Public Disclosure of Patent Applications, R&D, and Welfare[*]

by

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Abstract: In Europe and in Japan, patent applications are publicly disclosed after 18 month from the filing date regardless of whether a patent has been or will be registered. In the U.S. in contrast, patent applications are publicly disclosed only when a patent is granted. In this paper we examine the consequences of this difference for (i) firm's R&D and patenting behavior, (ii) consumers' surplus and social welfare, and (iii) the incentives of firms to innovate, in a setting where patent protection is imperfect in the sense that patent applications may be rejected and patents are not always upheld in court. We show that public disclosure of patent applications leads to fewer applications and fewer innovations, but for a given number of innovations, it raises the probability that new technologies will reach the product market and thereby enhances consumers' surplus and possibly total welfare as well.

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1. Introduction

The two main objectives of patent systems are to encourage inventors to engage in R&D by granting them a temporary monopoly over the use of their innovations and to facilitate the dissemination of new technologies for the benefit of society at large. Economists generally agree that the current U.S. patent system puts a greater emphasis on the first objective, while the system of the European Patent Office (EPO) and the Japanese patent system emphasize more the second goal.[1] One example that highlights this different emphasis is the fact that patent applications in Europe and Japan are publicly disclosed after 18 months from the filing date (a public disclosure system), whereas in the U.S. they remain confidential until a patent is actually granted (a confidential filing system).[2]

In an effort to harmonize the U.S. patent system with those of Japan and Europe, the U.S. Congress is currently considering the Examining Procedure Improvements Act (Title II of both H.R. 400 in the House and S. 507 in the Senate) that will require, among other things, that each patent application be published as soon as possible after 18 months from the earliest filing date. Given that the legislation will mark a fundamental change in the U.S. patent law, it is not surprising that it has generated a heated public debate. Supporters of the act, who include large and innovating corporations such as Eastman Kodak, GE, IBM, Lucent Technologies, Motorola, Texas Instruments, and Xerox, argue that the legislation is critical "to the competitiveness of American companies and the advancement of technology," and "for the continued vitality of U.S. industry and jobs."[3] On the other hand, a group of 26 American Nobel Laureates in economics, physics, chemistry, and medicine, led by Franco Modigliani, argues in an open letter to the U.S. Senate, that "[S. 507] will prove damaging to American small inventors and thereby discourage the flow of new invention... It will do so by curtailing the protection they obtain through patent relative to the large multi-national corporation." In addition, they write that "We believe that S.507 could

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[1] For example, Ordover (1991) argues that "... current U.S. policy stance that advocates very strong intellectual property rights may have gone too far in protecting the interests of the innovator." (p. 58-59), and "The Japanese patent system subordinates the short-term interests of the innovator in the creation of exclusionary rights to the broader policy goal of diffusion of technology." (p. 48).

[2] Since the late 1960's most industrialized countries adopted the public disclosure system (Ragusa, 1992).

[3] See http://www.ipo.org/COASSN.htm for a list of 86 corporations and 24 associations that support S. 507. The two quotes in the text are taken from http://www2.ipo.org/ipo/Houseltrfeb4.htm and http://www.ipo.org/PRESSRELEASE8598.htm. Additional arguments in favor of the legislation, can be found in http://www.ipo.org/21CPCdocs105th.html.

result in lasting harm to the United States and the world."[4] Given these widely conflicting views on the pending legislation, it seems that a formal economic analysis of the impact of public disclosure of patent applications is badly needed.

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, Regibeau, and Rockett, 1996; Eswaran and Gallini, 1996; O'Donoghue, 1998; and O'Donoghue, Scotchmer, and Thisse, 1998), priority rules such as "first to file" versus "first to invent" (e.g., Scotchmer and Green, 1990), novelty requirements (e.g., Scotchmer and Green, 1990; Scotchmer 1996; Eswaran and Gallini, 1996; and O'Donoghue, 1998), and the optimal renewal of patents (Cornelli and Schankerman, 1996). However, public disclosure of patent applications (PD) has received very little attention.[5] In this paper we try to fill this gap by developing a model that allows us to study the impact of PD on firms' R&D and patenting behavior and evaluate the resulting implications for consumers' surplus, social welfare, and the incentive to innovate.

Our model considers two firms that engage in a sequential R&D process that may lead to the development of a new technology. The R&D process consists of a research phase and a development phase. The research phase ends when one firm (the "winner" or W for short) makes an innovation. We assume that innovation gives W a head start in the development phase by lowering W's cost of developing the new technology. Having innovated, W faces the following trade-off: Applying for a patent on the innovation allows W to sue the loser of the research phase (ℓ for short) for patent infringement if ℓ develops the new technology. At the same time, the patent reveals information about the innovation to ℓ and hence lowers ℓ's cost in the development phase. The difference between the public disclosure (PD) and the confidential filing (CF) systems in our model is that under the PD system, information on W's innovation is revealed whenever W files for a patent (even if the patent application is eventually rejected), whereas under the CF system, information is revealed only if a patent is actually granted.

We show that the implications of PD depend on the strength of patent protection, which in our model, depends on two factors: (i) the likelihood that the patent office will grant W a patent, which we identify with novelty requirements (weaker requirements mean that patents are more likely to be granted),

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[4] The other Nobel Laureates in economics that signed the letter are Robert Solow, Milton Friedman, John Harsanyi, Merton Miller, Douglass North, Paul Samuelson, William Sharpe, Herbert Simon, and James Tobin. The letter can be found in http://www.alliance-dc.org/aainews/nobel-S507.html

[5] The only exception that we are aware of is Aoki and Prusa (1996) who show that PD credibly commits the first filer to a given technology choice and hence facilitates collusion in the product market.

and (ii) the likelihood that the court will rule in favor of the patentholder in a patent infringement suit, which we identify with the breadth of the patent (broader patents are more likely to be upheld in court). Thus, in our model, the strength of patents depends on the actions of two separate branches of the government: the patent office and the court. When patents provide weak protection against imitation, firms do not file for patents under neither patent system. Therefor PD can matter only if the protection of patents is strong or intermediate.

When patents provide a strong protection against imitation, firms file for a patent regardless of whether their applications are publicly disclosed or not. However, since PD reveals information on W's innovation to ℓ, it induces W to cut its investment in the development phase while encouraging ℓ to invest more. As it turns out, the latter effect is stronger, so the aggregate level of investment increases, and this benefits consumers by raising the likelihood that the new technology will reach the product market. When the cost functions in the development phase are sufficiently convex, social welfare (measured as the sum of consumers' surplus and profits) increases as well because the gap between the investments of W and ℓ shrinks, so the allocation of investments between them becomes more efficient. But, since PD benefits ℓ and hurts W, it weakens the incentive to innovate and become W rather than ℓ.

When the protection of patents is intermediate, W files for a patent under the CF system but not under the PD system. Therefore, PD discourages the dissemination of technological information in this case, contrary to what many proponents of the Examining Procedure Improvements Act argue.[6] Moreover, PD has a negative impact of the average quality of innovations (measured by the reduction in the cost of developing the new technology), for which W files for a patent. Now, the impact of PD on investments in the development phase depends on patent breadth. When patents are relatively broad (i.e., they are more likely to be upheld in court), W cuts its level of investment while ℓ invests more. When patents are relatively narrow, the impact on the investments of W and ℓ is ambiguous, although the aggregate level of investment falls unambiguously. Nonetheless, PD benefits consumers because W does not file for a patent under the PD system, and therefore cannot prevent ℓ from using the new technology

[6] For example, Representative Howard Coble (chairman of the subcommittee on Courts and Intellectual Property) stated in a Congress hearing that "[H.R. 400] will benefit American inventors, innovators, and society at large ... by furthering the constitutional incentive to disseminate information regarding new technologies more rapidly ..." Similarly, Representative 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

if ℓ develops it. When the cost functions in the development phase are sufficiently convex, PD is socially desirable if patents are relatively broad, and socially undesirable otherwise. As in the strong protection case, this is due to the gap between the investments of W and ℓ which is smaller under the PD system when patents are relatively broad and larger when they are relatively narrow. Finally, when patent protection is intermediate, PD has an ambiguous effect on the incentives to innovate because it hurts both W and ℓ. Nonetheless, we are able to show that when the cost of investment in the development phase is quadratic, PD hurts W by more than it hurts ℓ, so overall it weakens the incentives to innovate just as in the strong protection case.

The main conclusions from our analysis then are that PD leads to fewer patent applications, a lower average quality of patents, and fewer innovations, but for a given number of innovations, it raises the probability that new technologies will reach the product market and thereby enhances consumers' surplus and possibly total welfare as well.

Our paper focuses on the trade-off between the role of patents in disseminating technological information and their impact on investments in R&D. This trade-off is also the main focus of Scotchmer and Green (1990), Gallini (1992), and Matutes, Regibeau, and Rockett (1996). Like us, they also consider sequential R&D races and explicitly take into account the decision to patent early innovations.[7] Scotchmer and Green (1990) compare strong novelty requirements (only big innovations can be patented) with weak novelty requirements (small innovations can also be patented) under two priority rules: the first-to-invent rule used in the U.S., and first-to-file rule which is used elsewhere. They show that the first-to-file rule provides a stronger incentive to patent, but also leads to overinvestment in R&D relative to the socially efficient level. In contrast, the first-to-invent rule can sometimes lead to underinvestment. Gallini (1992) shows that extending the life of a patent may induce rivals to "invent around" the patent and thereby discourage investments in R&D. She also shows that the optimal policy is to grant patents which are just broad enough to deter imitation and adjust their length to provide sufficiently strong incentive to engage in R&D. Matutes, Regibeau, and Rockett (1996) consider an innovator who discovers a basic technology and can either wait before patenting it in order to get a head start in developing application technologies, or patent it immediately and risk imitation by rivals. They show that the socially optimal

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[7] The strategic decision to file for a patent is also considered in Horstman, MacDonald, and Slivinski (1985), Waterson (1990), and Anton and Yao (1995). In the first and third papers, the filing decision signals the inventor's private information about the product market to a rival firm. In Waterson (1990), an inventor decides to patent only if a rival decides to produce a close substitute for the inventor's product and the fixed cost of patenting is relatively small.

policy is to reserve a certain number of applications for the innovator in order to encourage him to patent the basic technology early on while preserving his incentive to innovate.

A key assumption in our model is that patents do not provide a perfect protection against imitation. A similar assumption has also been made earlier although the nature of the imperfection is different than in our paper. Waterson (1990) assumes that suing for patent infringement is costly so the patentholder does not always sue the rival, especially if the rival's product is not a close substitute for the inventor's product. Meurer (1989), Anton and Yao (1995), and Choi (1999) assume that patents can be challenged in court and may be ruled as invalid. However, unlike in our model, the possibility that patent applications may be rejected plays no role in these papers, since Meurer (1989) and Choi (1997) begin their analysis from the point where the innovator already has a patent, while Anton and Yao (1995) consider only a confidential filing system. Crampes and Langinier (1998) consider patent renewal decisions. Patent protection in their paper is imperfect because under certain conditions, firms may choose not renew their patents in order to conceal favorable information about the market from potential entrants. Like us, Kabla (1996) also assumes that patent applications may be rejected, but she does not consider the possibility that patents may not be upheld in court.

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 PD and the CF systems. In Section 5 we compare the two systems in terms of the equilibrium patenting and investment behavior of W and ℓ, and in Section 6 and 7 we examine the implications of PD for consumers' surplus and social welfare, and for the incentives to innovate. We conclude in Section 8. All proofs are in the Appendix.

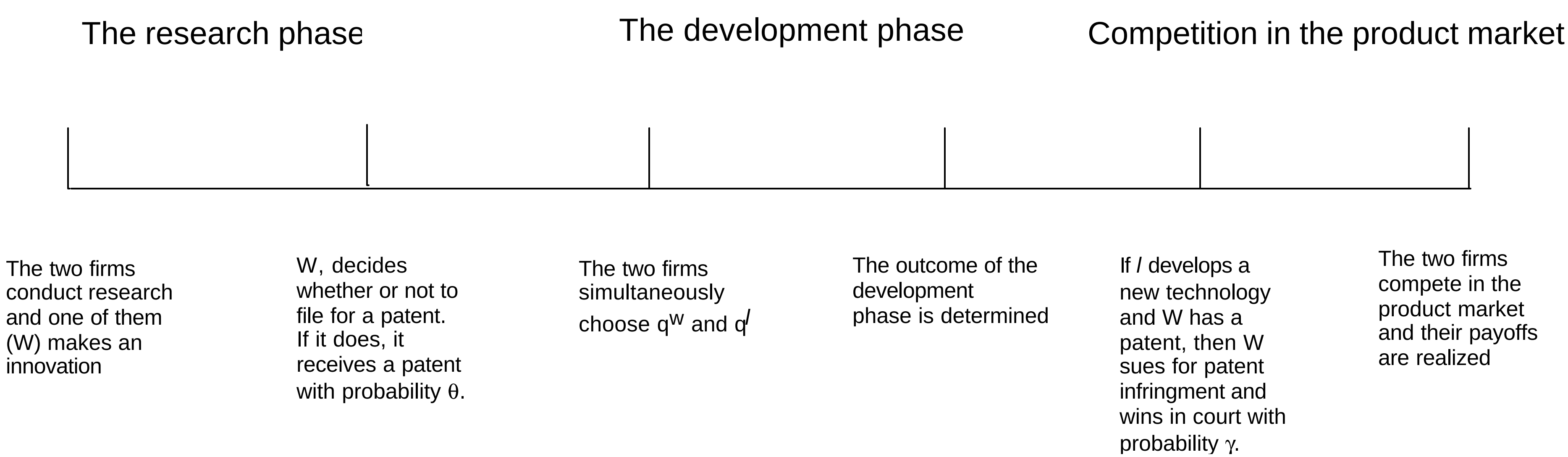
2. The model

Two firms engage in a sequential R&D process that consists of a research phase and a development phase and is followed by competition in the product market. The sequence of events is shown in Figure 1.

☐ **The research phase:** In this phase, the two firms conduct research that may lead to an innovation, which in turn, makes it easier to develop a new technology in the development phase. We assume that the research phase ends when exactly one firm makes an innovation and refer to this firm as "the winner," or W for short, and refer to its rival as "the loser," or ℓ for short.[8] Although ℓ has "lost"

[8] Our modelling choice has at least two interpretations. First, as in Scotchmer and Green (1990), the research phase might be viewed as a stochastic discovery process that ends when one firm makes an

Figure 1: The sequence of events in the sequential R&D game



in the research phase, we assume that by investing in the development phase, it can still develop the new technology, and can even leapfrog W if it succeeds in the development phase while W fails.

☐ **W's filing decision:** Having innovated, W needs to decide whether to apply for a patent. The cost of patenting is that the patent reveals technological information to ℓ and therefore diminishes W's advantage. The benefit from patenting is that if ℓ develops the new technology, W can sue it for patent infringement.[9] In practice, patent protection is imperfect for at least two reasons. First, patent applications can be rejected by the patent office if they are not deemed sufficiently novel, useful, or nonobvious. For instance, the acceptance rates of patent applications in 1993 were 74% in Europe, 67.2% in Japan, and only 65.2% in the U.S.[10] Second, patents are not always upheld in court. For instance, before the 1980's, U.S. courts upheld patents in only 30% of patent infringement cases, although after the establishment of the Court of Appeals for the Federal Circuit in 1982 this number has increased sharply

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innovation (the event that both firms innovate at once is a zero probability event). Second, the research phase could have a fixed length and lead to innovations by both firms, in which case W is the firm with the "better" or more "promising" innovation.

[9] In principle, W may prefer to license the innovation to ℓ instead of suing it, especially if W fails to develop the new technology while ℓ succeeds. But once we consider this possibility, we would also have to consider the possibility that W and ℓ will engage in cross-licensing when both develop the new technology (this allows them to restrain competition in the product market and increase their joint profits from $2\pi_{yy}$ to π_{yn}), as well as the possibility that W will license the innovation to ℓ before the development phase begins, or even cooperate with ℓ in the development phase in some other fashion (say by forming a research joint venture with ℓ). However, a serious consideration of these agreements, will also require us to take into account the potential responses of the antitrust authorities, and the impact of various features of the legal system on the terms of cooperation (see Aoki and Hu, 1999). All of these considerations are well beyond the scope of the current paper and we believe that they should be left for a separate paper that will focus on the impact of PD on the licensing of innovations.

