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. The main conclusions are that public disclosure leads to fewer patent 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 while the current U.S. patent system puts a greater emphasis on the first objective, 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 will increase certainty about legal rights in inventions, help avoid wasteful duplication of R&D expenses, reduce the number of useless patent filings, and create new possibilities for disseminating patent-related information.[3] They also maintain that "...such legislation is critical for the continued vitality of U.S. industry and jobs..."[4] 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

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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] For a list of 86 corporations and 24 associations that support S. 507, see http://www.ipo.org/COASSN.htm. Additional arguments in favor of the legislation appear in http://www.ipo.org/21CPCdocs105th.html

[4] See http://www.ipo.org/PRESSRELEASE8598.htm.

that have contributed so much to America's superior performance in the advancement of science and technology. 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 result in lasting harm to the United States and the world."[5] Given these 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), priority rules such as "first to file" versus "first to invent" (e.g., Scotchmer and Green, 1990), and novelty requirement (e.g., Scotchmer and Green, 1990; Scotchmer 1996; and Eswaran and Gallini, 1996). However, public disclosure of patent applications has received very little attention in the literature.[6] In this paper we try to fill this gap by developing a model that allows us to study the impact of public disclosure of patent applications 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. This process may lead to the development of a new technology that confers a competitive advantage in the product market. The R&D process consists of a research phase and a development phase. The research phase ends when one of the firms makes an innovation. This firm then has a head start in the development phase in the sense that its cost of developing the new technology are lower. Having made the innovation, the "winner" in the research phase (W for short) 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 boosts ℓ's chances to develop the new technology. 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.

[5] 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

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

We show that the implications of public disclosure of patent applications depend on the strength of the legal protection of patents. The latter depends in our model on two factors: (i) the likelihood that a patent will be granted, which we identify with novelty requirements (weaker requirements mean that patents are more likely to be granted), and (ii) the likelihood that the patentholder will win a patent infringement suit, which we identify with the breadth of the patent (broader patents are more likely to be upheld in court). When patents are relatively narrow, they provide weak protection against imitation because they are unlikely to be upheld in court. As a result, firms do not file for patents under neither patent system, so whether patent applications are publicly disclosed or not is completely irrelevant.

When patents provide a strong protection against imitation, firms file for a patent regardless of whether their applications are publicly disclosed or not. But since public disclosure of patent applications 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) is also enhanced because the gap between the investments of W and ℓ shrinks, so the allocation of investments across the two firms becomes more efficient. However, since public disclosure benefits ℓ and hurts W, it weakens the incentive to innovate and assume the role of W.

When the legal protection of patents is intermediate, W files for a patent under the CF system but not under the PD system. Therefore, in this case, public disclosure of patent applications discourages the dissemination of technological information, contrary to what many proponents of the Examining Procedure Improvements Act argue.[7] The impact of public disclosure of patent applications on investments in the development phase depends in this case on the likelihood that patents will be upheld in court. When this likelihood is high (patents are broad), W cuts its level of investment, while ℓ invests more. When this likelihood is relatively low (patents are narrow), the impact on the investments of W and ℓ is ambiguous,

[7] 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

although the aggregate level of investment falls unambiguously. Nonetheless, consumers are better-off under the PD system because W does not file for a patent under this system, and therefore cannot prevent ℓ from using the new technology in the product market if ℓ develops it. When the cost functions in the development phase are sufficiently convex, public disclosure of patent applications 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 conversely when they are relatively narrow. Finally, although public disclosure of patent applications hurts both W and ℓ, it turns out that it hurts W more so as before it weakens the incentives to innovate.

The main conclusions from our analysis then are that public disclosure leads to fewer patent 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.

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 our paper, these papers also consider sequential R&D races and explicitly take into account the decision to patent early inventions.[8] 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 latter provides firms with stronger incentives to patent (under the first-to-invent rule firms need not patent in order to keep a claim on the innovation), but it also induces firms to overinvest in R&D relative to the socially efficient level. In contrast, the first-to-invent rule can sometimes induce firms to underinvest. 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 shows that the optimal policy is to grant patents which are just broad enough to deter imitation and adjust their length to provide innovators with enough profits to induce them to engage in R&D. Matutes, Regibeau, and Rockett (1996) consider an

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[8] 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.

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

A key assumption in our model is that patents do not provide a perfect protection against imitation. A similar assumption has been also made in earlier papers but the reason why protection is imperfect in these papers 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 (1997) 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 has already issued a patent, while Anton and Yao (1995) consider only a confidential filing system. 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.

