\bar{q}_F^1\left(\pi_{yy}-\pi_{yn}\right) + \left(1-\bar{q}_F^1\right)\left(\pi_{yn}-\pi_{nn}\right)\right] - \theta(\beta_H-\beta_M)C\left(\bar{q}_F^2\right).$$

Substituting for the square bracketed term from the first order condition, $\frac{\partial \bar{\pi}^2(\bar{q}_F^1,\bar{q}_F^2|F)}{\partial q^2} = 0$, and recalling that $C(q)$ is strictly convex,

$$\begin{aligned}\pi^2\left(\bar{q}_F^1, \bar{q}_F^2|NF\right) - \bar{\pi}_F^2 &= \frac{\theta\gamma\bar{q}_F^2\beta_\theta C'\left(\bar{q}_F^2\right)}{1-\gamma\theta} - \theta(\beta_H-\beta_M)C\left(\bar{q}_F^2\right) \\ &> \frac{\theta\beta_H C\left(\bar{q}_F^2\right)}{1-\gamma\theta}\left[\gamma + 1 - \frac{\beta_M}{\beta_H}\right].\end{aligned}$$

Hence, $\pi^2(\bar{q}_F^1,\bar{q}_F^2|NF) > \bar{\pi}_F^2$ for all $\gamma > 1 - \beta_M/\beta_H$. If $q_{NF}^1 < \bar{q}_F^1$, then since $\partial \pi^2(q^1, q^2|NF)/\partial q^1 < 0$, it follows that

$$\pi_{NF}^2 \ge \pi^2\left(q_{NF}^1, \bar{q}_F^2|NF\right) > \pi^2\left(\bar{q}_F^1, \bar{q}_F^2|NF\right) > \bar{\pi}_F^2,$$

where the weak inequality follows by revealed preferences. □

Proof of Proposition 4. In the strong protection case, we need to compare $\bar{S}_F$ (consumers' surplus under the CF system) and S_F (consumers' surplus under the PP system). Now,

$$\begin{aligned}S_F - \bar{S}_F &= \frac{\left(\pi_{yn}-\pi_{nn}\right)^2 r(1-\gamma\theta)^2(r-\Pi)^2(\beta_\theta-\beta_L)(\beta_\theta-\beta_L)\left(s_{yn}-s_{nn}\right)}{(r\beta_\theta + (1-\gamma\theta)^2\Pi^2)(r^2\beta_L - (1-\gamma\theta)^2\Pi^2)} \\ &\quad + \left(\pi_{yn}-\pi_{nn}\right)^2(r-\Pi)(1-\gamma\theta)^2\left[\frac{r\beta_L - (1-\gamma\theta)^2\Pi}{(r^2\beta_L - (1-\gamma\theta)^2\Pi^2)^2} - \frac{r\beta_\theta - (1-\gamma\theta)^2\Pi}{(r^2\beta_\theta - (1-\gamma\theta)^2\Pi^2)^2}\right]s.\end{aligned}$$

Since $\beta_\theta > \beta_L$, this expression is strictly positive, implying that PP makes consumers better-off.

In the intermediate protection case, we need to compare $\bar{S}_F$ (consumers' surplus under the CF system) and S_{NF} (consumers' surplus under the PP system). Now,

$$\begin{aligned}S_{NF} - \bar{S}_F &= \frac{\left(\pi_{yn}-\pi_{nn}\right) r(r-\Pi)^2(\beta_\theta - \beta_H(1-\gamma\theta))\left(s_{yn}-s_{nn}\right)}{(r^2\beta_\theta - (1-\gamma\theta)^2\Pi^2)(r^2\beta_H - \Pi^2)} \\ &\quad + \left(\pi_{yn}-\pi_{nn}\right)^2(r-\Pi)\left[\frac{r\beta_H - \Pi}{(r^2\beta_H - \Pi^2)^2} - \frac{(1-\gamma\theta)^2\left(r\beta_\theta - (1-\gamma\theta)^2\Pi\right)}{(r^2\beta_\theta - (1-\gamma\theta)^2\Pi^2)(r^2\beta_H - \Pi^2)}\right]s.\end{aligned} \tag{13}$$

Recalling that in the intermediate protection case, $\gamma \ge \left(1 - \sqrt{\beta_\theta/\beta_H}\right)/\theta$, we get $\beta_\theta - \beta_H(1-\gamma\theta)^2 \ge 0$, so the first line of Eq. (13) is positive. The square bracketed expression in the second line is increasing with γ and it vanishes at $\gamma = \left(1 - \sqrt{\beta_\theta/\beta_H}\right)/\theta$; hence the second line is positive as well, so $S_{NF} > \bar{S}_F$ for all parameter values in the intermediate protection case. Finally, it is straightforward to establish that the first line of Eq. (13) is increasing with γ. Since the second line is also increasing with γ, it follows that the gain of consumers from PP is larger the larger is γ. □

Proof of Proposition 5.