[10] These numbers were constructed from Table II-8, p. 26, in Institute for Intellectual Property, 1995. The acceptance rate of patents may also vary across industries. For example, by dividing the number of patents registered in Japan in 1995 by the total number of patent applications in 1992 (allowing for a typical 3 years examination period) we can obtain a crude estimate of the acceptance rates of patent applications for the 7 patent groups traditionally used by the JPO. The estimates are 44.8% for "chemicals, materials, and textiles," 40.1% for "consumer products," 39.7% for "architectural," 34.4% for "machine engineering," 34.2% for "treatment, manipulation, and transportation," 25.5% for "physics," and 25.2% for "electric" (JPO 1992 Yearbook Table II-11, JPO 1995 Yearbook Table IV-3). These estimates are low compared with the overall acceptance rate in Japan reported in the text because the denominator in the latter is the number of examined applications which accounts in Japan to about half of the total number of patent applications.

to 80% (Warshofsky, 1994 p. 8-9).[11] To capture these imperfections of the patent office and the court, we assume that a patent is granted with probability $\theta \in [0, 1]$ and the court rules in favor of W with probability $\gamma \in [0, 1]$. The parameter θ can be thought of as reflecting novelty requirements, with higher values of θ being associated with weaker requirements. The parameter γ can be interpreted as a measure of patent breadth: as γ increases, the patent becomes broader and hence is more likely to be upheld in court.[12] As we shall see, unlike, say, Scotchmer and Green (1990), the distinction between novelty requirements and patent breadth plays an important role in our analysis. Throughout we treat θ and γ as exogenous parameters.[13]

☐ **The development phase:** Given W's filing decision, but before the patent office decides whether to grant W a patent, W and ℓ simultaneously choose how much to invest in the development of the new technology that can boosts their profits in the product market.[14] In principle, the advantage that the innovation confers on W can be modelled either by assuming that, all else equal, W has a higher probability, q, of developing the new technology, or that W has a lower cost of achieving a given q.[15]

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[11] Hylton (1993) estimates that between 1978 and 1985, U.S. courts upheld patents in 48% of patent infringement cases. In Japan, plaintiffs won in 51 cases out of 478 intellectual property cases concluded in the lower courts in 1995 (these cases include patents, utility models, industrial designs, and copyrights), while 298 cases settled out of court (Japanese Supreme Court General Secretariat, 1996).

[12] This interpretation differs from those in the literature, where breadth was identified with the flow rates of the patentee's profits (Gilbert and Shapiro, 1990, and Gallini 1992), the minimal degree of horizontal differentiation between the patentee's and the rival's products (Klemperer, 1990; Eswaran and Gallini, 1996; and Crampes and Langinier, 1998), the minimal degree of vertical differentiation between the patentee's and the rival's products (Green and Scotchmer, 1995; Chang, 1995; O'Donoghue, 1998; and O'Donoghue, Scotchmer, and Thisse, 1998), and the number of applications of the innovation that are reserved for the patentee's exclusive use (Matutes, Regibeau, and Rocket, 1996).

[13] 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 W can choose the scope of its disclosure, the breadth of W's patent, γ, would be an endogenous variable.

[14] The assumption that investment decisions are made before the patent office decides whether to grant a patent reflects the fact that patent examination is typically a lengthy process. For instance, in 1997, the average pendency of patents in the U.S. was 26.5 months from the original filing date (see Table 4 in the 1997 U.S. Patent office annual report).

[15] In Scotchmer and Green (1990), the advantage of the leader in the R&D race is a hybrid of the two cases. In their model, R&D follows a Poisson discovery process and the discovery of an advanced technology requires two Poisson hits. Therefore, the probability that a firm that already achieved the first

We adopt the second approach and assume that W's cost in the development phase is C(q), while ℓ's cost is $\beta_L C(q)$ if it learns about W's innovation, and $\beta_H C(q)$ otherwise, where $\beta_H > \beta_L > 1$. The assumption that $\beta_H > \beta_L$ reflects the idea that ℓ benefits from learning about W's innovation. Indeed, Mansfield, Schwartz and Wagner (1981) examined data from 48 product innovations and found that the ratio between the cost of imitating an existing product (β_L in our model) and the cost of innovating it from scratch (β_H in our model) was on average 0.65. The assumption that $\beta_L > 1$ reflects the idea that W enjoys a cost advantage over ℓ even if ℓ imitates it. This advantage could be, say, because of a learning-by-doing effect, a delay in the disclosure of the patent application (18 months in most countries), or simply because the patent does not reveal the full extent of W's information.

☐ **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 competition, we simply assume that if only one firm uses the new technology (this firm can be either W or ℓ), 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 use the new technology, the net present value of their profits is π_{yy}, and if neither firm uses the new technology, the net present value of their profits is π_{nn}. Throughout, we make the following assumptions:

A1 $\pi_{yn} > \pi_{yy} \geq \pi_{nn} \geq \pi_{ny}$

A2 $\pi_{yn} + \pi_{ny} > 2\pi_{yy}$

A3 C is twice continuously differentiable, increasing, and strictly convex, with $C'(0) = 0$, $C'(1) > \pi_{yn}-\pi_{nn}$, and $C''(q) > \pi_{yn}+\pi_{ny}-\pi_{yy}-\pi_{nn}$ for all $q \in [0, 1]$.

Assumption A1 is consistent with a broad class of duopoly models; for example, if the new technology is cost-reducing, then in a (one shot) Cournot model with homogeneous products, $\pi_{yn} > \pi_{yy} > \pi_{nn} > \pi_{ny}$, while in a Bertrand model with homogeneous products and linear cost functions, $\pi_{yn} > 0 = \pi_{yy} = \pi_{nn} = \pi_{ny}$. Assumption A2 rules out the possibility that the new technology will be licensed since it states that it is never optimal to share the new technology. Again, this holds in a broad class of duopoly models including Cournot (provided that production costs are not too convex) and Bertrand with linear cost

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hit will discover the advanced technology before any given date is twice as high as that of the rival firm while its expected cost of discovery is half of that of the rival firm.

functions. Assumption A3 ensures that the best-response functions of W and ℓ are well-behaved.[16]

☐ **The patent system:** We consider two types of patent systems. Under the first, which we call the "public disclosure system" (PD system), the contents of patent applications are publicly disclosed (possibly with some delay). This system is used in most industrialized countries, and it has the advantage of facilitating information dissemination. The disadvantage of this system is that it exposes firms to the risk that their technological information will be revealed to rivals even if eventually no patent is granted. Under the second patent system which is currently used in the U.S., the contents of the patent application are made public only when a patent is actually granted, but not otherwise. We refer to this system as the "confidential filing system" (CF system).

☐ **The expected payoff functions of the firms:** Let q^w and q^ℓ be the investment levels of W and ℓ in the development phase and recall that they also represent the probabilities that W and ℓ will develop the new technology. When W files for a patent, it can prevent ℓ from using the new technology (if ℓ develops it) with probability $\gamma\theta$, which is the probability that a patent is granted and is upheld in court. Consequently, the probability that ℓ will develop the new technology and will be able to use it is $q^\ell(1-\gamma\theta)$. Therefore, when W files for a patent, its expected payoff under both patent systems is given by

$$\begin{aligned}\pi^w(q^w,q^\ell \mid F) \;=\; & q^w\left[q^\ell(1-\gamma\theta)\pi_{yy} + \left(1-q^\ell(1-\gamma\theta)\right)\pi_{yn}\right] \\ & + (1-q^w)\left[q^\ell(1-\gamma\theta)\pi_{ny} + \left(1-q^\ell(1-\gamma\theta)\right)\pi_{nn}\right] - C(q^w).\end{aligned} \tag{1}$$

Unlike W, ℓ's expected payoff depends on the type of the patent system in use. Under the PD system, the expected payoff of ℓ when W files for a patent is given by

$$\begin{aligned}\pi^\ell(q^w,q^\ell \mid F) \;=\; & q^w\left[q^\ell(1-\gamma\theta)\pi_{yy} + \left(1-q^\ell(1-\gamma\theta)\right)\pi_{ny}\right] \\ & + (1-q^w)\left[q^\ell(1-\gamma\theta)\pi_{yn} + \left(1-q^\ell(1-\gamma\theta)\right)\pi_{nn}\right] - \beta_L C(q^\ell).\end{aligned} \tag{2}$$

Under the CF system, ℓ's expected payoff function, denoted $\bar{\pi}^\ell(q^w,q^\ell \mid F)$, is given by a similar expression, except that ℓ's cost of investment is higher, because ℓ learns about W's innovation only when a patent is granted, and this occurs with probability θ. Moreover, since patents are typically issued more

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[16] Note that Assumption A2 and the assumption that $\pi_{yn} \geq \pi_{nn}$ ensure that $\pi_{yn}-\pi_{nn} \geq \pi_{yy}-\pi_{ny}$; hence, $C'(1) > \pi_{yn}-\pi_{nn}$ implies that it is too costly to invest up to the point where developing the new technology becomes a sure thing, regardless of whether the rival firm has the new technology.

than 18 month after the filing date, we assume that ℓ's cost under the CF system, conditional on W getting a patent, is $\beta_M C(q^\ell)$, where $\beta_L < \beta_M < \beta_H$. With probability 1-θ, W's patent application is rejected and ℓ does not learn about W's innovation, in which case its cost is $\beta_H C(q^\ell)$. Thus, ℓ's expected cost of investment under the CF system when W files for a patent is $\beta_\theta C(q^\ell)$, where $\beta_\theta \equiv \theta\beta_M+(1-\theta)\beta_H$.

Absent filing, the expected payoffs of W and ℓ do not depend on the patent system in use. Since now W cannot prevent ℓ from using the new technology if ℓ develops it, W's expected payoff under both systems is

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

This expression coincides with $\pi^w(q^w,q^\ell \mid F)$ if either $\gamma = 0$ or $\theta = 0$. Similarly, the expected payoff of ℓ under both systems is

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

This expression differs from $\pi^\ell(q^w,q^\ell \mid F)$ in two ways: first, the probability that ℓ uses the new technology in the product market is now q^ℓ instead of $q^\ell(1-\gamma\theta)$. Second, absent filing, ℓ does not learn about W's innovation, so its cost of investment is $\beta_H C(q^\ell)$ instead of $\beta_L C(q^\ell)$.

☐ **The solution concept:** For each patent system, we solve the model backwards to obtain a subgame perfect equilibrium. Given W's filing decision, the development phase has a filing subgame and a no-filing subgame. For each subgame, we solve for the Nash equilibrium levels of investment. Then we compare W's equilibrium payoff across the two subgames and solve for W's filing decision. Finally, we compare the two patent systems in terms of their impact on consumers, on social welfare, and on the incentives to innovate.

3. The Public Disclosure (PD) system

When W files for a patent, its best-response function, $R^w(q^\ell \mid F)$, is determined implicitly by

$$\frac{\partial\pi^w(q^w,q^\ell \mid F)}{\partial q^w} = q^\ell(1-\gamma\theta)\left(\pi_{yy}-\pi_{ny}\right) + \left(1-q^\ell(1-\gamma\theta)\right)\left(\pi_{yn}-\pi_{nn}\right) - C'(q^w) = 0. \tag{5}$$

Similarly, the best-response function of ℓ, $R^\ell(q^w \mid F)$, is determined implicitly by

$$\frac{\partial\pi^{\ell}(q^{w},q^{\ell}\,|\,F)}{\partial q^{\ell}} \;=\; (1-\gamma\,\theta)\left[q^{w}\left(\pi_{yy}-\pi_{ny}\right)+(1-q^{w})\left(\pi_{yn}-\pi_{nn}\right)\right]-\beta_{L}C'(q^{\ell}) \;=\; 0. \qquad \textbf{(6)}$$

Assumptions A1 and A3 ensure that $R^w(q^\ell \mid F)$ and $R^\ell(q^w \mid F)$ are well-defined, single-valued, and downward sloping in the (q^w, q^ℓ) space. Hence, q^w and q^ℓ are strategic substitutes. A Nash equilibrium in the filing subgame, (q^w_F,q^ℓ_F), is determined by the intersection of $R^w(q^\ell \mid F)$ and $R^\ell(q^w \mid F)$; since q^w and q^ℓ are probabilities, the equilibrium point must lie in the unit square. In the Appendix we prove that Assumptions A1-A3 ensure the existence of a unique Nash equilibrium in which q^w_F, $q^\ell_F \in [0, 1]$.

When W does not file for a patent, the two best-response functions, $R^w(q^\ell \mid NF)$ and $R^\ell(q^w \mid NF)$, respectively, are implicitly defined by:

$$\frac{\partial\pi^{w}(q^{w},q^{\ell}\,|\,NF)}{\partial q^{w}} \;=\; q^{\ell}\left(\pi_{yy}-\pi_{ny}\right)+\left(1-q^{\ell}\right)\left(\pi_{yn}-\pi_{nn}\right)-C'(q^{w}) \;=\; 0, \qquad \textbf{(7)}$$

and

$$\frac{\partial\pi^{\ell}(q^{w},q^{\ell}\,|\,NF)}{\partial q^{\ell}} \;=\; q^{w}\left(\pi_{yy}-\pi_{ny}\right)+(1-q^{w})\left(\pi_{yn}-\pi_{nn}\right)-\beta_{H}C'(q^{\ell}) \;=\; 0. \qquad \textbf{(8)}$$

Again, Assumptions A1 and A3 ensure that $R^w(q^\ell \mid NF)$ and $R^\ell(q^w \mid NF)$ are well-defined, single-valued, and downward sloping. A Nash equilibrium in the no-filing subgame, (q^w_{NF},q^ℓ_{NF}), is determined by the intersection of $R^w(q^\ell \mid NF)$ and $R^\ell(q^w \mid NF)$. In the Appendix we prove that Assumptions A1-A3 ensure that there exists a unique equilibrium in which q^w_{NF}, $q^\ell_{NF} \in [0, 1]$.

To compare the outcomes of the filing and the no-filing subgames and determine when W files for a patent, we first establish the following result:

Lemma 1: *The equilibrium levels of investment in the development phase under the PD system have the following properties:*

(i) q^w_{NF} *and* q^ℓ_{NF} *are independent of* γ *and* θ, *whereas* q^w_F *increases and* q^ℓ_F *decreases with* $\gamma\theta$;

(ii) $q^\ell_{NF} < q^\ell_F < q^w_F < q^w_{NF}$ *when* $\gamma\theta = 0$ *and* $q^\ell_F < q^\ell_{NF} < q^w_{NF} < q^w_F$ *when* $\gamma\theta \geq 1\text{-}\beta_L/\beta_H$;

(iii) $q^w_F+q^\ell_F > q^w_{NF}+q^\ell_{NF}$ *for all* $\gamma < 1\text{-}\beta_L/\beta_H$.

Figure 2a shows the equilibrium points in the filing subgame, F_0, and the no-filing subgame, NF, when $\gamma\theta = 0$. Then W gets no protection if it files for a patent, so $R^w(q^\ell \mid F) = R^w(q^\ell \mid NF)$. As for ℓ, its marginal benefit from q^ℓ is the same in the two subgames because W's patent is never upheld in court.

But, since $\beta_H > \beta_L$, the marginal cost of q^ℓ is higher in the no-filing subgame, so $R^\ell(q^w | F) > R^\ell(q^w | NF)$. Consequently, F_0 lies northwest of NF. As $\gamma\theta$ increases, W gets more patent protection, and as Figure 2b shows, $R^w(q^\ell | F)$ shifts to the right whereas $R^\ell(q^w | F)$ shifts down. As a result, the equilibrium point moves southeast from F_0 to F. However, so long as $\gamma\theta < 1-\beta_L/\beta_H$, F remains above a 45 degrees line passing through NF, so the aggregate level of investment is higher in the filing subgame. Figure 2c shows that when $\gamma\theta \geq 1-\beta_L/\beta_H$, $R^\ell(q^w | F)$ drops below $R^\ell(q^w | NF)$, so F is attained southeast of NF (but not necessarily above a 45 degrees line passing though NF). Hence, in the filing subgame, $q^w_F > q^w_{NF}$ and $q^\ell_F < q^\ell_{NF}$. In all cases, the assumption that $\beta_H > \beta_L > 1$ ensures that F_0, NF, and F lie below a 45 degrees line passing through the origin, so $q^w > q^\ell$.