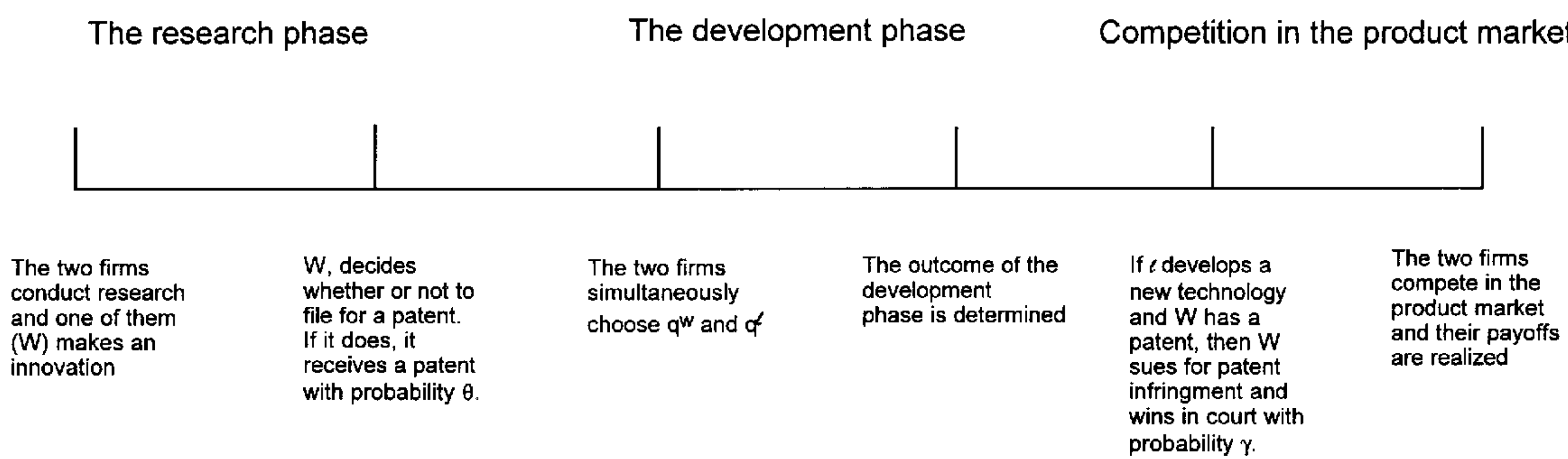
The rest of the paper is organized as follows: in Section 2 we describe the model. In Section 3 we study the equilibrium under the PD system, and in Section 4 we study the equilibrium under the CF system. In section 5 we compare the two systems in terms of the patenting and investment behavior of the firms, and in Section 6 and 7, respectively, we examine the implications of disclosing patent applications 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. In what follows we describe in detail each stage of the model, the features of the patent system, the expected payoffs of the two firms, and the solution concept we use.

□ **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 we refer to this firm

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



as "the winner," or W for short, and refer to its rival as "the loser," or ℓ for short.[9] Although ℓ has "lost" 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 applying for a patent is that the patent reveals information about the innovation to ℓ and therefore diminishes W's technological advantage. The benefit from patenting is that if ℓ eventually develops the new technology, W can sue it for patent infringement.[10] In practice, patent protection is imperfect for at least two reasons. First, patent applications can be rejected 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.[11] 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,

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[9] 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 innovation (the event that both firms innovate at once is a zero probability event). Second, one can think of the research phase as leading to innovations by both firms, in which case, W is the firm whose innovation is "better" or a more "promising." According to this interpretation, the length of the research phase is fixed rather than stochastic as in the first interpretation.

[10] In principle, W could license the right to use the innovation to ℓ instead of suing it for patent infringement. However, a serious consideration of this possibility would require us to distinguish between ex ante licensing (before the firms invest in the development phase), ex post licensing (after the outcome of the development phase is known), and possibly cross-licensing (e.g., when W fails in the development phase while ℓ succeeds). Moreover, we would have to take into account the impact of various features of the legal system on the terms of the licensing (see Aoki and Hu, 1999), as well as potential responses of antitrust authorities to various licensing agreements. All of these considerations are well beyond the scope of this paper and we believe that they should be examined in a separate paper that will focus on the impact of public disclosure of patent applications on the licensing of innovations.