(i) In the strong protection case we need to compare W_F and $\bar{W}_F$. Noting that $\bar{W}_F$ is identical to W_F, expect that β_θ replaces β_L, we can show that $W_F > \bar{W}_F$ by establishing a sufficient condition for $\partial W_F/\partial\beta < 0$ for all $\beta \in [\beta_L, \beta_\theta]$. From Eq. (10),

$$\begin{aligned}\frac{\partial W_F}{\partial \beta} &= -\frac{\left(\pi_{yn}-\pi_{nn}\right) r(1-\gamma\theta)^2(r-\Pi)}{2(r^2\beta - (1-\gamma\theta)^2\Pi^2)^3} \\ &\quad \times \left[\left(\pi_{yn}-\pi_{nn}\right)Z(r,\beta) + 2\left(\pi_{yn}-\pi_{nn}\right)M(\beta)S\right. \\ &\quad \left. + 2(r-\Pi)\left(r^2\beta - (1-\gamma\beta)^2\Pi^2\right)\left(s_{yn}-s_{nn}+\pi_{ny}-\pi_{nn}\right)\right],\end{aligned} \tag{14}$$

where

$$M(\beta) \equiv (r-(1-\gamma\theta)\Pi)^2 + r^2(\beta-1) + 2r\gamma\theta(1-\gamma\theta)\Pi > 0,$$

and

$$Z(r,\beta) \equiv r^2\beta(r-3\Pi) + (1-\gamma\theta)^2\Pi^2(3r-\Pi).$$

The expression outside the square brackets in Eq. (14) is negative, while the last two expressions inside the square brackets are positive (the last term is positive by Assumption A4). Hence $Z(r, \beta) \geq 0$ is sufficient for $\partial W_F/\partial\beta < 0$ for all $\beta \in [\beta_L, \beta_\theta]$, which in turn ensures that $W_F > \overline{W}_F$. Now, surely, $Z(r, \beta) > 0$ if $r - 3\Pi \geq 0$. Otherwise, $Z(r, \beta) \geq 0$ is sufficient for $Z(r, \beta) > 0$ for all $\beta \in [\beta_L, \beta_\theta)$. Recalling from Assumption A3 that $r > \Pi$ and noting that $Z(r, \beta_\theta)$ is a convex function of r and that $Z'(\Pi, \beta_\theta) < 0$ and $Z(\Pi, \beta_\theta) < 0$, it follows that $Z(r, \beta_\theta) > 0$, provided that $r \geq \hat{r}(\beta_\theta)$, where $\hat{r}(\cdot)$ is defined in the proposition.

(ii) When protection is intermediate, we need to compare W_{NF} and $\overline{W}_F$. Noting that $W_{NF} = \overline{W}_F$ when $\theta = 0$ (in that case $\beta_\theta = \beta_H$), a sufficient condition for PP to enhance (lower) welfare is that $\partial\overline{W}_F/\partial\theta < 0$ ($\partial\overline{W}_F/\partial\theta > 0$) for all $\theta \in \left[0, \widehat{\gamma\theta}/\gamma\right)$. Using Eq. (10),

$$\frac{\partial \overline{W}_F}{\partial\theta} = \frac{\left(\pi_{yn} - \pi_{nn}\right) r(1-\gamma\theta)(r-\Pi)(\beta_H - \beta_M - \gamma(\beta_H + \beta_\theta))}{2\left(r^2\beta_\theta + (1-\gamma\theta)^2\Pi\right)^2}$$
$$\times \left[\left(\pi_{yn} - \pi_{nn}\right) Z(r,\beta_\theta) + 2\left(\pi_{yn} - \pi_{nn}\right) M(\beta_\theta) s\right.$$
$$\left. + 2(r-\Pi)\left(r^2\beta_\theta - (1-\gamma\theta)^2\Pi^2\right)\left(s_{yn} - s_{nn} + \pi_{ny} - \pi_{nn}\right)\right].$$