Now let $\pi^w_F \equiv \pi^w(q^w_F,q^\ell_F | F)$ and $\pi^w_{NF} \equiv \pi^w(q^w_{NF},q^\ell_{NF} | NF)$ be the Nash equilibrium payoffs of W in the filing and in the no-filing subgames, and define π^ℓ_F and π^ℓ_{NF} similarly. Then,

Proposition 1: *There exists a critical value of* $\gamma\theta$*, denoted* $\overline{\gamma\theta}$*, where* $\overline{\gamma\theta} \in (0, 1-\beta_L/\beta_H)$*, such that* $\pi^w_F \gtreqless \pi^w_{NF}$ *as* $\gamma\theta \gtreqless \overline{\gamma\theta}$*. The critical value* $\overline{\gamma\theta}$ *is decreasing with* β_L *and increasing with* β_H*. Furthermore,* $\pi^\ell_F < \pi^\ell_{NF}$ *whenever* $\gamma\theta > 1-\beta_L/\beta_H$*.*

Proposition 1 implies that W files for a patent if and only if the effective protection of patents, $\gamma\theta$, exceeds a threshold level, $\overline{\gamma\theta}$. The intuition for this is straightforward. When $\gamma\theta$ is small, W does not file for a patent because this reveals technological information to ℓ, while offering W little protection against imitation. As $\gamma\theta$ increases, patents receive more protection so filing become more attractive to W. As soon as $\gamma\theta > \overline{\gamma\theta}$, W begins to file for a patent because its expected benefit from being more likely to be the sole user of the new technology exceeds its corresponding loss from revealing technological information to ℓ. Proposition 1 also shows that the threshold $\overline{\gamma\theta}$ is bounded from above by $1-\beta_L/\beta_H$, where β_L/β_H is the ratio of imitation to innovation costs. This implies that we should expect more patent applications when (i) the cost of imitating W's patent is high (i.e., β_L is high), and (ii) the cost of developing the new technology from scratch is low (i.e., β_H is low). While implication (i) is obvious, implication (ii) may seem surprising at first glance. But, as β_H falls, ℓ invests more in the no filing subgame and is therefore more likely to develop the new technology. As a result, W has a stronger incentive to file for a patent and try to prevent ℓ from using the new technology.

We conclude this section by noting that since the innovation lowers W's cost of developing the new technology from $\beta_H C(q)$ to $C(q)$, it is natural to associate higher values of β_H with innovations of higher quality. That is, the higher is the quality of the innovation, the larger is the reduction in W's cost.

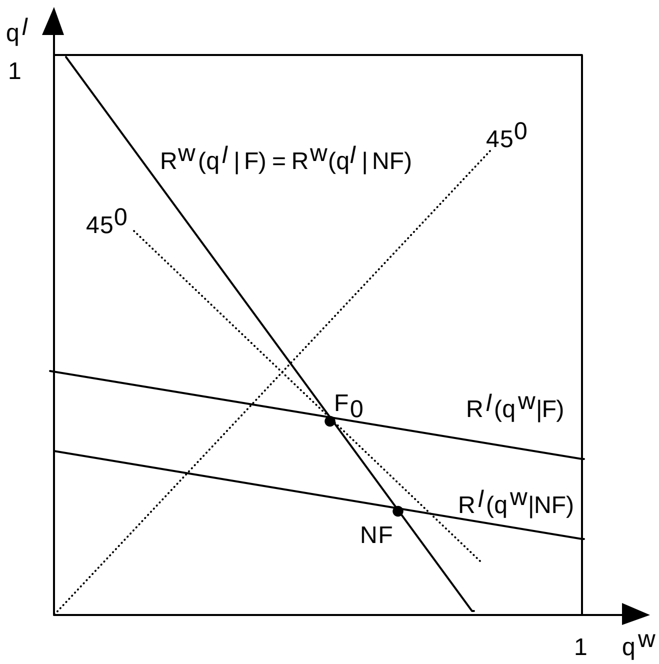


Figure 2a: The best-response functions under the PD system when $\gamma\theta = 0$

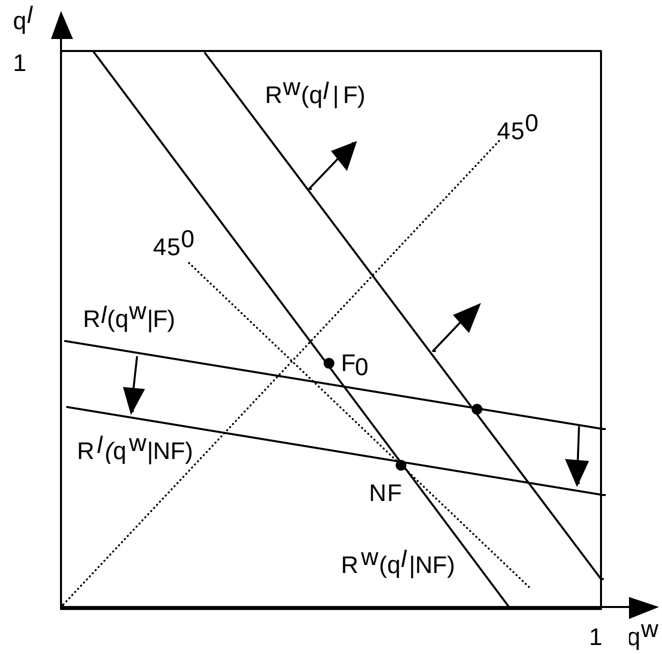


Figure 2b: The best-response functions under the PD system when $0 < \gamma\theta < 1\text{-}\beta_H/\beta_L$

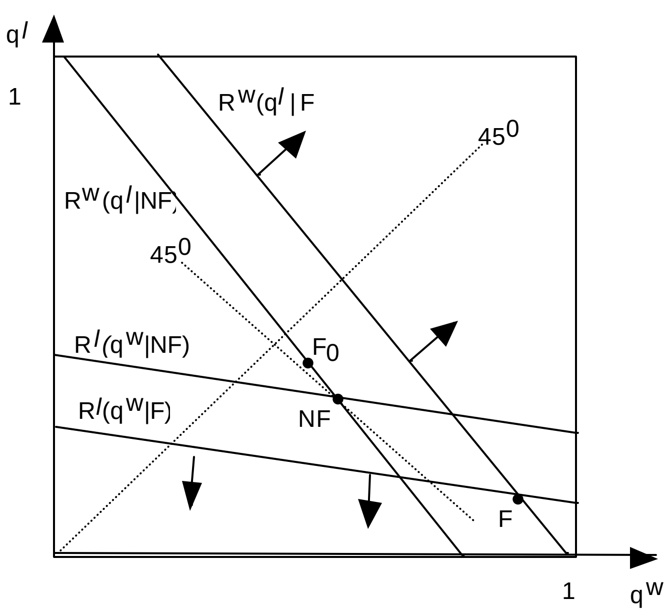


Figure 2c: The best-response functions under the CF system when $\gamma\theta > 1\text{-}\beta_H/\beta_L$

Recalling from Proposition 1 that the threshold for filing for a patent, $\overline{\gamma\theta}$, is increasing with β_H, it follows that the higher is the quality of the W's innovation, the smaller is the set of parameters for which W files for a patent. The reason is that an increase in β_H raises the cost of patenting because it means that more information is revealed to ℓ (and reduces ℓ's cost from $\beta_H C(q)$ to $\beta_L C(q)$). Therefore our model yields the interesting prediction that when patent protection is imperfect, W files for a patent only if the quality of its innovation is not too high. Otherwise, W is better-off relying on trade secrets.

4. The Confidential Filing (CF) system

In this section we solve for the Nash equilibrium in the filing and in the no-filing subgames under the CF system and solve for W's filing decision. Since absent filing, the expected payoffs of W and ℓ do not depend on the patent system in use, the Nash equilibrium in the no-filing subgame continues to be (q^w_{NF}, q^ℓ_{NF}). As for the filing subgame, W's expected payoff is also the same across the two patent systems, so it best-response function, $R^w(q^\ell \mid F)$, continues to be defined implicitly by equation (5). The best-response function of ℓ, $\bar{R}^\ell(q^w \mid F)$, is now defined implicitly by

$$\frac{\partial \bar{\pi}^\ell(q^w, q^\ell \mid F)}{\partial q^\ell} = (1-\gamma\theta)\left[q^w(\pi_{yy}-\pi_{ny}) + (1-q^w)(\pi_{yn}-\pi_{nn})\right] - \beta_\theta C'(q^\ell) = 0, \qquad \textbf{(9)}$$

where $\beta_\theta \equiv \theta\beta_M+(1-\theta)\beta_H$. Assumptions A1 and A3 ensure that $\bar{R}^\ell(q^w \mid F)$ is well-defined, single-valued and downward sloping in the (q^w, q^ℓ) space. A Nash equilibrium in the filing subgame, ($\bar{q}^w_F$, $\bar{q}^\ell_F$), is determined by the intersection of $R^w(q^\ell \mid F)$ and $\bar{R}^\ell(q^w \mid F)$. In the Appendix we prove that the Nash equilibrium is unique and $\bar{q}^w_F, \bar{q}^\ell_F \in (0,1)$.

Equation (9) reveals that under the CF system, novelty requirements affect the filing subgame not only through the effective protection parameter, $\gamma\theta$, but also through ℓ's cost function. Hence, unlike the PD system, now γ and θ have potentially different impact on the equilibrium.

Lemma 2: *The equilibrium levels of investment in the development phase under the CF system have the following properties:*

(i) $\bar{q}^w_F$ *increases and* $\bar{q}^\ell_F$ *decreases with* γ, $\bar{q}^w_F$ *increases and* $\bar{q}^\ell_F$ *decreases with* θ *if* $\gamma \geq 1-\beta_M/\beta_H$, *and either* $\bar{q}^w_F$ *increases, or* $\bar{q}^\ell_F$ *increases, or both increase with* θ *if* $\gamma < 1-\beta_M/\beta_H$.

(ii) $q^\ell_{NF} = \bar{q}^\ell_F < \bar{q}^w_F = q^w_{NF}$ *if* $\theta = 0$, $\bar{q}^\ell_F < q^\ell_{NF} < q^w_{NF} < \bar{q}^w_F$ *if* $\theta > 0$ *and* $\gamma \geq 1-\beta_L/\beta_H$, *and either* $q^\ell_{NF} < \bar{q}^\ell_F$, *or* $q^w_{NF} < \bar{q}^w_F$, *or both, if* $\theta > 0$ *and* $\gamma < 1-\beta_M/\beta_H$.

(iii) $\bar{q}^w_F+\bar{q}^\ell_F > q^w_{NF}+q^\ell_{NF}$ *for all* $\gamma < 1-\beta_M/\beta_H$.

Figure 3a shows that in the extreme case where $\theta = 0$ (novelty requirements are so strict that no patents are granted), the equilibrium points in the filing subgame, F_0, and in the no-filing subgame, NF, coincide. As θ increases, novelty requirements are relaxed and patents are more likely to be granted; as a result, $\bar{R}^w(q^\ell \mid F)$ shifts to the right. As for ℓ, an increase in θ lowers the probability that ℓ will be able to use the new technology in the product market, so the marginal benefit from q^ℓ falls; but since ℓ is also more likely to learn about W's innovation, the marginal cost of q^ℓ falls as well. Whether $\bar{R}^\ell(q^w \mid F)$ shifts up or down, depends on the value of γ. When $\gamma \geq 1\text{-}\beta_L/\beta_H$, patents are relatively broad, so the marginal benefit from q^ℓ falls more than the marginal cost of q^ℓ. Consequently, as Figure 3b shows, $\bar{R}^\ell(q^w \mid F)$ shifts down, so the equilibrium point in the filing subgame, $\bar{F}$, lies southeast of NF. When $\gamma < 1\text{-}\beta_L/\beta_H$, a small increase in θ lowers the marginal cost of q^ℓ by more than it lowers the marginal benefit from q^ℓ, so $\bar{R}^\ell(q^w \mid F)$ shifts up. Figure 3c shows that now, $\bar{F}$, lies either northwest, northeast, or southeast of NF, so the comparison between the filing and the no-filing subgames becomes ambiguous. Nonetheless, part (iii) of Lemma 2 shows that the aggregate level of investment is larger in the filing subgame, so $\bar{F}$ lies above a 45 degree line passing through NF. Since $\beta_H > \beta_\theta > 1$, $\bar{F}$ and NF lie below a 45 degrees line passing through the origin, so $q^w > q^\ell$.

Let $\bar{\pi}^w_F \equiv \pi^w(\bar{q}^w_F, \bar{q}^\ell_F \mid F)$ and $\bar{\pi}^\ell_F \equiv \bar{\pi}^\ell(\bar{q}^w_F, \bar{q}^\ell_F \mid F)$ be the equilibrium payoffs of W and ℓ in the filing subgame, and recall that the equilibrium payoffs in the no-filing subgame are π^w_{NF} and π^ℓ_{NF}, as in Section 3. Now,

Proposition 2: *For each $\theta > 0$, there exists a critical value of γ, denoted $\bar{\gamma}$, where $\bar{\gamma} \in (0, 1\text{-}\beta_L/\beta_H)$, such that $\bar{\pi}^w_F \gtreqless \pi^w_{NF}$ as $\gamma \gtreqless \bar{\gamma}$. The critical value $\bar{\gamma}$ is decreasing with β_M, increasing with β_H, and moreover, it is increasing with θ if and only if the elasticity of $\bar{q}^\ell_F$ with respect to θ exceeds $\bar{\gamma}\theta/(1\text{-}\bar{\gamma}\theta)$. Furthermore, $\pi^\ell_{NF} > \bar{\pi}^\ell_F$ whenever $\gamma > 1\text{-}\beta_M/\beta_H$.*

Proposition 2 implies that given the likelihood of getting a patent, θ, W files for a patent under the CF system if and only if patent breadth exceeds a threshold level, $\bar{\gamma}$. This threshold is bounded from above by $1\text{-}\beta_M/\beta_H$ and it may either increase or decrease with θ, depending on the sensitivity of $\bar{q}^\ell_F$ with respect to θ. To see why, note that an increase in θ affects W directly by raising its chances to get a patent and indirectly by affecting $\bar{q}^\ell_F$. When $\bar{q}^\ell_F$ decreases, the second indirect effect reinforces the first direct effect, and W has a stronger incentive to file. When $\bar{q}^\ell_F$ increases, filing for a patent becomes riskier from W's perspective since it boosts ℓ chances to develop the new technology; consequently, now the indirect effect weakens W's incentive to file. When the elasticity of $\bar{q}^\ell_F$ with respect to θ is

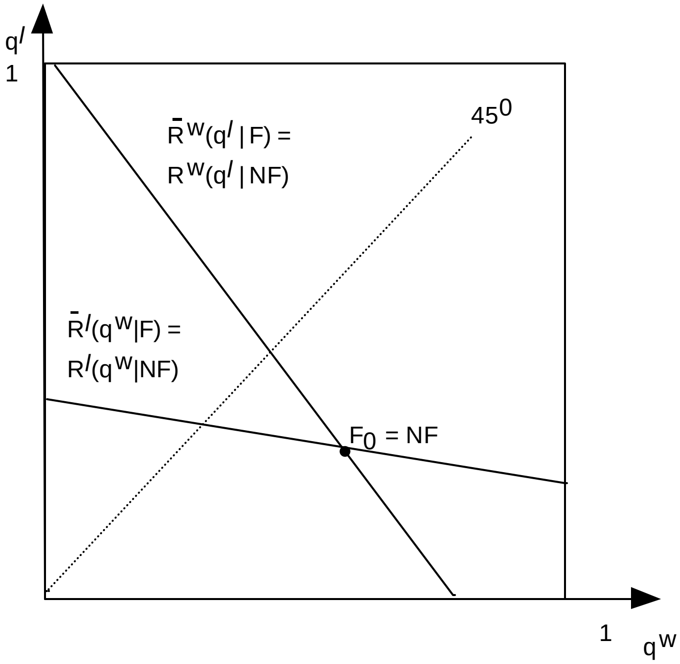


Figure 3a: The best-response functions under the CF sytem when $\theta = 0$

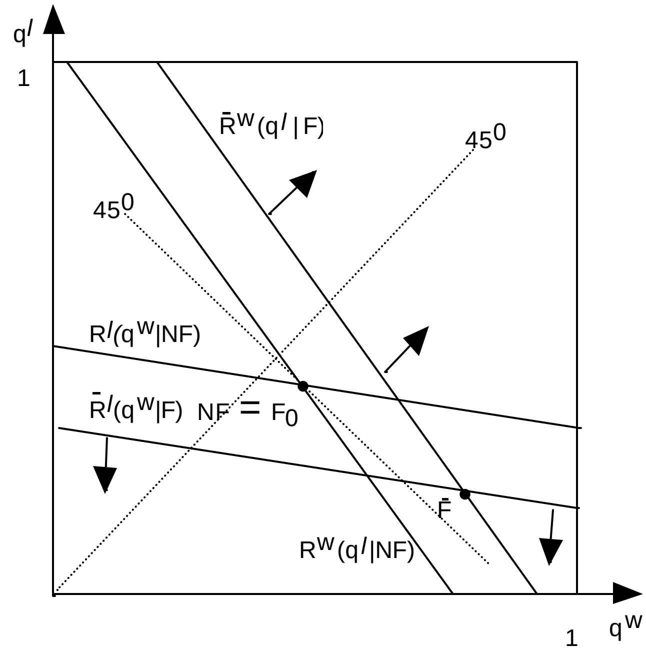


Figure 3b: The best-response functions under the CF system when $\gamma > 1 - \beta_L/\beta_H$.