[11] 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 <u>examined</u> applications which accounts in Japan to about half of the total number of patent applications.

although after the establishment of the Court of Appeals for the Federal Circuit in 1982 this number has increased sharply to 80% (Warshofsky, 1994 p. 8-9).[12] To capture these imperfections, 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 effective protection that applying for a patent provides is therefore $\gamma\theta$. 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.[13] Throughout we treat θ and γ as exogenous parameters.[14]

□ **The development phase:** Given W's filing decision, W and ℓ simultaneously choose how much to invest in the development of the new technology. This technology either lowers the cost of production in the product market or enables the firm to produce a new or an improved product. Let q denote the probability that a firm succeeds to develop the new technology. In principle, the advantage that the innovation confers on W can be modelled either by assuming that, all else equal, W has a higher q than ℓ, or by assuming that W has a lower cost of achieving a given q.[15] We adopt the second approach and

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[12] 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).

[13] Note that we distinguish between novelty requirements that affect the patentability of the innovation and patent breadth that affects the likelihood that the court will rule in favor of W. This is in contrast to say, Scotchmer and Green (1990) where stronger novelty requirements also mean broader patents. Also note that our interpretation of patent breadth differs from the one used 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 that a rival needs to keep between its product and the patentee's product (Klemperer, 1990 and Eswaran and Gallini, 1996), the minimal improvement in the a rival's product over the patentee's product (Green and Scotchmer, 1995 and Chang, 1995), and the number of new applications of a basic innovation that are reserved for the patentee's exclusive use (Matutes, Regibeau, and Rocket, 1996).

[14] 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.

[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

assume that W's cost of investment in the development phase is C(q), while ℓ's cost is $\beta_L C(q)$ if it learns 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 W's innovation. This could be, say, because of a learning-by-doing effect, or 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 sequential 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}. We make the following assumptions on the profits in the product market and on the cost of investment in the development phase:

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 the net present value of the industry profits when only one firm uses the new technology is larger than it is when both firms use it. Again this assumption holds in a broad class of duopoly models including

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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.

Cournot (provided that production costs are not too convex) and Bertrand with linear cost functions. Assumption A3 ensures that the best-response functions of both firms are well-behaved.[16]

□ **The patent system:** We consider two types of patent systems. Under the first system which we call the "public disclosure system" (PD system), the contents of patent applications are publicly disclosed. 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 system which is currently used in the U.S., the contents of the patent application are made public only when the patent is actually issued; if the application is rejected, no information is revealed. 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 $\gamma\theta$ (the probability that a patent is granted times the probability that the patent is upheld in court). Consequently, the probability that ℓ will develop the new technology and will be allowed to use it is $q^\ell(1-\gamma\theta)$. Therefore, when W files for a patent, its expected payoff under both patent systems, as a function of q^w and q^ℓ, is given by

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

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, as a function of q^w and q^ℓ, is given by

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

Under the CF system, ℓ's expected payoff function, denoted $\tilde{\pi}^\ell(q^w,q^\ell|F)$, is given by the same

[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 or not.

expression, except that ℓ's cost function is now given by $\beta_\theta C(q^\ell)$, where $\beta_\theta \equiv \theta\beta_L+(1-\theta)\beta_H$. This reflects the fact that under the CF system, ℓ learns about W's innovation only if a patent is actually granted and this event occurs with probability θ; with probability $1-\theta$, W's patent application is rejected and ℓ does not learn about W's innovation, so its cost function is $\beta_H C(q^\ell)$.

Absent filing, the type of the patent system in use is irrelevant, so the expected payoffs of W and ℓ are the same across the two systems. Since absent filing W cannot prevent ℓ from using the new technology if ℓ develops it, the expected payoff of W under both systems is

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

This expression coincides with W's expected payoff function in the filing subgame when either γ or θ are equal to 0. Similarly, the expected payoff of ℓ under both systems is

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

This expression differs from $\pi^\ell(q^w,q^\ell|F)$ 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 two subgames: 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 ex ante expected profits. The latter are important because they indicate which system provides firms with stronger incentives to innovate.

3. The public disclosure (PD) system

First consider the filing subgame. The best-response function of W in this subgame, $R^w(q^\ell|F)$, is determined implicitly by the following first order condition:

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

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

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

Assumptions A1 and A3 ensure that $R^w(q^\ell | F)$ and $R^\ell(q^w | F)$ 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, $(q^w{}_F, q^\ell{}_F)$, is determined by the intersection of $R^w(q^\ell | F)$ and $R^\ell(q^w | F)$; 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 $q^w{}_F$, $q^\ell{}_F \in [0, 1]$.