The expression inside the square brackets is similar to the expression inside the square brackets in Eq. (14) and is therefore positive when $r \geq \hat{r}(\beta_\theta)$. In that case, the sign of $\frac{\partial \overline{W}_F}{\partial\theta}$ depends on the sign of $(\beta_H - \beta_M) - \gamma(\beta_H - \beta_\theta)$ which is negative (positive) if $\gamma > (<) \frac{\beta_H - \beta_M}{\beta_H + \beta_\theta}$.
Finally, note that W_{NF} is independent of γ, while using Eq. (10),

$$\frac{\partial \overline{W}_F}{\partial\gamma} = -\frac{\left(\pi_{yn} - \pi_{nn}\right) r\beta_\theta(1-\gamma\theta)(r-\Pi)}{\left(r^2\beta - (1-\gamma\theta)^2\Pi^2\right)^3} \times \left[\left(\pi_{yn} - \pi_{nn}\right) Z(r,\beta)\right.$$
$$+ 2\left(\pi_{yn} - \pi_{nn}\right) M(\beta_\theta) s + 2(r-\Pi)\left(r^2\beta_\theta - (1-\gamma\beta)^2\Pi^2\right)$$
$$\left.\times \left(s_{yn} - s_{nn} + \pi_{ny} - \pi_{nn}\right)\right],$$

which is negative when $r \geq \hat{r}(\beta_\theta)$. Thus, W_{NF} does better relative to $\overline{W}_F$ as γ increases. □

Proof of Proposition 6. Under PP, firm 1 files for patent if $\gamma > \left(1 - \sqrt{\beta_L/\beta_H}\right)/\theta$. As β_L falls, the right side of the inequality increases, so firm 1 files for a smaller set of parameters. If the inequality still holds, firm 1 files for a patent under both filing systems, so the welfare effect of PP is given by $W_F - \overline{W}_F$, where $\overline{W}_F$ is independent of β_L, while $\partial W_F/\partial\beta_L < 0$ if $r \geq \hat{r}(\beta_L)$ (see Eq. (10)). Hence, so long as $r \geq \hat{r}(\beta_L)$, lowering β_L boosts the welfare gain from PP. □

Proof of Proposition 7. In the strong protection case, the effect of PP on the incentive to accumulate interim R&D knowledge depends on the sign of the following expression:

$$B_F - \overline{B}_F = -\frac{\left(\pi_{yn} - \pi_{nn}\right)\left(\pi_{yn} + \pi_{nn} - 2\pi_{ny}\right) r\left(r^2 - \Pi^2\right)(1-\gamma\theta)^2(\beta_\theta - \beta_L)}{2\left(r^2\beta_L - (1-\gamma\theta)^2\Pi^2\right)\left(r^2\beta_\theta - (1-\gamma\theta)^2\Pi^2\right)} < 0.$$

Straightforward calculation reveals that this expression increases with γ; hence PP weakens the incentive to invent, but less so as γ increases.

In the intermediate protection case, the effect of PP depends on the sign of:

$$B_{NF} - \overline{B}_F = \frac{\left(\pi_{yn} - \pi_{nn}\right)\left(\pi_{yn} + \pi_{nn} - 2\pi_{ny}\right) r\left(r^2 - \Pi^2\right)\left(\beta_H(1-\gamma\theta)^2 - \beta_\theta\right)}{2\left(r^2\beta_H - \Pi^2\right)\left(r^2\beta_\theta - (1-\gamma\theta)^2\Pi^2\right)} < 0,$$

where the inequality follows because in the intermediate protection case, $\gamma \geq \left(1 - \sqrt{\beta_\theta/\beta_H}\right)/\theta$ (see Lemma 2), which ensures that $\beta_H(1-\gamma\theta)^2 - \beta_\theta \leq 0$. Hence, once again, PP weakens the incentives to accumulate interim R&D knowledge. However now, straightforward calculation reveals that $B_{NF} - \bar{B}_F$ decreases with γ, so the negative impact of PP increases when γ increases. □