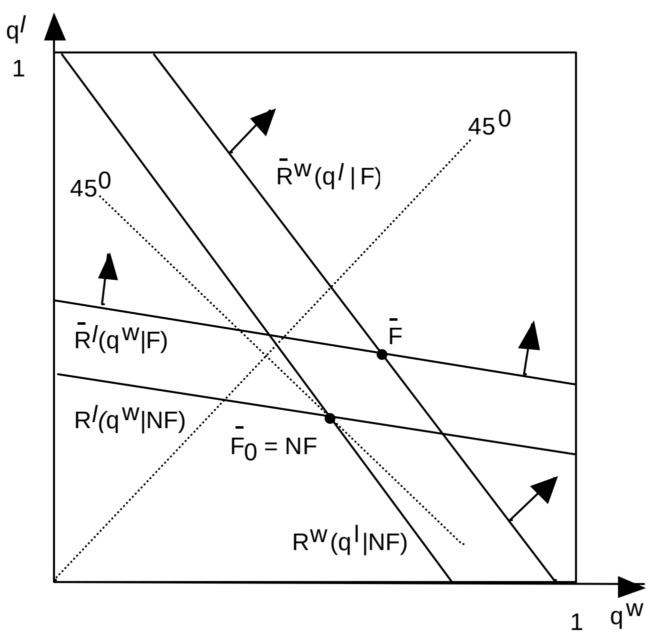


Figure 3c: The best-response functions under the CF system when $\gamma < 1 - \beta_L/\beta_H$.

sufficiently large, the negative indirect effect dominates, so $\overline{\gamma}$ declines with θ, implying that W files for a patent for a smaller set of parameters.

As in the case of the PD system, the threshold for filing for a patent is increasing with β_H. Since β_H can be interpreted as a measure of the quality of W's innovation, it follows that when the innovation has a higher quality (i.e., when β_H is high), the set of parameters for which W files for a patent shrinks.

5. Comparing the PD and the CF systems

Having characterized the equilibrium levels of investment in the development phase and solved for W's filing decision under each patent system, we now compare the equilibrium outcomes under the two systems. Since PD matters only when W files for a patent, we only need to consider the filing subgames.

Proposition 3: *The equilibrium investment levels and payoffs in the filing subgame under the two patent systems have the following relationships:*

(i) $\overline{q}^{\ell}_F < q^{\ell}_F < q^{w}_F < \overline{q}^{w}_F$ *and* $q^{w}_F + q^{\ell}_F > \overline{q}^{w}_F + \overline{q}^{\ell}_F$

(ii) $\pi^{w}_F < \overline{\pi}^{w}_F$ *and* $\pi^{\ell}_F > \overline{\pi}^{\ell}_F$.

Part (i) of Proposition 3 is illustrated in Figure 4. The expected marginal cost of q^{ℓ} is higher under the CF system since then ℓ has access to W's information only when W gets a patent (even then the information is typically revealed more than 18 month from the filing date). Consequently, $\overline{R}^{\ell}(q^w \mid F)$ lies below $R^{\ell}(q^w \mid F)$. Since W's best-response function is the same under the two patent systems, the equilibrium point under the PD system, F, is attained northwest of the equilibrium point under the a CF system, $\overline{F}$. Given Assumption A3, $\overline{F}$ lies under a 45 degrees line passing through F, so the aggregate level of investment is larger under the PD system.

Part (ii) of Proposition 3 shows that in the filing subgame, PD benefits ℓ and hurts W. The result that $\overline{\pi}^{w}_F > \pi^{w}_F$, together with the results that $\pi^{w}_F > \pi^{w}_{NF}$ whenever $\gamma > \overline{\gamma\theta}/\theta$ (Proposition 1), and that $\overline{\pi}^{w}_F > \pi^{w}_{NF}$ whenever $\gamma > \overline{\gamma}$ (Proposition 2), implies that $\overline{\gamma}$ lies strictly below $\overline{\gamma\theta}/\theta$ in the (γ, θ) space. This has the following implications for W's filing decision:

Proposition 4: *W does not file for a patent under both patent systems if* $\gamma < \overline{\gamma}$*, files for a patent under both systems if* $\gamma > \overline{\gamma\theta}/\theta$*, and files for a patent only under the PD system if* $\overline{\gamma} \leq \gamma \leq \overline{\gamma\theta}/\theta$.

Proposition 4 is summarized in Figure 5. When $\gamma < \overline{\gamma}$, protection is weak since patents are

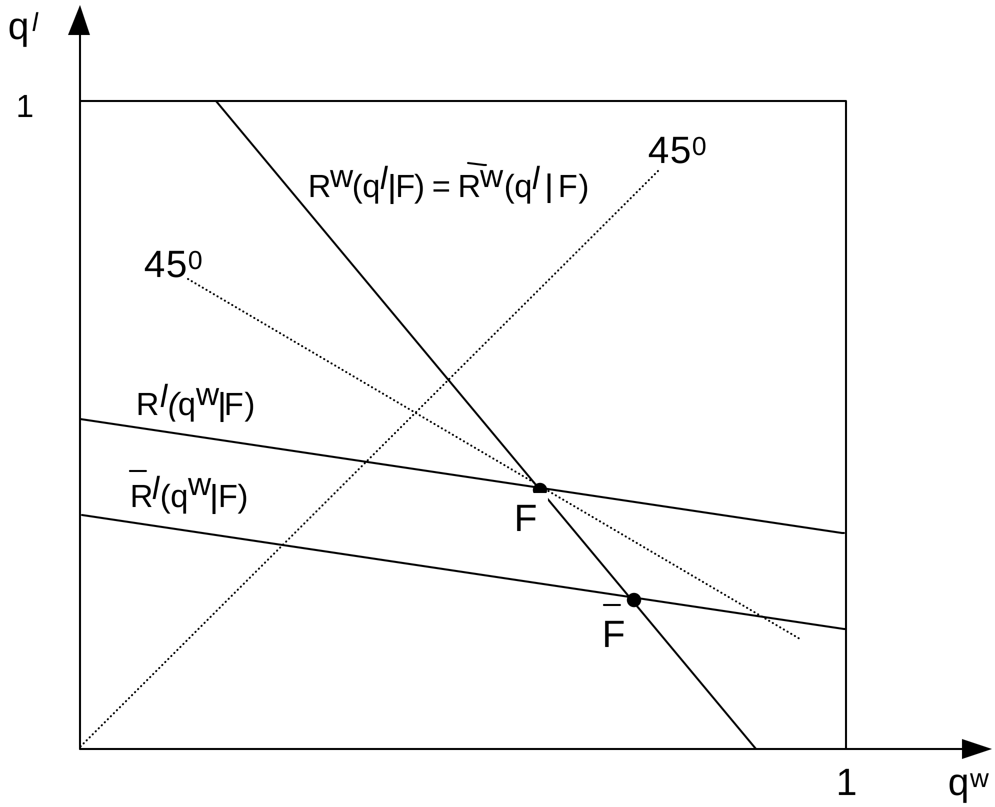


Figure 4: The best-response functions in the filing subgame under the PD and the CF systems

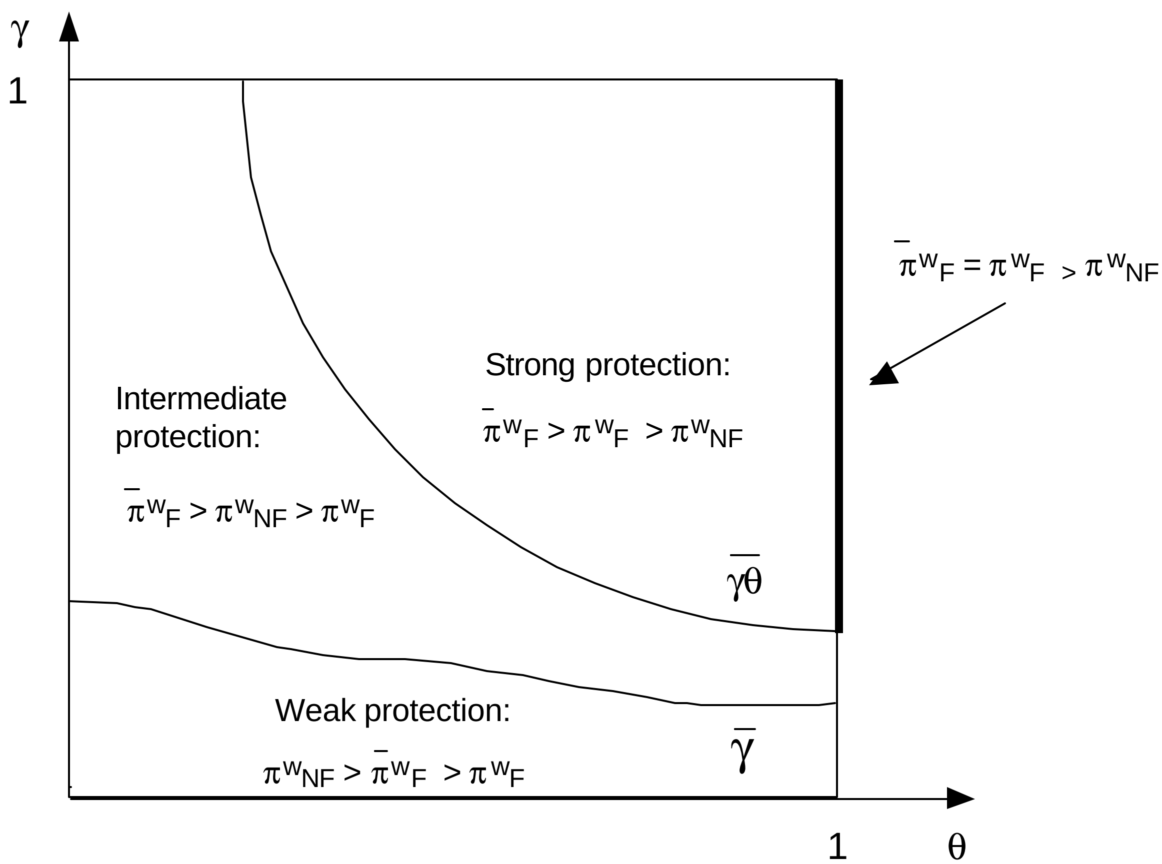


Figure 5: W's equilibrium profits under the two patent systems. W does not file for a patent under both systems when patent protection is weak, files under both systems when patent protection is strong, and files

relatively narrow. Consequently, W does not file for a patent under neither patent system and PD is irrelevant. Examples for industries where this might be the case include some mature industries like textile, food processing, and fabricated metal products (Arundel and Kabala 1998, Levin et. al., 1987). When $\gamma > \overline{\gamma\theta}/\theta$, patents receive strong protection and W files for a patent under both patent systems. Yet, PD is not irrelevant because it affects the investment levels of W and ℓ. Examples for industries where patents are regarded as providing strong protection include pharmaceuticals, organic chemicals, and pesticides (Arundel and Kabala 1998, Levin et. al., 1987, Mansfield, 1986). Finally, when $\overline{\gamma} \leq \gamma \leq \overline{\gamma\theta}/\theta$, patent protection is intermediate and W files for a patent only under the CF system. Industries where patents provide an intermediate protection (relative to other forms of protection 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).

The analysis so far reveals that PD has several important implications. First, Proposition 4 shows that under the PD system, W files for a patent for a smaller set of parameters. This 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." However, Proposition 4 qualifies this argument by suggesting that this adverse effect of PD pertains only to industries in which patent protection is intermediate.

Second, Proposition 4 shows that in the strong protection case, the equilibrium levels of investments in the development phase are q^w_F and q^ℓ_F under the PD system and $\overline{q}^w_F$ and $\overline{q}^\ell_F$ under the CF system. Using part (i) of Proposition 3, this implies that with strong protection, PD leads to a decrease in q^w, and an increase in q^ℓ and in the aggregate level of investment. When patent protection is intermediate, Proposition 4 implies that the equilibrium levels of investment are q^w_{NF} and q^ℓ_{NF} under the PD system and $\overline{q}^w_F$ and $\overline{q}^\ell_F$ under the CF system. Using Lemma 2, it follows that PD leads once again to a decrease in q^w and an increase in q^ℓ and in the aggregate level of investment if $1 - \beta_L/\beta_H < \gamma < \overline{\gamma\theta}/\theta$. When $\overline{\gamma} < \gamma < 1\text{-}\beta_L/\beta_H$, PD has an ambiguous impact on the equilibrium levels of investment, although the aggregate level of investment increases unambiguously.

Third, by revealed preferences, PD hurts W because it induces W to stop filing for patents. This is consistent with Putnam's (1997) estimate that PD is associated with a $479 decrease in the mean value of patents. In our model, W's loss is even larger since Putnam's estimate is conditional on a patent being granted, while we examine the impact of PD on the unconditional expected profit of W. As for ℓ, then part (ii) of Proposition 3 implies that PD benefits ℓ in the strong protection case, and Proposition 2 implies that at least when $\gamma > 1-\beta_L/\beta_H$, it also benefits ℓ in intermediate protection case.

Fourth, in the context of our model it is natural to identify W mainly with small inventors and ℓ mainly with large corporations. This is because large corporations, who are active in product development, are likely to have the capacity and resources needed to absorb the informational spillovers generated by PD, whereas small inventors typically do not have such resources and are mainly busy developing a small number of original innovations. With this interpretation in mind, our model suggests that PD is likely to benefit large corporations and hurt small inventors. This can explain perhaps why the main opposition for the Examining Procedure Improvements Act in the U.S. comes from small and independent inventors while the main support for the legislation comes from large corporations.

Finally, recall that higher values of β_H can be interpreted as representing innovations of higher quality. With this interpretation in mind, we can ask how PD affects the average quality of innovations for which W files for a patent. But, since our model is far too general to provide a conclusive answer to this question, we shall make the following assumption:

A4 $C(q) = rq^2/2$, where $r > \pi_{yn}-\pi_{nn}$.

The restriction on r ensures that Assumption A3 is satisfied.

Proposition 5: *Given Assumption A4, W files for a patent under the PD system if and only if* $\beta_H \leq \beta_L/(1-\gamma\theta)^2$*, whereas under the CF system, it files for a patent if and only if* $\beta_H \leq \beta_M/(1-2\gamma+\theta\gamma^2)$*. Since* $\beta_L/(1-\gamma\theta)^2 < \beta_M/(1-2\gamma+\theta\gamma^2)$*, patent applications have on average higher values of* β_H *under the CF system, implying that the average quality of innovations for which W files for a patent is higher under the CF system than under the PD system.*

Roughly speaking, holding β_L and β_M fixed, an increase in β_H (and hence the quality of the innovation) raises the cost of patenting since it means that more information is revealed to ℓ (ℓ's cost drops from $\beta_H C(q)$ to $\beta_L C(q)$ under the PD system and to $\beta_\theta C(q)$ under the CF system). Therefore, W files for a patent if and only if the quality of the innovation is not too high. But, given Assumption A4, the cost of patenting is higher under the PD system, so on average, PD leads to a reduction in the quality of patented innovations.