Next consider the no-filing subgame. The two best-response functions, $R^w(q^\ell | NF)$ and $R^\ell(q^w | NF)$, respectively, are now implicitly defined by the following first-order conditions:

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

and

$$\frac{\partial \pi^{\ell}(q^{w},q^{\ell}|NF)}{\partial q^{\ell}} = q^{w}(\pi_{yy}-\pi_{ny}) + (1-q^{w})(\pi_{yn}-\pi_{nn}) - \beta_H C'(q^{\ell}) = 0. \tag{8}$$

Again, Assumptions A1 and A3 ensure that $R^w(q^\ell | NF)$ and $R^\ell(q^w | NF)$ are well-defined, single-valued, and downward sloping in the (q^w, q^ℓ) space. A Nash equilibrium in the no-filing subgame, $(q^w{}_{NF}, q^\ell{}_{NF})$, is determined by the intersection of $R^w(q^\ell | NF)$ and $R^\ell(q^w | NF)$. 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 two subgames and determine when W files for a patent, we first examine the equilibrium levels of investment.

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

(i) $q^w{}_{NF}$ *and* $q^\ell{}_{NF}$ *are independent of* $\gamma\theta$, *whereas* $q^w{}_F$ *increases and* $q^\ell{}_F$ *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* $\gamma\theta \geq 1-\beta_L/\beta_H$;

(iii) $q^w{}_F + q^\ell{}_F > q^w{}_{NF} + q^\ell{}_{NF}$ *for all* $\gamma < 1-\beta_L/\beta_H$.

Proposition 1 is illustrated in Figure 2. 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 at all if it files for a patent, so $R^w(q^\ell | F) = R^w(q^\ell | NF)$. As for ℓ, its marginal benefit from q^ℓ is the same in the two subgames because W cannot prevent it from using the new technology. 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. Since $\beta_H > \beta_L > 1$, ℓ invests less than W so both F_0 and NF lie below a 45 degrees line passing through the origin.

Figure 2b shows the equilibrium points, F and NF, when $0 < \gamma\theta < 1-\beta_L/\beta_H$. As $\gamma\theta$ increases, W gets more protection if it applies for a patent, so in the filing subgame, the marginal benefit from q^w increases and the marginal benefit from q^ℓ decreases. Consequently, $R^w(q^\ell | F)$ shifts to the right while $R^\ell(q^w | F)$ shifts down, and 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. When $\gamma\theta \geq 1-\beta_L/\beta_H$, $R^\ell(q^w | F)$ drops below $R^\ell(q^w | NF)$, and as Figure 2c shows, F is attained southeast of NF (but not necessarily above a 45 degrees line passing though NF), implying that in the filing subgame, W invests more and ℓ invests less than they respectively invest in the no-filing subgame. 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 ℓ invests in equilibrium less than W.

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 2: *The equilibrium payoffs under the PD system have the following properties:*

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

(ii) *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.

(iii) $\pi^\ell_F < \pi^\ell_{NF}$ *whenever* $\gamma\theta > 1-\beta_L/\beta_H$.

Proposition 2 implies that W files for a patent iff the effective protection from applying for a patent, $\gamma\theta$, 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 his technological information to ℓ, while offering him little protection against imitation. As $\gamma\theta$ increases, patents receive more protection and become more attractive to W. As soon as $\gamma\theta > \overline{\gamma\theta}$, W's expected benefit from increasing the likelihood of being the sole user of the new technology exceeds the associated loss from revealing technological information to ℓ, so W files for a patent. Proposition 2 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 in turn 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)