References

Allison, J., Lemley, M., 1998. Empirical evidence on the validity of litigated patents. AIPLA Quarterly Journal 26, 185–275.
Anton, J., Yao, D., 2003. Patents, invalidity, and the strategic transmission of enabling information. Journal of Economics and Management Strategy 12, 151–178.
Anton, J., Yao, D., 2004. Little patents and big secrets: managing intellectual property. Rand Journal of Economics 35 (1), 1–22.
Aoki, R., Prusa, T., 1996. Product development and the timing of information disclosure under U.S. and Japanese patent systems. Journal of the Japanese and International Economics 10, 233–249.
Arundel, A., Kabla, I., 1998. What percentage of innovations are patented? Empirical estimates for European firms. Research Policy 27, 127–141.
Bloch, F., Markowitz, P., 1996. Optimal disclosure delay in multistage R&D competition. International Journal of Industrial Organization 14 (2), 159–179.
Chang, H., 1995. Patent scope, antitrust policy, and cumulative innovation. RAND Journal of Economics 26, 34–57.
Choi, J.P., 1998. Patent litigation as an information transmission mechanism. American Economic Review 89, 860–869.
Cornelli, F., Schankerman, M., 1999. Patent renewals and R&D incentives. RAND Journal of Economics 30, 197–213.
Crampes, C., Langinier, C., 1998. Information disclosure in the renewal of patents. Annales D'Economie et de Statistique 49/50, 265–288.
Crampes, C., Langinier, C., 2002. Litigation and settlement in patent infringement cases. RAND Journal of Economics 33, 258–274.
Erkal, N., 2005. The decision to patent, cumulative innovation, and optimal policy. International Journal of Industrial Organization 23, 535–562.
Eswaran, M., Gallini, N., 1996. Patent policy and the direction of technological change. RAND Journal of Economics 27, 722–746.
FTC (2005), "A Summary Report of Discussions at Town Meetings on Patent Reforms," available at www.ftc.gov/opp/intellect/050601summarytownmtg.pdf.
Gallini, N., 1992. Patent policy and costly imitation. RAND Journal of Economics 23, 52–63.
Gilbert, R. (1994), Statement Submitted to the Subcommittee on Patents, Copyrights and Trademarks, Committee on the Judiciary, United States Senate, Concerning The Patent Term and Publication Reform Act of 1994, S. 1854, March 9, 1994, reprinted in Journal of Reprints in Antitrust, Law, and Economics, 23, 455–462.
Gilbert, R., Shapiro, C., 1990. Optimal patent length and breath. RAND Journal of Economics 21, 106–113.
Gill, D., 2008. Strategic disclosure of intermediate research results. Journal of Economics and Management Strategy 17 (3), 733–758.
Gordon, S. (2004), "Publishing to Deter in R&D Competition," Mimeo.
Green, J., Scotchmer, S., 1995. On the division of profit in sequential innovation. RAND Journal of Economics 26, 131–146.
Horstman, I., MacDonald, G., Slivinski, A., 1985. Patents as information transfer mechanism: to patent or (maybe) not to patent. Journal of Political Economy 93, 837–856.
Jansen, J. (2008), "Strategic Information Disclosure and Competition for an Imperfectly Protected Innovation," Mimeo.
Johnson, D.K.N., Popp, D., 2003. Forced out of the closet: the impact of the American Inventors Protection Act on the timing of patent disclosure. RAND Journal of Economics 34 (1), 96–112 (Spring).
Kabla, I. (1996), "Easiness of Imitation, Patent Disclosure and the Optimal Patent Scope," INSEE and Hebrew University of Jerusalem.
Klemperer, P., 1990. How broad should the scope of patent protection be? RAND Journal of Economics 21, 113–130.
Levin, R., Klevorick, A., Nelson, R., Winter, S., 1987. Appropriating the returns from industrial research and development. Brookings Papers on Economic Activity 783–831.
Lichtman, D., Baker, S., Kraus, K., 2000. Strategic disclosure in the patent system. Vanderbilt Law Review 53, 2175–2217.
Mansfield, E., 1986. Patents and innovation: an empirical study. Management Science 32, 173–181.
Mansfield, E., Schwartz, M., Wagner, S., 1981. Imitation costs and patents: an empirical study. Economic Journal 91, 907–918.
Matutes, C., Regibeau, P., Rockett, K., 1996. Optimal patent design and the diffusion of innovations. RAND Journal of Economics 27, 60–83.
Merges, R., Nelson, R., 1994. On limiting or encouraging rivalry in technical progress: the effect of patent scope decisions. Journal of Economic Behavior and Organization 25, 1–24.
Meurer, M., 1989. The settlement of patent litigation. RAND Journal of Economics 20, 77–91.
Nordhaus, W., 1969. Invention, Growth and Welfare. MIT Press, Cambridge Mass.
O'Donoghue, T., 1998. A patentability requirement for sequential innovation. RAND Journal of Economics 29, 654–679.
O'Donoghue, T., Scotchmer, S., Thisse, J.-F., 1998. Patent breadth, patent life, and the pace of technological progress. Journal of Economics and Management Strategy 7, 1–32.

Putnam, J. (1997), "The Value of International Patent Rights." Mimeo, Charles River Associates.
Ragusa, A.P., 1992. Eighteen month to publication: should the United States join Europe and Japan by promptly publishing patent applications? George Washington Journal of International Law and Economics 26, 143–180.
Scotchmer, S., 1996. Protecting early innovators: should second-generation products be patentable? RAND Journal of Economics 27, 322–331.
Scotchmer, S., Green, J., 1990. Novelty and disclosure in patent law. RAND Journal of Economics 21, 131–146.
Spiegel, Y. (2008), "Licensing Interim R&D Knowledge," Mimeo.
Tepperman, A. (2002), "Do Priority and Disclosure Rules Matter? Canadian Evidence from the 1989 Patent Reforms," Mimeo, Charles River Associates.
U.S. Patent and Trademark Office Ed. (2004), Trilateral Statistical Report 2003 Edition. Jointly produced with European Patent Office and Japan Patent Office.
Waterson, M., 1990. The economics of product patents. American Economic Review 80, 860–869.