6. The implications of PD for consumer surplus and social welfare

Let S_{yy} be the net present value of consumers' 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. Social welfare is given by the sum of consumers' 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 consumers' surplus and social welfare under the two systems is in general very complex, we shall impose Assumption A4. Recalling from Proposition 1 that $\overline{\gamma\theta}$ is implicitly defined by $\pi^{w}{}_{F} = \pi^{w}{}_{NF}$, and recalling from Proposition 2 that $\bar{\gamma}$ is implicitly defined by $\bar{\pi}^{w}{}_{F} = \pi^{w}{}_{NF}$, it is straightforward to establish that given Assumption A4, $\overline{\gamma\theta} \equiv 1 - \sqrt{\beta_L/\beta_H}$ and $\bar{\gamma} \equiv \left(1 - \sqrt{\beta_\theta/\beta_H}\right)/\theta$. Therefore, patents receive a strong protection if $\gamma > \left(1 - \sqrt{\beta_L/\beta_H}\right)/\theta$, intermediate protection if $\left(1 - \sqrt{\beta_\theta/\beta_H}\right)/\theta \le \gamma \le \left(1 - \sqrt{\beta_L/\beta_H}\right)/\theta$, and a weak protection if $\gamma < \left(1 - \sqrt{\beta_\theta/\beta_H}\right)/\theta$. In addition to Assumption A4, we make the following assumptions:

A5 $\quad S_{yy} \ge S_{yn} \ge S_{nn}$, $S_{yy} + S_{nn} \ge 2S_{yn}$, and S_{yn}-$S_{nn} > \pi_{nn}$-π_{ny}

A6 $\quad W_{yy} \ge W_{yn} \ge W_{nn}$

Assumption A5 implies that the net present value of consumers' surplus is increasing with the number of firms that use the new technology at an increasing rate. It also implies that when only one firm develops the new technology, the benefit to consumers outweighs the loss to the firm that failed to develop the technology. Assumption A6 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 A5 and A6 hold in the Cournot model with homogeneous products and a linear demand and in the Bertrand model with linear cost functions.

6.1 Expected Consumers' surplus

The expected consumers' surplus under both filing systems when W files for a patent is given by,

$$S(q^w,q^\ell\,|\,F) \;=\; q^w q^\ell (1-\gamma\theta) S_{yy} + (1-q^w)\big(1-q^\ell(1-\gamma\theta)\big) S_{nn}$$
$$+\left[q^w\big(1-q^\ell(1-\gamma\theta)\big) + (1-q^w)\, q^\ell (1-\gamma\theta)\right] S_{yn}. \qquad \textbf{(10)}$$

Likewise the expected consumers' surplus under both systems absent filing is given by,

$$S(q^w,q^\ell\,|\,NF) \;=\; q^w q^\ell S_{yy} + (1-q^w)\big(1-q^\ell\big) S_{nn} + \left[q^w\big(1-q^\ell\big) + (1-q^w)\, q^\ell\right] S_{yn}. \qquad \textbf{(11)}$$

Let $S_F \equiv S(q^w{}_F, q^\ell{}_F \mid F)$ be the equilibrium expected value of consumers' surplus under the PD system when there is filing, and define $\overline{S}_F \equiv \overline{S}(\overline{q}^w{}_F, \overline{q}^\ell{}_F \mid F)$ similarly for the CF system. When W does not file for a patent, PD plays no role, so the equilibrium expected value of consumers' surplus, denoted $S_{NF} \equiv S(q^w{}_{NF}, q^\ell{}_{NF} \mid NF)$, is the same under both patent systems.

When patents receive strong protection, W files for a patent under both patent systems. Hence, we need to compare S_F and $\overline{S}_F$. Given Assumption A4, the equilibrium levels of investment under the CF system are given by

$$\overline{q}^w_F \;=\; \frac{(\pi_{yn}-\pi_{nn})\big(r\,\beta_\theta + (1-\gamma\theta)^2\,\Pi\big)}{r^2\,\beta_\theta - (1-\gamma\theta)^2\,\Pi^2}, \qquad \overline{q}^\ell_F \;=\; \frac{(\pi_{yn}-\pi_{nn})\,(1-\gamma\theta)\,(r+\Pi)}{r^2\,\beta_\theta - (1-\gamma\theta)^2\,\Pi^2}, \qquad \textbf{(12)}$$

where $\Pi \equiv \pi_{yy}+\pi_{nn}-\pi_{yn}-\pi_{ny} < 0$ by Assumption A2. The assumption that $r > \pi_{yn}-\pi_{nn}$ implies that $r > -\Pi$, and together with the assumption that $\beta_H > \beta_L > 1 \geq 1-\gamma\theta$, this ensures that $\overline{q}^w{}_F$ and $\overline{q}^\ell{}_F$ are strictly between 0 and 1. Under the PD system, the investment levels are also given by equation (12), except that now β_L replaces β_θ. Substituting for $\overline{q}^w{}_F$ and $\overline{q}^\ell{}_F$ into (10),

$$\overline{S}_F \;=\; S_{nn} \;+\; \frac{(\pi_{yn}-\pi_{nn})^2\,(1-\gamma\theta)^2\,(r+\Pi)\big(r\,\beta_\theta + (1-\gamma\theta)^2\,\Pi\big)\,S}{\big(r^2\,\beta_\theta - (1-\gamma\theta)^2\,\Pi^2\big)^2}$$
$$+\;\frac{(\pi_{yn}-\pi_{nn})\big(r\,\beta_\theta + (1-\gamma\theta)^2\,(r+2\Pi)\big)\big(S_{yn}-S_{nn}\big)}{r^2\,\beta_\theta - (1-\gamma\theta)^2\,\Pi^2}, \qquad \textbf{(13)}$$

where $S \equiv S_{yy}+S_{nn}-2S_{yn} > 0$ by Assumption A5. The expression for S_F is identical to $\overline{S}_F$, except that β_L replaces β_θ.

In the intermediate protection case, W files for a patent under the CF system but not under the PD system. Therefore, we need to compare $\overline{S}_F$ and S_{NF}, where S_{NF} is equal to $\overline{S}_F$ when the latter is evaluated at $\theta = 0$ ($\theta = 0$ means that no information is revealed to ℓ under the CF system, exactly as if W did not file for a patent).

Proposition 6: *Suppose that Assumptions A4 and A5 hold and patent protection is intermediate or strong, i.e.,* $\gamma \geq \bar{\gamma}$ *(otherwise PD is irrelevant). Then PD enhances consumers' surplus. Moreover, when patent protection is intermediate, the increase in consumers' surplus due to PD is larger the larger is* γ.

Intuitively, in the strong protection case, W files for a patent under both patent systems; but as Proposition 3 shows, W invests less and ℓ invests more under the PD system. Given Assumption A4, the latter effect dominates, so the new technology is more likely to reach the product market and this makes consumers better-off. Under intermediate protection, W files for a patent under the CF system but not under the PD system. To examine how this affects consumers, note that as γ increases, patents become broader, so W is more likely to block ℓ from using the new technology; hence, consumers' surplus under the CF system, $\bar{S}_F$, decreases with γ. On the other hand, under the PD system, W does not file for a patent so consumers' surplus, S_{NF}, is independent of γ. Since $S_{NF} = \bar{S}_F$ when $\gamma = \left(1 - \sqrt{\beta_\theta / \beta_H}\right)/\theta$, consumers' surplus is higher under a PD system and moreover, the gain of consumers from PD is larger, the larger is γ.

6.2 Expected social welfare

The expected social welfare when W files for a patent is $W_F = S_F + \pi^w_F + \pi^\ell_F$ under the PD system, and $\bar{W}_F = \bar{S}_F + \bar{\pi}^w_F + \bar{\pi}^\ell_F$ under the CF system. When W does not file for a patent, the expected social welfare is $W_{NF} = S_{NF} + \pi^w_{NF} + \pi^\ell_{NF}$. When patents receive a strong protection, W files for a patent under both systems. Hence, the equilibrium expected social welfare is $\bar{W}_F$ under the CF system and W_F under the PD system. Given Assumption A4 and using equations (1), (2), (12), and (13),

$$\begin{aligned}\bar{W}_F = W_{nn} &+ \frac{(\pi_{yn} - \pi_{nn})^2 (1-\gamma\theta)^2 (r + \Pi)\left(r\beta_\theta + (1-\gamma\theta)^2 \Pi\right) S}{\left(r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2\right)^2} \\ &+ \frac{(\pi_{yn} - \pi_{nn})\left(r\beta_\theta + (1-\gamma\theta)^2 (r + 2\Pi)\right)\left(S_{yn} - S_{nn} + \pi_{ny} - \pi_{nn}\right)}{r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2} \\ &+ \frac{(\pi_{yn} - \pi_{nn})^2 r \left(\left(r\beta_\theta + (1-\gamma\theta)^2 \Pi\right)^2 + \beta_\theta (1-\gamma\theta)^2 (r + \Pi)^2\right)}{2\left(r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2\right)^2}.\end{aligned} \quad \textbf{(14)}$$

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

In the intermediate protection case, W files for a patent only under the CF system. Hence, the equilibrium expected social welfare is $\overline{W}_F$ under the CF system and W_{NF} under the PD system, where W_{NF} is equal to $\overline{W}_F$ evaluated at θ = 0, since under the CF system, the situation when θ = 0 is the same as if W did not file for a patent.

Using the fact that $\overline{W}_F$ and W_F differ only with respect to β, and $\overline{W}_F$ and W_{NF} differ only with respect to θ, we prove the following result:

Proposition 7: *Suppose that Assumptions A4-A6 hold and let*

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

Then,

(i) *a sufficient condition for PD to enhance expected welfare when patent protection is strong is r ≥ $\bar{r}(\beta_\theta)$;*

(ii) *a sufficient condition for PD to enhance (lower) expected welfare when patent protection is intermediate is r ≥ $\bar{r}(\beta_\theta)$ and γ > (<) $(\beta_H-\beta_M)/(\beta_H+\beta_\theta)$; moreover, if r ≥ $\bar{r}(\beta_\theta)$ and γ > (<) $(\beta_H-\beta_M)/(\beta_H+\beta_\theta)$, the welfare gain (loss) from to PD is larger (smaller) the larger is γ.*

Proposition 7 reveals that when r, which measures the slope of the marginal cost functions in the development phase, is sufficiently large, PD is socially desirable if patent protection is strong, but depending on the value of γ, it may be socially desirable or undesirable when patent protection is intermediate. Intuitively, Proposition 3 shows that when patent protection is strong, the gap between q^w and q^ℓ is smaller under the PD system. Since the cost functions in the development phase are convex, this implies that all else equal, the allocation of investments in the development phase is more efficient under the PD system, and the resulting efficiency gain increases with r. Consequently, when patent protection is strong, PD is surely welfare enhancing when r is sufficiently large. This result is reinforced by the fact that as r increases, the aggregate levels of investment under the two patent systems converge, so the two systems differ mainly with respect to the allocation of investments between W and ℓ.

When patent protection is intermediate, things are more complex because the sufficient condition also depends on the breadth of patents, γ. The reason that γ matters now is that part (ii) of Lemma 2 shows that when $\gamma > 1-\beta_M/\beta_H$, the allocation of investments between W and ℓ is more even under the PD system, whereas when $\gamma < 1-\beta_M/\beta_H$, the opposite holds. Given the convexity of the cost functions in the development phase, the allocation of investments is more efficient under the PD system if γ is large and more efficient under the CF system if γ is small.

To get a better sense for the welfare implications of PD, we consider the following example.

☐ **A Cournot example with a cost-reducing technology:** Suppose that the two firms are Cournot-competitors and face an inverse demand function $P = 6\text{-}x_1\text{-}x_2$, where x_i is the output of firm i, i = 1,2. In addition, assume that firm i's marginal cost of production is 0 if it develops the new technology and 3 otherwise. Given these assumptions, $\pi_{yn} = 9$, $\pi_{yy} = 4$, $\pi_{nn} = 1$, $\pi_{ny} = 0$, $S_{yy} = 8$, $S_{yn} = 4.5$, and $S_{nn} = 2$; these expressions satisfy Assumptions A1, A2, and A5. To ensure that $r > \pi_{yn}\text{-}\pi_{nn}$ as Assumption A4 requires, let r > 8. The example allows us to derive the precise conditions under which PD enhances or lowers social welfare (this is in contrast with Proposition 7 that reports only (overly strong) sufficient conditions).

In the strong protection case, PD is welfare-enhancing when $W_F\text{-}\overline{W}_F > 0$. In Figure 6, we set $\beta_L = \beta_M = 2$ and $\beta_H = 3$ (i.e., $\beta_L/\beta_H = 0.66$, similarly to the ratio of the cost of imitation to the cost of innovation obtained by Mansfield, Schwartz, and Wagner (1981)) and present $W_F\text{-}\overline{W}_F$ as a function of r for different combinations of γ and θ. The figure shows that PD is welfare-enhancing if and only if r is sufficiently large. Moreover, the figure shows that when PD is socially desirable, it generates a larger welfare gain as θ is smaller (novelty requirements are weak) and as γ is smaller (patents are narrow). To see why, note from equation (12) that the difference between $\overline{q}^w_F\text{-}\overline{q}^\ell_F$ and $q^w_F\text{-}q^\ell_F$ widens as γ and θ decrease, so the efficiency gain from PD increases. Thus, PD is more likely to be socially desirable when the marginal cost of developing new products rises sufficiently fast, and the welfare gain (when there is one) is bigger when novelty requirements are weak and patents are narrow.

When the protection of patents is intermediate, PD is welfare-enhancing if $W_{NF}\text{-}\overline{W}_F > 0$. In Figure 7, we set $\beta_L = \beta_M = 2$, $\beta_H = 18$, and $\theta = 0.25$ and present $W_{NF}\text{-}\overline{W}_F$ as a function of r for five values of γ (we restrict γ to be between 0.118 and 0.667 since protection is intermediate and hence $\left(1 - \sqrt{\beta_\theta/\beta_H}\right)/\theta \leq \gamma \leq \left(1 - \sqrt{\beta_L/\beta_H}\right)/\theta$). Since $\beta_L/\beta_H = 2/18$, patents create a relatively large informational spillover. The figure shows that when γ is relatively large (γ = 0.5 and 0.6), PD is welfare enhancing if and only of r is sufficiently large (above 8.241 and 8.245 respectively), whereas when γ is relatively small (γ = 0.2, 0.3, and 0.4) the opposite is true (r is below 8.231, 8.234, and 8.238, respectively). Moreover, Figure 7 shows that when PD is socially desirable, it generates a larger welfare gain when γ is large, i.e., when patents are relatively broad. As explained above, this is due to the effect of γ on the allocation of investments in the development phase between the two firms, which in turn affects the efficiency of R&D.