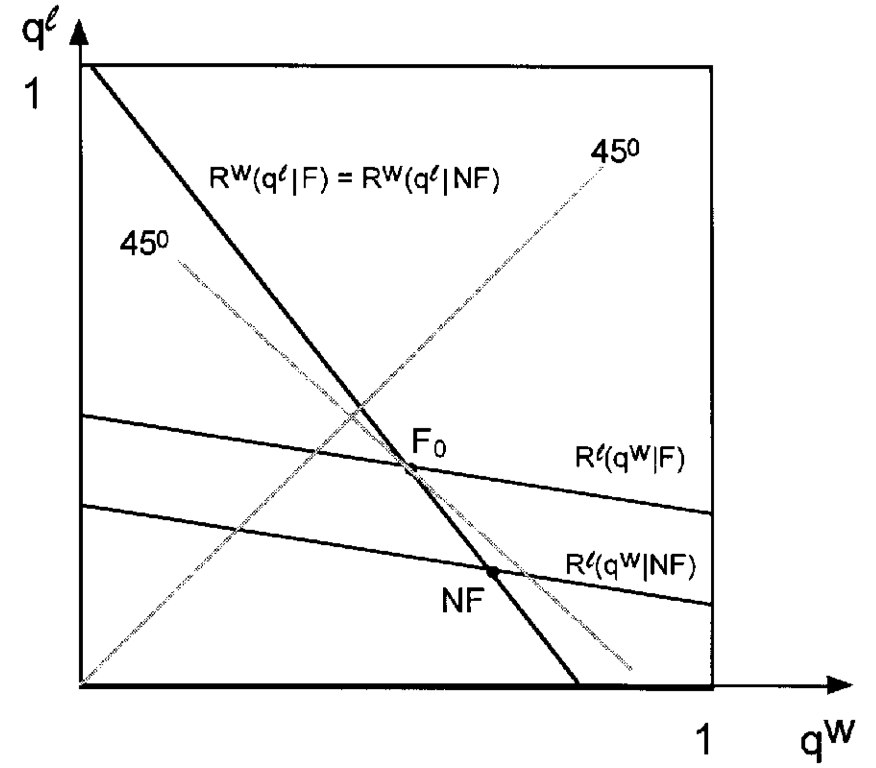

Figure 2a: The best-response functions under the PD system when $\gamma\theta = 0$

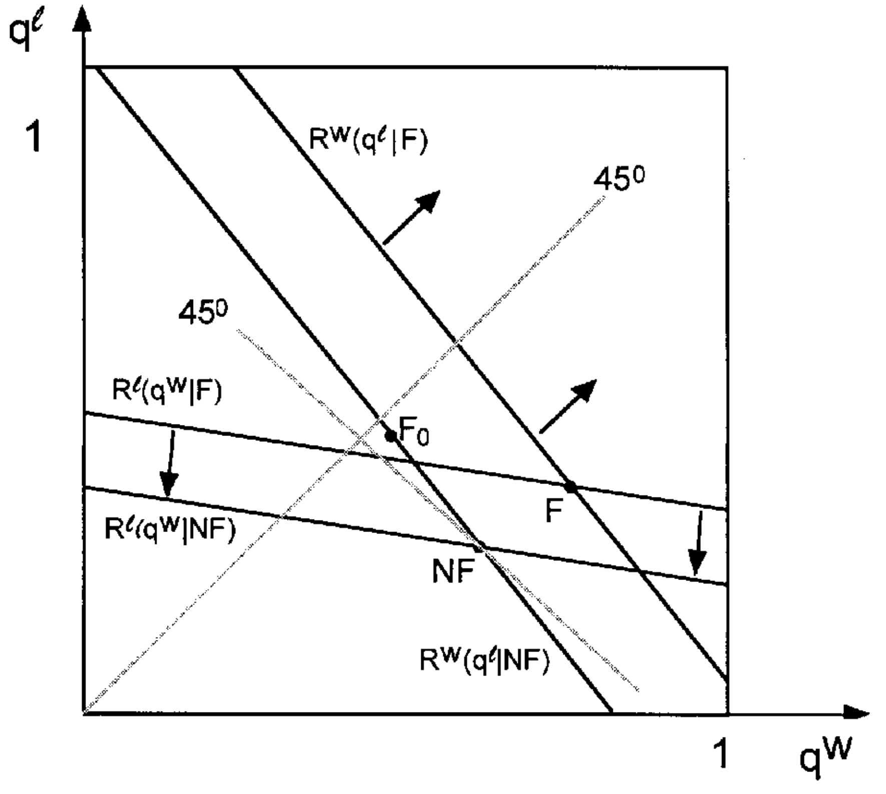

Figure 2b: The best-response functions under the PD system when $0 < \gamma\theta < 1\text{-}\beta_H/\beta_L$