Figure 6: The change in welfare due to public disclosure of patent applications in the strong protection case

Figure 6a: gamma = 0.7

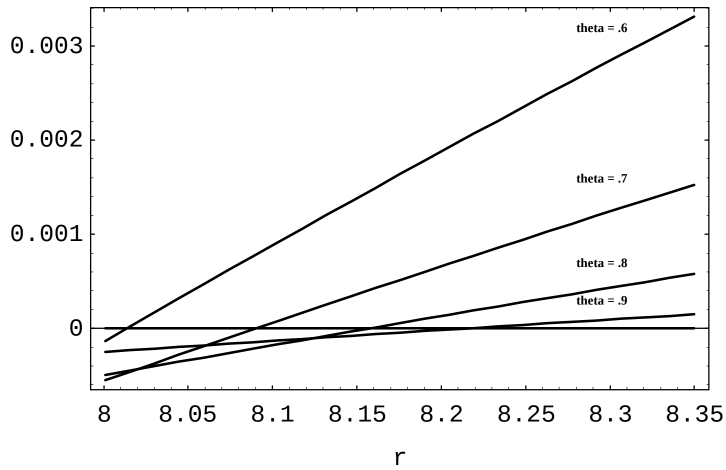


Figure 6b: theta = 0.7

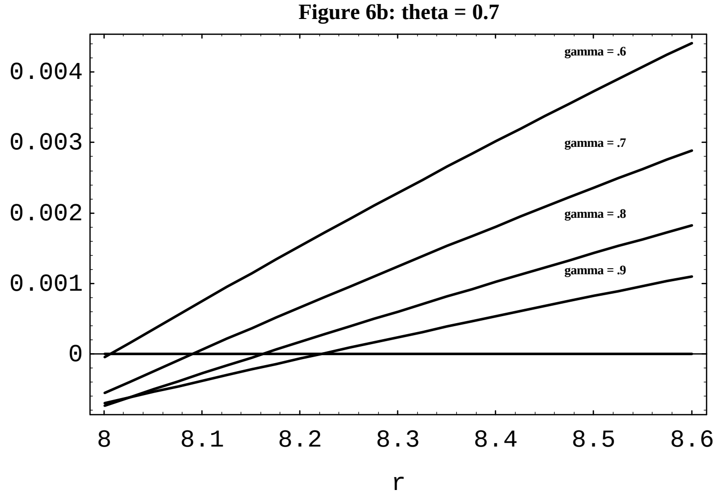
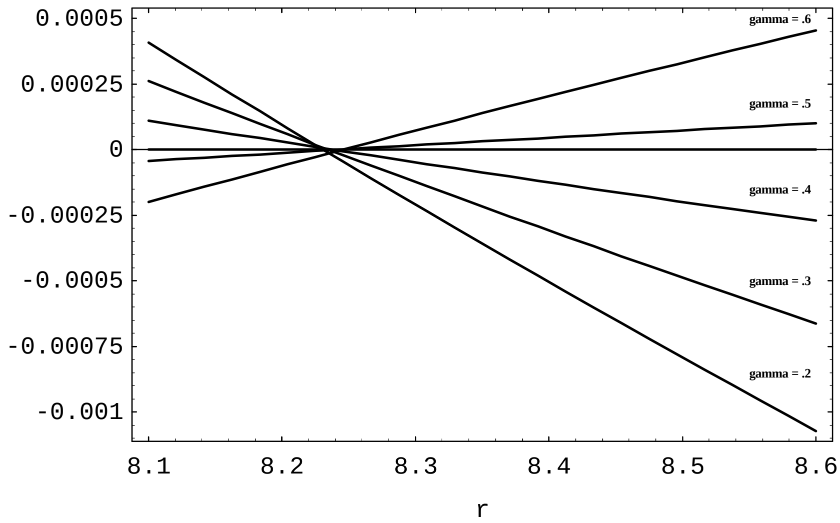


Figure 7: The change in welfare due to public disclosure of patent applications in the intermediate protection case (theta = 0.25)



☐ **The timing of PD:** In countries that already adopted the PD system, patent applications are disclosed after 18 month from the filing date (Ragusa 1992). We now examine the impact of the timing of disclosure on social welfare. To this end, we shall assume that the earlier patent applications are disclosed, the lower is β_L which measures the cost of imitation under the PD system. Then:

Proposition 8: *Suppose that Assumptions A4-A6 hold. Then as* β_L *falls, there are fewer patent applications under the PD system, but so long as* $r \geq \overline{r}(\beta_L)$*, the welfare gain from PD when patent applications are made, grows.*

Proposition 8 shows that cutting the time between the filing date and the date of disclosure has mixed welfare effects: on the one hand, it increases the cost of patenting and as a result, less technological information will be disseminated. On the other hand, conditional on patents being filed, the welfare gain from PD increases, at least when the cost functions in the development phase are sufficiently convex (note that this is also the condition for PD to be socially desirable).

☐ **Foreign patent applications and domestic welfare:** At least in the U.S., many patent applications are made by foreign innovators whose payoffs should be ignored if we are only interested in domestic welfare. For instance, between 1993 and 1997, 42.2% of all patent applications in the U.S. were made by non-U.S. residents and 43.6% of all U.S. patents were issued to non-U.S. residents.[17] Moreover, in 1997, 17 organizations among the top 30 organizations receiving U.S. patents (and 7 out of the top 10) were foreign.[18] To examine how the disclosure of patent applications filed by foreign innovators affects domestic welfare, suppose that W is a foreign firm. Then, domestic welfare in the strong protection case is $\overline{S}_F+\overline{\pi}^{\ell}_F$ under the CF system and $S_F+\pi^{\ell}_F$ under the PD system. Since Propositions 6 and 3, respectively, imply that $S_F \geq \overline{S}_F$ and $\pi^{\ell}_F \geq \overline{\pi}^{\ell}_F$, it is clear that PD enhances domestic welfare. In the intermediate protection case, domestic welfare is still $\overline{S}_F+\overline{\pi}^{\ell}_F$ under the CF system, but under the PD

[17] See Tables 2,6,9, and 10 in the 1997 U.S. Patent office annual report.

[18] 13 of the organizations were Japanese (Canon K.K.; NEC Corp.; Fujitsu Ltd.; Hitachi Ltd.; Mitsubishi Denki K.K.; Toshiba Corp.; Sony Corp.; Matsushita Electric Industrial Co., Ltd.; Nikon Corp.; Fuji Photo Film Co., Ltd.; Sharp K.K.; Honda Motor Co., Ltd.; and Ricoh Co., Ltd.), 3 were Germans (Siemens A.G., Bayer A.G., and Hoechst A.G.), and one was Korean (Samsung Electronics Co., Ltd.). See http://www.ipo.org/Top2001997.html

system it becomes $S_{NF}+\pi^{\ell}_{NF}$. Proposition 6 implies that now, $S_{NF} \geq \overline{S}_F$, while Proposition 2 implies that $\pi^{\ell}_{NF} > \overline{\pi}^{\ell}_F$ whenever $\gamma > 1\text{-}\beta_L/\beta_H$. Hence, whenever $\gamma \geq 1\text{-}\beta_L/\beta_H$ so the patent is sufficiently broad, PD surely enhances domestic welfare. When $\gamma < 1\text{-}\beta_L/\beta_H$, the comparison between π^{ℓ}_{NF} and $\overline{\pi}^{\ell}_F$ is ambiguous, so we cannot determine the impact on domestic welfare without imposing further structure on the model.

Proposition 9: *Suppose that W is a foreign firm. Then, PD always enhances domestic welfare when patent protection is strong. When patent protection is intermediate, a sufficient condition for PD to enhance domestic welfare is that* $\gamma \geq 1\text{-}\beta_L/\beta_H$ *(i.e., the patent is sufficiently broad).*

Comparing Propositions 7 and 9 reveals that PD is more likely to enhance domestic welfare if W is a foreign firm. This is because PD always hurts W, so if we ignore W's payoff, we get a more positive picture of the welfare implications of PD. In addition, Proposition 9 shows that in the intermediate protection case, domestic welfare is more likely to increase when patents are relatively broad (i.e., γ is relatively large). To understand why, note that as patents become broader, W which is now a foreign firm, is more likely to file for a patent and block the domestic firm, ℓ, from using the new technology. But, in the intermediate protection case, PD induces W to stop filing for patents, so ℓ is more likely to be able to introduce the new technology if it develops it.

7. The incentives to innovate

Thus far we have focused on the implications of PD, assuming that one firm has already made an innovation. We now go back one step and ask how PD affects the incentive to innovate in the research phase. To this end, we assume that the outcome of the research phase is binary (a firm either innovates or else it learns nothing) and that investment in the research phase increases the chances to innovate. Given these assumptions, the benefit from investment in the research phase is $B \equiv \pi^w - \pi^{\ell}$, i.e., the difference between the expected profits of being W and being ℓ. We argue that the patent system that gives rise to a higher B, provides a stronger incentive to innovate. As before, we only study the cases of strong and intermediate protection since PD is completely irrelevant when protection is weak.

In the strong protection case, W files for a patent under both patent systems, so the benefit from investing in the research phase is $B_F = \pi^w_F - \pi^{\ell}_F$ under the PD system, and $\overline{B}_F = \overline{\pi}^w_F - \overline{\pi}^{\ell}_F$ under the CF system. Since part (ii) of Proposition 3 implies that PD hurts W and benefits ℓ, it is clear that $B_F - \overline{B}_F < 0$. Hence, PD weakens the incentive to innovate and become W.

Things are more subtle when protection is intermediate. Now PD induces W to stop filing for a patent and this has an adverse effect on both W and ℓ. To study this case further, we impose Assumption A4. Then, the benefit from investing in the research phase under the CF system is

$$\bar{B}_F = \frac{(\pi_{yn} - \pi_{nn})(\pi_{yn} + \pi_{nn} - 2\pi_{ny})\, r\left(\beta_\theta - (1-\gamma\theta)^2\right)}{2\left(r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2\right)}. \quad \textbf{(15)}$$

Under the PD system, W does not file for a patent, so the benefit from investing in the research phase is $B_{NF} = \pi^w_{NF} - \pi^\ell_{NF}$, where B_{NF} is identical to $\bar{B}_F$ when $\theta = 0$. The impact of PD, then, depends on the sign of $B_{NF} - \bar{B}_F$.

Proposition 10: *PD weakens the incentive to innovate when patent protection is strong, and given Assumption A4, it also diminishes the incentive to innovate when patent protection is intermediate. Moreover, given Assumption A4, the negative impact of PD on the incentive to innovate decreases with* θ *when patent protection is strong but increases with* γ *when patent protection is intermediate.*

Proposition 10 supports the concern of opponents of the Examining Procedure Improvements Act in the U.S. that PD might discourage innovative activity. Given the importance of innovations to the economy as a whole, this adverse effect of PD should be given a serious consideration. In addition, the proposition shows that as patents become broader, this drawback of PD becomes less significant if patent protection is strong, but more significant if patent protection is intermediate. The reason for this difference between the two cases is that when protection is strong, W files for a patent under both patent systems. As patents become broader, PD is less detrimental to W and less beneficial to ℓ, so the negative impact of PD on the incentive to innovate diminishes. When patent protection is intermediate, W does not file for a patent under the PD system so γ has no impact on the incentive to innovate. But, since an increase in γ boosts the incentive to innovate under the CF system, the detrimental impact of PD on the incentive to innovate (i.e., the difference between B_{NF} and $\bar{B}_F$) increases.

8. Conclusion

This paper contributes to the on going public debate in the U.S. regarding the Patent Examination Improvement Act which requires, among other things, that patent applications be published after 18 month from the filing date, even if no patent has been (or ever will be) granted.[19] Our results suggest that the legislation will discourage patent applications in industries in which patents receive intermediate protection against imitation, and in addition, it may also have an adverse effect on the quality of innovations that are patented and on the incentives to innovate. These findings provide a theoretical support for the concern expressed in the Nobel Laureates' open letter to the U.S. Senate (see footnote 4) that the legislation will "discourage the flow of new inventions."

At the same time, our results also suggest that, holding the number of innovations fixed, PD may raise the likelihood that new technologies will reach the product market by either raising the aggregate level of investment in the development of new technologies or by lowering the legal hurdles for introducing such technologies into the market by firms who do not own patents on the underlying innovations. This implies that once we fix the number of innovation, the legislation will benefit consumers and, depending on patent breath and the shape of the cost functions of R&D, it may also enhance social welfare. When the innovations are made by foreign firms, these benefits are even larger if we restrict attention to domestic welfare.

Another advantage of the PD system is that it can help eliminate the phenomenon of "submarine" patents which refers to patent applications that are intentionally delayed by applicants until a similar idea is commercialized by someone else (typically a large corporation), at which point the application is completed and entitles the patentholder to collect royalties.[20] Although we assumed throughout that at the end of the research phase it is common knowledge that W is ahead in the race to develop the new technology, in reality this is often not the case. Adoption of a PD system will eliminate the possibility to engage in submarine patents by giving other innovators a due warning that they should direct their efforts in a different direction.

Finally, although our model is quite general (we do not assume a particular type of competition

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[19] It should be pointed out that the proposed legislation includes additional controversial parts that we do not deal with in this paper such as turning the U.S. Patents and Trademarks office into a government corporation (S. 507 Title I) and prior user rights (S.507 Title IV) that provide a defense against patent suits for U.S. manufacturers who commercialized a technology before an inventor filed for a patent on this technology.

[20] A case in point are the patents that were issued in the 1980's and the 1990's to Jerome H. 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. It should be noted though that there is a disagreement on the significance of submarine patents. For more details, see for instance http://www2.ipo.org/ipo/myth3.htm

in the product market, we do not need to make a distinction between product and process innovations, and we derive many of the results without assuming a particular functional form for the R&D cost functions), there is no doubt a need for further investigation of PD. In particularly, throughout the paper we have assumed away the possibility that W may license its innovation to ℓ instead of suing ℓ for patent infringement. In future research it would be interesting to examine how PD affects the incentive of firms to engage in licensing agreements and the terms of these agreements. Such investigation is particularly important for industries like pharmaceuticals, electronic components and accessories, and computers and office equipment where patent protection is either strong or intermediate (so that PD is highly relevant) and licensing agreements are prevalent (Anand and Khanna, 1997).

Appendix

Proving the existence of a unique Nash equilibrium in the filing and no-filing subgame under the PD and the CF systems: First consider the filing subgame under the PD system. It is useful to rewrite the two best-response functions, given by equations (5) and (6), as follows:

$$q^{\ell} = H_1(q^{w}) \equiv \frac{\left(\pi_{yn} - \pi_{nn}\right) - C^{\prime}(q^{w})}{-(1-\gamma\theta)\Pi}, \qquad \textbf{(A-1)}$$

and

$$q^{w} = H_2(q^{\ell}) \equiv \frac{(1-\gamma\theta)\left(\pi_{yn} - \pi_{nn}\right) - \beta_L C^{\prime}(q^{\ell})}{-(1-\gamma\theta)\Pi}, \qquad \textbf{(A-2)}$$

where $\Pi \equiv \pi_{yy}+\pi_{nn}-\pi_{yn}-\pi_{ny} \leq 2\pi_{yy}-\pi_{yn}-\pi_{ny} < 0$ (the first inequality follows because $\pi_{yy} > \pi_{nn}$ by Assumption A1 and the second inequality follows from Assumption A2). $H_1(q^w)$ and $H_2(q^\ell)$ intersect in the (q^w, q^ℓ) space in the unit square (recall that q^w and q^ℓ are probabilities and hence must be between 0 and 1) provided that (i) $H_1(0) > 1$ (ii) $H_1(1) < 0$, (iii) $H_2(1) < 0$, and (iv) $H_2(0) > 1$. Condition (ii) is satisfied if $C'(1) > \pi_{yn}-\pi_{nn}$, which is ensured by Assumption A3. Condition (iii) is satisfied if $C'(1) > (1-\gamma\theta)(\pi_{yn}-\pi_{nn})/\beta_L$; since $\beta_L > 1 > 1-\gamma\theta$, this inequality is implied by Assumption A3. Since $\Pi < 0$ and recalling from Assumption A3 that $C'(0) = 0$, conditions (i) and (iv) are both satisfied if $\pi_{yn}-\pi_{nn} > -(1-\gamma\theta)\Pi$. It is now easy to verify that the last inequality holds since $\pi_{yy} > \pi_{ny}$.

To prove uniqueness, note that the slopes of $R^w(q^\ell \mid F)$ and $R^\ell(q^w \mid F)$ are given by $C''(q^w)/((1-\gamma\theta)\Pi)$ and $(1-\gamma\theta)\Pi/\beta_L C''(q^\ell)$, respectively. Given Assumption A3, $C''(q^w)/((1-\gamma\theta)\Pi) < -1 < (1-\gamma\theta)\Pi/\beta_L C''(q^\ell)$, which in turn implies that $R^w(q^\ell \mid F)$ and $R^\ell(q^w \mid F)$ intersect only once.

Under the CF system, the best-response functions in the filing subgame are also given by (A-1) and (A-2), except that β_L is replaced by $\beta_\theta \equiv \theta\beta_M+(1-\theta)\beta_H$; the proof however goes through as before.

The proof of existence and uniqueness in the no-filing subgame under both the PD and the CF systems is similar to that in the filing subgame and is therefore omitted. *Q.E.D.*

Proof of Lemma 1: (i) First, since γ and θ do not appear in equations (7) and (8), q^w_{NF} and q^ℓ_{NF} are independent of γ and θ. Second, Assumptions A1 and A2 ensure that $\pi_{yy}+\pi_{nn}-\pi_{yn}-\pi_{ny} < 2\pi_{yy}-\pi_{yn}-\pi_{ny} < 0$. Hence it follows from equations (5) and (6) that $\partial R^w(q^\ell \mid F)/\partial(\gamma\theta) > 0$ and $\partial R^\ell(q^w \mid F)/\partial(\gamma\theta) < 0$, and since q^w and q^ℓ are strategic substitutes, it follows that q^w_F increases and q^ℓ_F decreases with $\gamma\theta$.

(ii) Suppose that $\gamma\theta = 0$. Then, by equations (5) and (7), $R^w(q^\ell \mid F) = R^w(q^\ell \mid NF)$. Since $\beta_L < \beta_H$, equations (6) and (8) imply that $R^\ell(q^w \mid F) > R^\ell(q^w \mid NF)$ for all q^w and since q^w and q^ℓ are strategic substitutes, it follows that $q^w_F < q^w_{NF}$ and $q^\ell_F > q^\ell_{NF}$. To prove that $q^\ell_F < q^w_F$, note that if $\gamma\theta = 0$ and $\beta_L = 1$, equations (5) and (6) are symmetric, and hence $q^\ell_F = q^w_F$. As β_L increases from 1, $R^\ell(q^w \mid F)$ shifts so since the best-response functions are downward sloping, it must be that $q^\ell_F < q^w_F$.

Next, suppose that $\gamma\theta \geq 1-\beta_L/\beta_H$, and rewrite equation (6) as follows:

$$\frac{\partial\pi^\ell(q^w,q^\ell \mid F)}{\partial q^\ell} = q^w\left(\pi_{yy}-\pi_{ny}\right) + (1-q^w)\left(\pi_{yn}-\pi_{nn}\right) - \frac{\beta_L C'(q^\ell)}{1-\gamma\theta} = 0. \qquad \textbf{(A-3)}$$

Since $\gamma\theta \geq 1-\beta_L/\beta_H$, the third term here exceeds the third term in equation (8), so $R^\ell(q^w \mid F) \leq R^\ell(q^w \mid NF)$. Together with the fact that by equations (5) and (7), $R^w(q^\ell \mid F) > R^w(q^\ell \mid NF)$ for all $\gamma\theta > 0$, it follows that $q^w_F > q^w_{NF}$ and $q^\ell_F < q^\ell_{NF}$. The proof that $q^\ell_{NF} < q^w_{NF}$ is similar to the proof that $q^\ell_F < q^w_F$.

(iii) Suppose that $\gamma\theta = 1-\beta_L/\beta_H$. Then, $R^\ell(q^w \mid F) = R^\ell(q^w \mid NF)$, so (q^w_F, q^ℓ_F) and (q^w_{NF}, q^ℓ_{NF}) lie on the same curve in the (q^w, q^ℓ) space, with (q^w_F, q^ℓ_F) being southeast of (q^w_{NF}, q^ℓ_{NF}). Using equation (8), the slope of this curve is $\partial R^\ell(q^w \mid F)/\partial q^w = -(1-\gamma\theta)\Pi/\beta_H C''(q^\ell_F)$. Given Assumption A3, $C''(q) >$
$-\Pi$ for all $q \in [0, 1]$, so $\partial R^\ell(q^w \mid F)/\partial q^w > -1$, implying that (q^w_F, q^ℓ_F) lies above a 45 degrees line passing through (q^w_{NF}, q^ℓ_{NF}). Consequently, $q^w_F+q^\ell_F > q^w_{NF}+q^\ell_{NF}$. When $\gamma\theta < 1-\beta_L/\beta_H$, $\bar{R}^\ell(q^w \mid F)$ shifts upward, reinforcing the result. *Q.E.D.*

Proof of Proposition 1: By equations (3) and (4), π^w_{NF} and π^ℓ_{NF} are independent of γ and θ. Using the envelope theorem, equation (1) implies that

$$\frac{\partial\pi^w_F}{\partial(\gamma\theta)} = -q^\ell_F\left[q^w_F(\pi_{yy}-\pi_{yn}) + (1-q^w_F)(\pi_{ny}-\pi_{nn})\right] + \frac{\partial\pi^w_F}{\partial q^\ell}\frac{\partial q^\ell_F}{\partial(\gamma\theta)}. \qquad \textbf{(A-4)}$$

Assumption A1 ensures that the expression inside the square brackets and $\partial\pi^w_F/\partial q^\ell$ are negative. Since $\partial q^\ell_F/\partial(\gamma\theta) < 0$ by Lemma 1, it follows that $\partial\pi^w_F/\partial\gamma\theta > 0$. The proof that $\partial\pi^\ell_F/\partial\gamma\theta < 0$ is analogous.

To prove the existence of $\overline{\gamma\theta} \in (0, 1-\beta_L/\beta_H)$, such that $\pi^w_F \gtreqless \pi^w_{NF}$ as $\gamma\theta \gtreqless \overline{\gamma\theta}$, note that $\overline{\gamma\theta}$ is defined implicitly by $\pi^w_F = \pi^w_{NF}$. Since π^w_F increases with $\gamma\theta$, whereas π^w_{NF} is independent of $\gamma\theta$, it is sufficient to show that $\pi^w_F < \pi^w_{NF}$ if $\gamma\theta = 0$ and conversely if $\gamma\theta = 1-\beta_L/\beta_H$. If $\gamma\theta = 0$, equations (1) and (3) imply that $\pi^w(q^w,q^\ell \mid F) = \pi^w(q^w,q^\ell \mid NF)$. Consequently,

$$\pi_F^w < \pi^w(q_F^w, q_{NF}^\ell \,|\, F) = \pi^w(q_F^w, q_{NF}^\ell \,|\, NF) \leq \pi_{NF}^w, \tag{A-5}$$

where the strict inequality follows because $\partial\pi^w(q^w,q^\ell \,|\, F)/\partial q^\ell < 0$ and because by Lemma 1, $q^\ell_F > q^\ell_{NF}$ when $\gamma\theta = 0$, and the weak inequality is implied by revealed preferences (i.e., the definition of q^w_{NF}). Next suppose that $\gamma\theta = 1-\beta_L/\beta_H$. Then Lemma 1 indicates that $q^\ell_F < q^\ell_{NF}$. Using equations (1) and (3) and Assumption 1, it is easy to show that $\pi^w(q^w,q^\ell \,|\, F) > \pi^w(q^w,q^\ell \,|\, NF)$ for all $q^\ell > 0$ and all $\gamma,\theta > 0$, so

$$\pi_F^w \geq \pi^w(q_{NF}^w, q_F^\ell \,|\, F) > \pi^w(q_{NF}^w, q_F^\ell \,|\, NF) = \pi_{NF}^w, \tag{A-6}$$

where the left inequality is implied by revealed preferences and the right inequality follows because $\partial\pi^w(q^w,q^\ell \,|\, F)/\partial q^\ell < 0$ and $q^\ell_F < q^\ell_{NF}$.

To examine how $\overline{\gamma\theta}$ varies with β_L and β_H, we first differentiate the equation $\pi^w_F = \pi^w_{NF}$ (which implicitly defines $\overline{\gamma\theta}$) with respect to $\gamma\theta$ and β_L. Noting that π^w_{NF} is independent of $\gamma\theta$ and β_L and using the envelope theorem, we obtain

$$\frac{\partial\overline{\gamma\theta}}{\partial\beta_L} = \frac{(1-\gamma\theta)\dfrac{\partial q_F^\ell}{\partial\beta_L}}{q_F^\ell - (1-\gamma\theta)\dfrac{\partial q_F^\ell}{\partial\gamma\theta}}, \tag{A-7}$$

where $\partial q^\ell_F/\partial(\gamma\theta) < 0$ by Lemma 1 and $\partial q^\ell_F/\partial\beta_L < 0$ since $R^\ell(q^w \,|\, F)$ decreases with β_L while $R^w(q^\ell \,|\, F)$ is independent of β_L. Hence, $\overline{\gamma\theta}$ decreases with β_L. Similarly, differentiating the equation $\pi^w_F = \pi^w_{NF}$ with respect to $\gamma\theta$ and β_H,

$$\frac{\partial\overline{\gamma\theta}}{\partial\beta_H} = \frac{-\dfrac{\partial q_{NF}^\ell}{\partial\beta_H}}{q_F^\ell - (1-\gamma\theta)\dfrac{\partial q_F^\ell}{\partial\gamma\theta}}, \tag{A-8}$$

where $\partial q^\ell_{NF}/\partial\beta_H < 0$ since $R^\ell(q^w \,|\, NF)$ decreases with β_H, while $R^w(q^\ell \,|\, NF)$ is independent of β_H. Hence, $\overline{\gamma\theta}$ increases with β_H.

Finally, using equations (2) and (4) we get,

$$\pi^\ell(q_F^w, q_F^\ell \,|\, NF) - \pi_F^\ell = \gamma\,\theta\, q_F^\ell\left[q_F^w(\pi_{yy} - \pi_{ny}) + (1-q_F^w)(\pi_{yn} - \pi_{nn})\right] - (\beta_H - \beta_L)\,C(q_F^\ell). \tag{A-9}$$

Substituting for the square bracketed term from equation (6) and using the fact that by Assumption A3, C(q) is strictly convex yields

$$\pi^{\ell}(q_F^w, q_F^{\ell} \,|\, NF) - \pi_F^{\ell} = \frac{\gamma\,\theta\,\beta_L\, q_F^{\ell}\, C'(q_F^{\ell})}{1-\gamma\theta} - (\beta_H - \beta_L)\, C(q_F^{\ell})$$

$$> \frac{\beta_H\, C(q_F^{\ell})}{1-\gamma\theta}\left[\gamma\,\theta - \left(1 - \frac{\beta_L}{\beta_H}\right)\right] > 0. \tag{A-10}$$

Using this inequality, we have

$$\pi_{NF}^{\ell} \geq \pi^{\ell}(q_{NF}^{w}, q_F^{\ell} \,|\, NF) > \pi^{\ell}(q_F^{w}, q_F^{\ell} \,|\, NF) > \pi_F^{\ell}, \tag{A-11}$$

where the left inequality follows by revealed preferences, and the middle inequality follows because $\partial\pi^{\ell}(q^w, q^{\ell} \,|\, NF)/\partial q^w < 0$, and because by Lemma 1, $q^w_F > q^w_{NF}$ for all $\gamma\theta > 1-\beta_L/\beta_H$. *Q.E.D.*

Proof of Lemma 2: (i) First note from equations (5) and (9) that $\partial R^w(q^{\ell} \,|\, F)/\partial\gamma > 0$ and $\partial \bar{R}^{\ell}(q^w \,|\, F)/\partial\gamma < 0$. Since q^w and q^{ℓ} are strategic substitutes and $R^w(q^{\ell} \,|\, F)$ is steeper than $\bar{R}^{\ell}(q^w \,|\, F)$, it follows that $\bar{q}^w_F$ increases and $\bar{q}^{\ell}_F$ decreases with γ. Second, from equation (5) it is clear that $\partial R^w(q^{\ell} \,|\, F)/\partial\theta > 0$. Using equation (9), we get:

$$\frac{\partial \bar{R}^{\ell}(q^w \,|\, F)}{\partial\theta} \stackrel{s}{=} -\gamma\left[q_F^w(\pi_{yy} - \pi_{ny}) + (1-q_F^w)(\pi_{yn} - \pi_{nn})\right] - \left(\beta_M - \beta_H\right) C'(\bar{q}_F^{\ell}), \tag{A-12}$$

where $\stackrel{s}{=}$ stand for "equal in sign." Substituting for $C'(\bar{q}^{\ell}_F)$ from equation (9) and rearranging terms,

$$\frac{\partial \bar{R}^{\ell}(q^w \,|\, F)}{\partial\theta} \stackrel{s}{=} \frac{\beta_H}{\beta_\theta}\left[\bar{q}_F^w(\pi_{yy} - \pi_{ny}) + (1-\bar{q}_F^w)(\pi_{yn} - \pi_{nn})\right]\left[\left(1 - \frac{\beta_M}{\beta_H}\right) - \gamma\right]. \tag{A-13}$$

Since the expression outside the square brackets is positive, it follows that $\partial \bar{R}^{\ell}(q^w \,|\, F)/\partial\theta \gtreqless 0$ as $\gamma \lesseqgtr 1-\beta_M/\beta_H$. Thus, when $\gamma > 1-\beta_M/\beta_H$, $\partial \bar{R}^{\ell}(q^w \,|\, F)/\partial\theta < 0$. Together with the fact that $\partial R^w(q^{\ell} \,|\, F)/\partial\theta > 0$ and the fact that q^w and q^{ℓ} are strategic substitutes and $R^w(q^{\ell} \,|\, F)$ is steeper than $\bar{R}^{\ell}(q^w \,|\, F)$, this implies that $\bar{q}^w_F$ increases and $\bar{q}^{\ell}_F$ decreases. When $\gamma < 1-\beta_M/\beta_H$, $\partial \bar{R}^{\ell}(q^w \,|\, F)/\partial\theta > 0$. Since $\partial R^w(q^{\ell} \,|\, F)/\partial\theta > 0$ as well, it follows that either $\bar{q}^w_F$ increases, or $\bar{q}^{\ell}_F$ increases, or both.

(ii) When $\theta = 0$, equation (5) coincides with equation (7) and equation (9) coincides with equation (8), so $R^w(q^{\ell} \,|\, F) = R^w(q^{\ell} \,|\, NF)$ and $\bar{R}^{\ell}(q^w \,|\, F) = R^{\ell}(q^w \,|\, NF)$. The proof that $\bar{q}^w_F > \bar{q}^{\ell}_F$ when $\theta = 0$ and the proof for the case where $\theta > 0$ are similar to the proofs that appear in part (ii) of Lemma 1.

(iii) The proof is similar to the proof of part (iii) of Lemma 1. *Q.E.D.*

Proof of Proposition 2: The proof that $\bar{\gamma}$ exists and decreases with β_L and increases with β_H is similar to the proof of Proposition 1 and is therefore omitted.

To establish the sufficient condition $\partial\bar{\gamma}/\partial\theta < 0$, note that $\bar{\gamma}$ is defined implicitly by $\bar{\pi}^w_F = \pi^w_{NF}$. Differentiating this equation with respect to $\bar{\gamma}$ and θ, using the envelope theorem, and recalling that π^w_{NF} is independent of γ and θ, yields

$$\frac{\partial\bar{\gamma}}{\partial\theta} = \frac{-\bar{\gamma}\,\bar{q}^{\ell}_F + (1-\bar{\gamma}\theta)\dfrac{\partial\bar{q}^{\ell}_F}{\partial\theta}}{\theta\bar{q}^{\ell}_F - (1-\bar{\gamma}\theta)\dfrac{\partial\bar{q}^{\ell}_F}{\partial\gamma}}. \qquad \textbf{(A-14)}$$

The denominator here is positive since by part (i) of Lemma 2, $\partial\bar{q}^{\ell}_F/\partial\gamma < 0$. As for the numerator then,

$$-\bar{\gamma}\,\bar{q}^{\ell}_F + (1-\bar{\gamma}\theta)\frac{\partial\bar{q}^{\ell}_F}{\partial\theta} = \frac{(1-\bar{\gamma}\theta)\,\bar{q}^{\ell}_F}{\theta}\left[\bar{\eta}^{\ell}_F(\theta) - \frac{\bar{\gamma}\,\theta}{1-\bar{\gamma}\,\theta}\right], \qquad \textbf{(A-15)}$$

where $\bar{\eta}^{\ell}_F(\theta) \equiv (\partial\bar{q}^{\ell}_F/\partial\theta)/(\bar{q}^{\ell}_F/\theta)$ is the elasticity of $\bar{q}^{\ell}_F$ with respect to θ. Hence, $\partial\bar{\gamma}/\partial\theta > 0$ if and only if $\bar{\eta}^{\ell}_F(\theta) > \bar{\gamma}\theta/(1-\bar{\gamma}\theta)$.

Finally, we compare the $\bar{\pi}^{\ell}_F$ and π^{ℓ}_{NF} for $\gamma > 1-\beta_M/\beta_H$. Using equation (4) and recalling that $\bar{\pi}^{\ell}(q^w,q^{\ell}\,|\,F)$ is given by (2) with β_θ instead of β_L, we get,

$$\pi^{\ell}(\bar{q}^{w}_F,\bar{q}^{\ell}_F\,|\,NF) - \bar{\pi}^{\ell}_F = \theta\gamma\,\bar{q}^{\ell}_F\Big[\bar{q}^{w}_F(\pi_{yy}-\pi_{yn}) - (1-\bar{q}^{w}_F)(\pi_{yn}-\pi_{nn})\Big] - \theta(\beta_H-\beta_M)C(\bar{q}^{\ell}_F). \qquad \textbf{(A-16)}$$

Substituting for the square bracketed term from equation (9) and recalling that C(q) is strictly convex,

$$\begin{aligned}\bar{\pi}^{\ell}(\bar{q}^{w}_F,\bar{q}^{\ell}_F\,|\,NF) - \bar{\pi}^{\ell}_F &= \theta\Big[\gamma\,\beta_\theta\,\bar{q}^{\ell}_F\,C'(\bar{q}^{\ell}_F) - (\beta_H-\beta_M)C(\bar{q}^{\ell}_F)\Big] \\ &> \frac{\theta\,\beta_H\,C(\bar{q}^{\ell}_F)}{1-\gamma\theta}\left[\gamma - \left(1-\frac{\beta_M}{\beta_H}\right)\right] > 0.\end{aligned} \qquad \textbf{(A-17)}$$

Using this inequality,

$$\bar{\pi}^{\ell}_{NF} \geq \pi^{\ell}(q^{w}_{NF},\bar{q}^{\ell}_F\,|\,NF) > \pi^{\ell}(\bar{q}^{w}_F,\bar{q}^{\ell}_F\,|\,NF) > \bar{\pi}^{\ell}_F, \qquad \textbf{(A-18)}$$

where the first (weak) inequality follows by revealed preferences, and the second (strict) inequality follows because $\partial\pi^{\ell}(q^w,q^{\ell}|NF)/\partial q^w < 0$, and $\bar{q}^w_F > q^w_{NF}$ for all $\gamma > 1-\beta_M/\beta_H$. *Q.E.D.*

Proof of proposition 3: (i) Equations (6) and (9) and the assumption that $\beta_\theta > \beta_L$, imply that $\bar{R}^{\ell}(q^w|F) < R^{\ell}(q^w|F)$. Since W's best-response function is the same under the PD and CF systems and q^w and q^{ℓ} are strategic substitutes, it follows that $q^w_F < \bar{q}^w_F$ and $q^{\ell}_F > \bar{q}^{\ell}_F$. To prove that $q^{\ell}_F < q^w_F$, note that if $\gamma\theta = 0$ and $\beta_L = 1$, equations (5) and (6) are symmetric and hence $q^{\ell}_F = q^w_F$. As $\gamma\theta$ increases from 0 and β_L increases from 1, $\bar{R}^{\ell}(q^w|F)$ shifts down while $R^w(q^{\ell}|F)$ shifts to the right; since the two best-response functions are downward sloping, it follows that $q^{\ell}_F < q^w_F$.