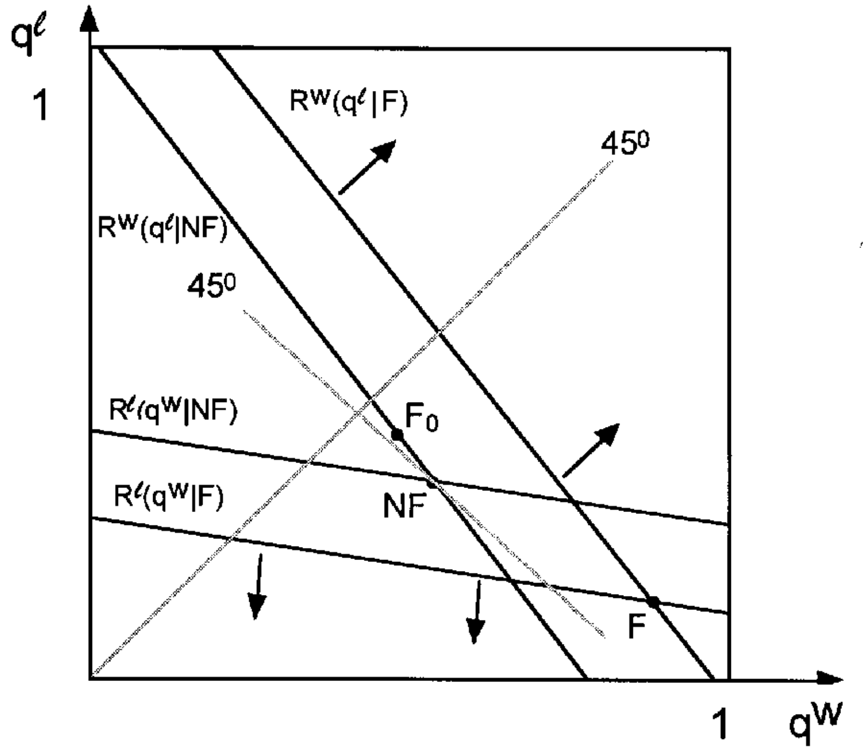

Figure 2c: The best-response functions under the CF system when $\gamma\theta > 1-\beta_H/\beta_L$

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.

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. Recalling that absent filing, the expected payoffs of W and ℓ are the same across the two patent systems, 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

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

where $\beta_\theta \equiv \theta\beta_L+(1-\theta)\beta_H$. 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 $\bar{R}^\ell(q^w \mid F)$. Since $R^w(q^\ell \mid F)$ and $\bar{R}^\ell(q^w \mid F)$ are downward sloping, q^w and q^ℓ are strategic substitutes. In the Appendix we prove that the Nash equilibrium is unique and $\bar{q}^w_F, \bar{q}^\ell_F \in (0,1)$.

Comparing equations (9) and (6) 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, under the CF system, γ and θ have potentially different impact on the equilibrium. We begin the analysis of the CF system by comparing the equilibrium levels of investment across the filing and the no-filing subgames.

Proposition 3: *The equilibrium levels of investment in the development phase under the CF system have the following properties:*

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

(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* $\gamma < 1\text{-}\beta_L/\beta_H$.

(iii) $\bar{q}^{w}_{F}+\bar{q}^{\ell}_{F} > q^{w}_{NF}+q^{\ell}_{NF}$ *for all* $\gamma < 1\text{-}\beta_L/\beta_H$.

Proposition 3 is illustrated in Figure 3. When $\theta = 0$, novelty requirements are so strict that no patents are granted. Figure 3a shows that the resulting equilibrium points in the filing subgame, F_0, and in the no-filing subgame, NF, coincide. When θ increases, novelty requirements are relaxed and patents are more likely to be granted; consequently, $\bar{R}^{w}(q^{\ell} \mid F)$ 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 from the patent application, 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 and therefore likely to be upheld in court. Consequently, the marginal benefit from q^{ℓ} falls more than the marginal cost of q^{ℓ}, so as Figure 3b shows, $\bar{R}^{\ell}(q^{w} \mid F)$ shifts down. Hence, the equilibrium point in the filing subgame, $\bar{F}$, lies southeast of the equilibrium point in the no-filing subgame, NF. Since $\beta_H > \beta_\theta > 1$, the two equilibrium points lie below a 45 degrees line passing through the origin, so ℓ invests less than W in both subgames.

When $\gamma < 1\text{-}\beta_L/\beta_H$, the reduction in the marginal cost of q^{ℓ} due to a small increase in θ outweighs the corresponding reduction in the marginal benefit from q^{ℓ}, so $\bar{R}^{\ell}(q^{w} \mid F)$ shifts up. Figure 3c shows that now, the equilibrium point in the filing subgame, $\bar{F}$, is either northwest, northeast, or southeast of NF, so the comparison between the two subgames becomes ambiguous. Nonetheless, part (iii) of Proposition 3 shows that the aggregate level of investment is larger in the filing subgame, so $\bar{F}$ lies in Figure 3c above a 45 degree line that passes through NF. In the extreme case where $\gamma = 0$, patents are so narrow that it is impossible to defend them in court. The situation then is similar to the one shown in Figure 2a, and the equilibrium point in the filing subgame, $\bar{F}_0$, lies northwest of NF.