To examine the aggregate level of investment, note that since W's best-response function in the filing subgame is the same under both patent systems, $(\bar{q}^w_F, \bar{q}^{\ell}_F)$ and (q^w_F, q^{ℓ}_F) lie on the same curve in the (q^w, q^{ℓ}) space, with $(\bar{q}^w_F, \bar{q}^{\ell}_F)$ being southeast of (q^w_F, q^{ℓ}_F). Using equation (3), the slope of this curve is $\partial R^w(q^{\ell}|F)/\partial q^{\ell} = (1-\gamma\theta)\Pi/C''(q^w_F)$. Given Assumption A3, $C''(q) > -\Pi$ for all $q \in [0, 1]$, so $\partial R^w(q^{\ell}|F)/\partial q^{\ell} > -1$, implying that $(\bar{q}^w_F, \bar{q}^{\ell}_F)$ lies below a 45 degrees line passing through (q^w_F, q^{ℓ}_F). Consequently, $\bar{q}^w_F+\bar{q}^{\ell}_F \leq q^w_F+q^{\ell}_F$.

(ii) First, note that

$$\pi^w_F < \pi^w(q^w_F, \bar{q}^{\ell}_F | F) \leq \bar{\pi}^w_F, \tag{A-19}$$

where the left inequality follows since $\partial\pi^w(q^w,q^{\ell}|F)/\partial q^{\ell} < 0$ and since $q^{\ell}_F > \bar{q}^{\ell}_F$, and the right inequality follows by revealed preferences. Second, using equation (4) and the fact that $\bar{\pi}^{\ell}(q^w,q^{\ell}|F)$ is given by (2) with β_θ instead of β_L, it follows that $\pi^{\ell}(q^w,q^{\ell}|F) > \bar{\pi}^{\ell}(q^w,q^{\ell}|F)$. Hence,

$$\pi^{\ell}_F \geq \pi^{\ell}(q^w_F, \bar{q}^{\ell}_F | F) > \pi^{\ell}(\bar{q}^w_F, \bar{q}^{\ell}_F | F) \geq \bar{\pi}^{\ell}_F, \tag{A-20}$$

where the left inequality follows from revealed preferences and the middle inequality follows since $\partial\bar{\pi}^{\ell}(q^w,q^{\ell}|F)/\partial q^w < 0$ and $q^w_F < \bar{q}^w_F$. *Q.E.D.*

Proof of Proposition 5: Given Assumption A4, W's expected payoff if it files for a patent under the PD system is

$$\pi_F^w = \pi_{nn} + \frac{(\pi_{yn} - \pi_{nn})^2\, r\left(r\beta_L + (1-\gamma\theta)^2\Pi\right)^2}{2\left(r^2\beta_L - (1-\gamma\theta)^2\Pi^2\right)^2} + \frac{(\pi_{yn} - \pi_{nn})(\pi_{nn} - \pi_{ny})(r+\Pi)(1-\gamma\theta)^2}{r^2\beta_L - (1-\gamma\theta)^2\Pi^2}. \qquad \textbf{(A-21)}$$

If W does not file for a patent, its expected payoff, π^w_{NF}, is given by a similar expression with β_H replacing β_L and $\theta = 0$. Clearly, π^w_F is independent of β_H while a straightforward (though tedious) differentiation reveals that given Assumption A2 and the assumptions that $r > \pi_{yn}-\pi_{nn}$ and $\beta_L > 1 \geq 1-\gamma\theta$, π^w_{NF} is increasing with β_H. Now, setting $\pi^w_F = \pi^w_{NF}$ and solving for β_H, the largest β_H for which W still files for a patent under the PD system is $\beta_L/(1-\gamma\theta)^2$.

Under the CF system, the expected payoff of W if it files for a patent, $\bar{\pi}^w_F$ is similar to π^w_F, except that $\beta_\theta = \theta\beta_M+(1-\theta)\beta_H$ replaces β_L. Now things are more complex since both $\bar{\pi}^w_F$ and π^w_{NF} depend on β_H. Setting $\bar{\pi}^w_F = \pi^w_{NF}$ and solving for β_H yields 3 solutions, but two of them are less than β_M and are therefore irrelevant (by assumption, $\beta_H > \beta_M$). The third solution is equal to $\beta_M/(1-2\gamma+\theta\gamma^2)$. Since the derivative of $\bar{\pi}^w_F - \pi^w_{NF}$ is decreasing at $\beta_H = \beta_M/(1-2\gamma+\theta\gamma^2)$ it follows that W files for a patent if and only if $\beta_H < \beta_M/(1-2\gamma+\theta\gamma^2)$. *Q.E.D.*

Proof of Proposition 6: 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 PD system). Now,

$$S_F - \bar{S}_F = \frac{(\pi_{yn} - \pi_{nn})\, r\,(1-\gamma\theta)^2(r+\Pi)^2(\beta_\theta - \beta_L)\left(S_{yn} - S_{nn}\right)}{\left(r^2\beta_\theta - (1-\gamma\theta)^2\Pi^2\right)\left(r^2\beta_L - (1-\gamma\theta)^2\Pi^2\right)} + (\pi_{yn} - \pi_{nn})^2(r+\Pi)(1-\gamma\theta)\left[\frac{r\beta_L - (1-\gamma\theta)^2\Pi}{\left(r^2\beta_L - (1-\gamma\theta)^2\Pi^2\right)^2} - \frac{r\beta_\theta - (1-\gamma\theta)^2\Pi}{\left(r^2\beta_\theta - (1-\gamma\theta)^2\Pi^2\right)^2}\right]S. \qquad \textbf{(A-22)}$$

Since $\beta_\theta > \beta_L$, this expression is strictly positive, implying that PD 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 PD system). Now,

$$S_{NF} - \bar{S}_F = \frac{(\pi_{yn} - \pi_{nn})\, r\, (r + \Pi)^2 \left(\beta_\theta - \beta_H (1 - \gamma\theta)\right)(S_{yn} - S_{nn})}{\left(r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2\right)\left(r^2 \beta_H - \Pi^2\right)} \tag{A-23}$$

$$+ (\pi_{yn} - \pi_{nn})^2 (r + \Pi) \left[\frac{r \beta_H + \Pi}{\left(r^2 \beta_H - \Pi^2\right)^2} - \frac{(1-\gamma\theta)^2 \left(r \beta_\theta + (1-\gamma\theta)^2 \Pi\right)}{\left(r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2\right)^2} \right] S.$$

Recalling that in the intermediate protection case, $\gamma \geq \left(1 - \sqrt{\beta_\theta / \beta_H}\right)/\theta$, we get $\beta_\theta - \beta_H(1-\gamma\theta)^2 \geq 0$, so the first line of (A-23) is positive. The square bracketed expression inside 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 (A-23) is increasing with γ. Since the second line is also increasing with γ, it follows that the gain of consumers from PD is larger the larger is γ. *Q.E.D.*

Proof of Proposition 7: (i) Since in the strong protection case, expected social welfare under the CF system, $\bar{W}_F$, and under the PD system, W_F, differ only with respect to β, we can establish a sufficient condition for $W_F > \bar{W}_F$ by replacing β_θ with β in equation (14) and deriving a condition that ensures that $\partial\bar{W}_F/\partial\beta < 0$ for all $\beta \in [\beta_L, \beta_\theta]$. From equation (14),

$$\frac{\partial \bar{W}_F}{\partial \beta} = - \frac{(\pi_{yn} - \pi_{nn})\, r\, (1-\gamma\theta)^2 (r + \Pi)}{2\left(r^2 \beta - (1-\gamma\theta)^2 \Pi^2\right)^3} \times \Big[(\pi_{yn} - \pi_{nn}) Z(r, \beta) \tag{A-24}$$

$$+ 2\,(\pi_{yn} - \pi_{nn})\, M(\beta)\, S + 2\,(r + \Pi)\left(r^2 \beta - (1-\gamma\theta)^2 \Pi^2\right)\left(S_{yn} - S_{nn} + \pi_{ny} - \pi_{nn}\right)\Big],$$

where

$$M(\beta) \equiv (r + (1-\gamma\theta)\Pi)^2 + r^2(\beta - 1) - 2 r \gamma\theta (1-\gamma\theta)\Pi > 0, \tag{A-25}$$

and

$$Z(r, \beta) \equiv r^2 \beta\, (r + 3\Pi) + (1-\gamma\theta)^2 \Pi^2 (3r + \Pi). \tag{A-26}$$

The expression outside the square brackets in (A-24) is negative and the last two expressions inside the square brackets are positive (the last term is positive by Assumption A5). Hence $Z(r,\beta) \geq 0$ is sufficient for $\partial\bar{W}_F/\partial\beta < 0$ for all $\beta \in [\beta_L, \beta_\theta]$, which in turn ensures that $W_F > \bar{W}_F$. Now, surely, $Z(r,\beta) > 0$ if $r+3\Pi \geq 0$. Otherwise, $Z(r,\beta_\theta) \geq 0$ is sufficient for $Z(r,\beta) > 0$ for all $\beta \in [\beta_L, \beta_\theta)$. Recalling 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 $r \geq \bar{r}(\beta_\theta)$, where $\bar{r}(.)$ is defined in the Proposition.

(ii) Recall that in the intermediate protection case, expected social welfare under the CF system is $\bar{W}_F$, and under the PD system, it is W_{NF}, where W_{NF} is equal to $\bar{W}_F$ when it is evaluated at $\theta = 0$. Since $\bar{W}_F$ and W_{NF} differ only with respect to θ, a sufficient condition for PD to enhance (lower) welfare is that $\partial\bar{W}_F/\partial\theta > 0$ ($\partial\bar{W}_F/\partial\theta < 0$) for all $\theta \in [0, \overline{\gamma\theta}/\gamma)$. Using equation (14), we get

$$\frac{\partial \bar{W}_F}{\partial\theta} = \frac{(\pi_{yn}-\pi_{nn})\, r\,(1-\gamma\theta)(r+\Pi)\big(\beta_H-\beta_M-\gamma(\beta_H+\beta_\theta)\big)}{2\left(r^2\beta_\theta-(1-\gamma\theta)^2\Pi^2\right)^3}\times\Big[(\pi_{yn}-\pi_{nn})Z(r,\beta_\theta) + 2(\pi_{yn}-\pi_{nn})\,M(\beta_\theta)\,S + 2(r+\Pi)\left(r^2\beta_\theta-(1-\gamma\theta)^2\Pi^2\right)\left(S_{yn}-S_{nn}+\pi_{ny}-\pi_{nn}\right)\Big]. \qquad \textbf{(A-27)}$$

To determine the sign of the derivative, note that the expression inside the square brackets is similar to the expression inside the square brackets in (A-24), and hence is positive when $r \geq \bar{r}(\beta_\theta)$. In that case, the sign of the derivative depends on the sign of $(\beta_H-\beta_M)-\gamma(\beta_H+\beta_\theta)$.

Finally, note that W_{NF} is independent of γ, while using equation (14),

$$\frac{\partial \bar{W}_F}{\partial\gamma} = -\frac{(\pi_{yn}-\pi_{nn})\, r\,\beta_\theta\,\theta\,(1-\gamma\theta)\,(r+\Pi)}{\left(r^2\beta_\theta-(1-\gamma\theta)^2\Pi^2\right)^3}\times\Big[(\pi_{yn}-\pi_{nn})Z(r,\beta_\theta) + 2(\pi_{yn}-\pi_{nn})\,M(\beta_\theta)\,S + 2(r+\Pi)\left(r^2\beta_\theta-(1-\gamma\theta)^2\Pi^2\right)\left(S_{yn}-S_{nn}+\pi_{ny}-\pi_{nn}\right)\Big]. \qquad \textbf{(A-28)}$$

If $r \geq \bar{r}(\beta_\theta)$, then $\partial\bar{W}_F/\partial\gamma < 0$. Thus, if $W_{NF} > \bar{W}_F$ (PD is welfare-enhancing), the welfare gain from PD increase as γ increases. If on the other hand $W_{NF} < \bar{W}_F$ (PD is welfare-reducing), the welfare loss from PD becomes smaller as γ increases. *Q.E.D.*

Proof of Proposition 8: Under the PD system, W files for a patent if and only if $\gamma > \left(1-\sqrt{\beta_L/\beta_H}\right)/\theta$. As β_L falls, the right side of the inequality increases, so W files for a smaller set of parameters. If the inequality still holds, W files for a patent under both patent systems, so the impact of PD on expected social welfare is given by $W_F - \bar{W}_F$ (i.e., the difference between expected welfare under PD and under CF). To examine how β_L affects $W_F - \bar{W}_F$, note that $\bar{W}_F$ is independent of β_L, while equation (A-24) implies that if $r \geq \bar{r}(\beta_L)$, then $\partial W_F/\partial\beta_L < 0$. Hence, whenever $r \geq \bar{r}(\beta_L)$, lowering β_L boosts the welfare gain from PD. *Q.E.D.*

Proof of Proposition 10: Given Assumption A4, the benefit from innovating under the CF system when patent protection is strong or intermediate is

$$\bar{B}_F = \frac{(\pi_{yn} - \pi_{nn})(\pi_{yn} + \pi_{nn} - 2\pi_{ny})\, r\left(\beta_\theta - (1-\gamma\theta)^2\right)}{2\left(r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2\right)}. \qquad \textbf{(A-29)}$$

Under the PD system, the benefit from innovating is B_F if protection is strong, where B_F is identical to $\bar{B}_F$ except that β_L replaces β_θ. Thus, the impact of PD on the incentive to innovate when patent protection is strong depends on the sign of the following expression:

$$B_F - \bar{B}_F = -\frac{(\pi_{yn} - \pi_{nn})(\pi_{yn} + \pi_{nn} - 2\pi_{ny})\, r\left(r^2 - \Pi^2\right)(1-\gamma\theta)^2\left(\beta_\theta - \beta_L\right)}{4\left(r^2 \beta_L - (1-\gamma\theta)^2 \Pi^2\right)\left(r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2\right)} < 0. \qquad \textbf{(A-30)}$$

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

In the intermediate protection case, the impact of PD on the incentive to innovate depends on the sign of the following expression:

$$B_{NF} - \bar{B}_F = \frac{(\pi_{yn} - \pi_{nn})(\pi_{yn} + \pi_{nn} - 2\pi_{ny})\, r\left(r^2 - \Pi^2\right)\left(\beta_H (1-\gamma\theta)^2 - \beta_\theta\right)}{2\left(r^2 \beta_H - \Pi^2\right)\left(r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2\right)}, \qquad \textbf{(A-31)}$$

where $\beta_H(1-\gamma\theta)^2 - \beta_\theta \leq 0$, since in the intermediate protection case, $\gamma \geq \left(1 - \sqrt{\beta_\theta / \beta_H}\right)/\theta$. Hence, PD weakens the incentives to innovate in this case as well. However now, straightforward calculation reveals that $B_{NF} - \bar{B}_F$ decreases with γ so the negative impact of PD increases when γ increases. *Q.E.D.*

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