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. To solve for W's filing decision, note first that π^{w}_{NF} and π^{ℓ}_{NF} are independent of γ and θ. On the other hand, differentiating $\bar{\pi}^{w}_{F}$ and $\bar{\pi}^{\ell}_{F}$ with respect to γ and using the envelope theorem and Proposition 3, it follows that $\partial\bar{\pi}^{w}_{F}/\partial\gamma > 0$ and $\partial\bar{\pi}^{\ell}_{F}/\partial\gamma < 0$. Thus as patents become broader and therefore more likely to be upheld in court, W becomes better-off by filing for a patent whereas ℓ becomes worse-off. Using these observations, we prove the following result:

Proposition 4: *For each* $\theta > 0$, *there exists a critical value of* γ, *denoted* $\hat{\gamma}$, *where* $\hat{\gamma} \in (0, 1\text{-}\beta_L/\beta_H)$, *such*

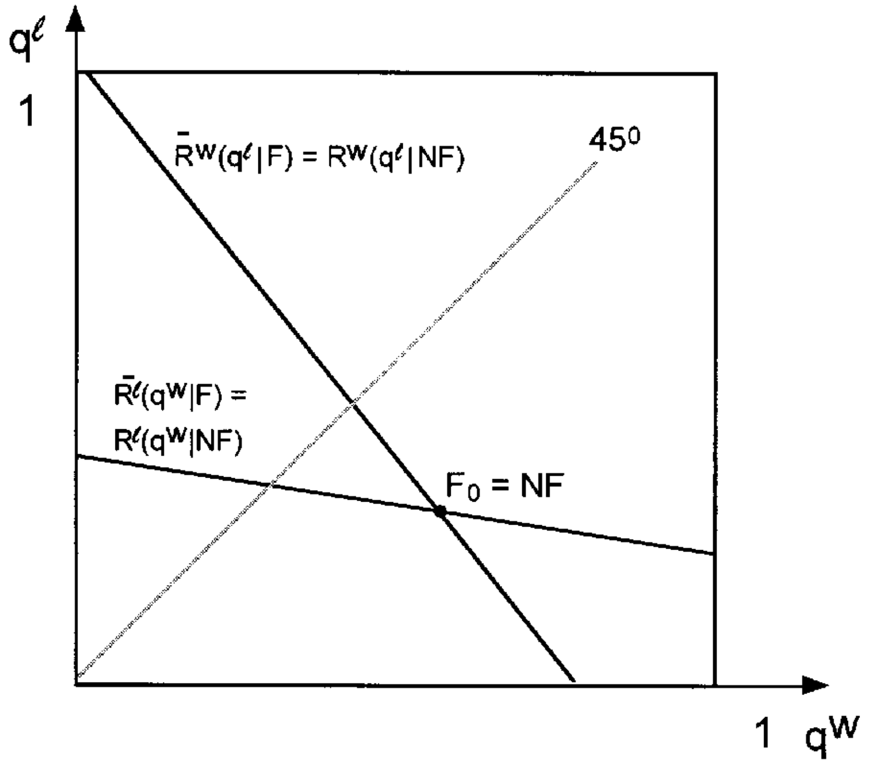

Figure 3a: The best-response functions under the CF sytem when $\theta = 0$

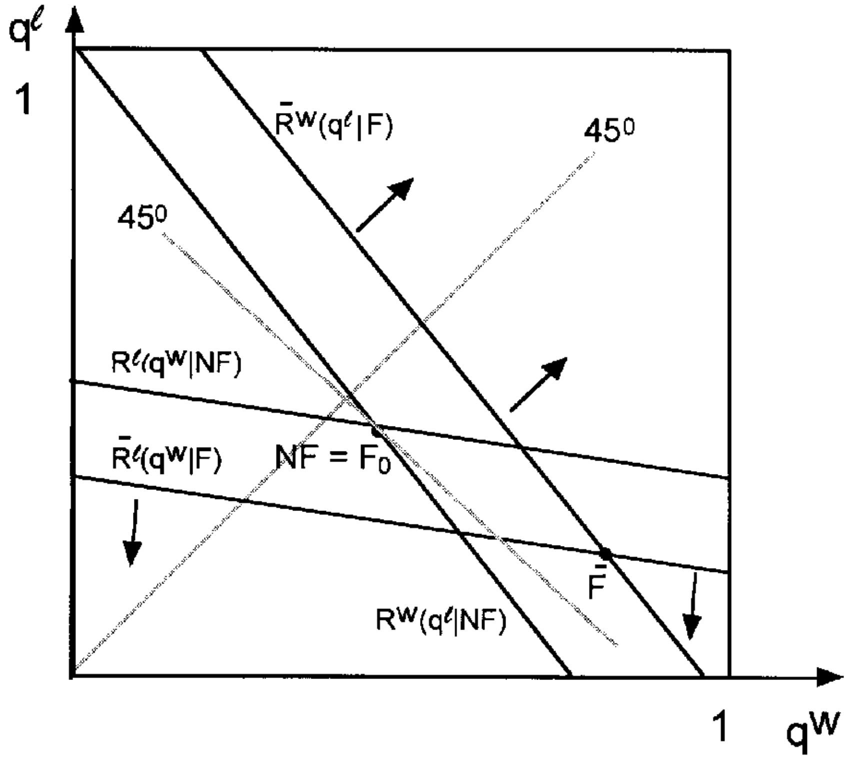

Figure 3b: The best-response functions under the CF system when $\gamma > 1 - \beta_L/\beta_H$.

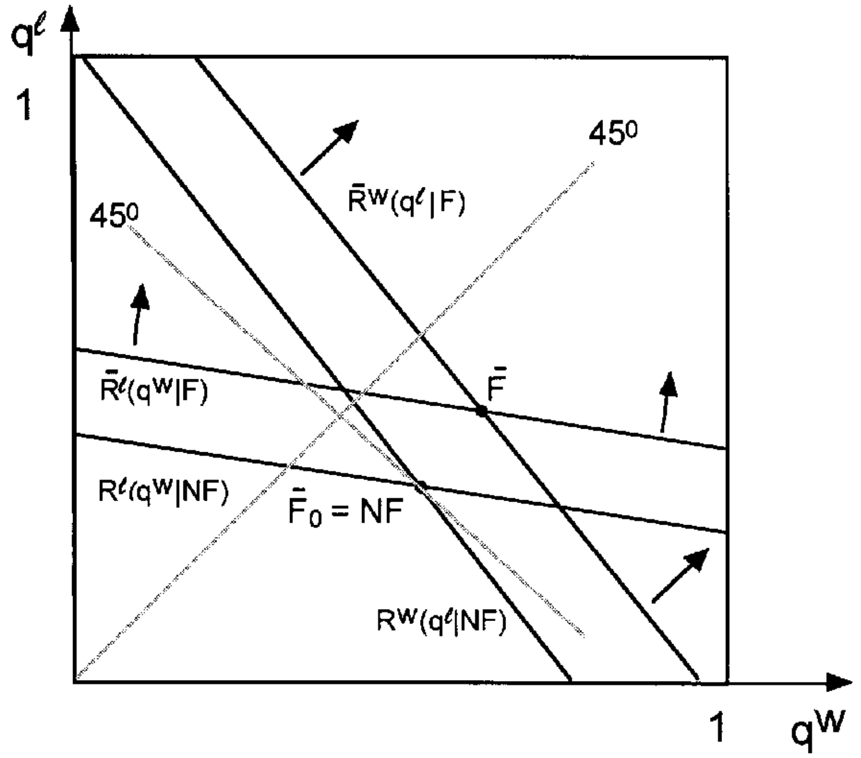

Figure 3c: The best-response functions under the CF system when $\gamma < 1 - \beta_L/\beta_H$.

that $\tilde{\pi}^w_F \gtreqless \pi^w_{NF}$ *as* $\gamma \gtreqless \tilde{\gamma}$. *The critical value* $\tilde{\gamma}$ *is decreasing with* β_L, *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* $\tilde{\gamma}\theta/(1-\tilde{\gamma}\theta)$. *Furthermore,* $\pi^\ell_{NF} > \tilde{\pi}^\ell_F$ *for all* $\gamma > 1-\beta_L/\beta_H$.

Proposition 4 implies that given the likelihood of getting a patent, θ, W files for a patent under the CF system iff the breadth of the patent, γ, exceeds a threshold level, $\tilde{\gamma}$. This threshold is bounded from above by $1-\beta_L/\beta_H$ and it may either increase or decrease with θ, depending on the sensitivity of $\bar{q}^\ell_F$ with respect to changes in θ. To see why, note that an increase in θ has two effects on W: First, it raises the chances that a patent will be granted and this strengthens W's incentive to file. Second, an increase in θ can either lead to an increase or a decrease in $\bar{q}^\ell_F$. When $\bar{q}^\ell_F$ decreases, the second effect reinforces the first effect. 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, the second effect weakens W's incentive to file. When the elasticity of $\bar{q}^\ell_F$ with respect to θ is sufficiently large, the second negative effect dominates, so $\tilde{\gamma}$ declines with θ, implying that W files for a smaller set of parameters.

5. Comparing the PD and the CF systems

Having characterized the equilibrium levels of investment in the development phase and having solved for W's filing decision under each patent system, we are now ready to compare the equilibrium outcomes under the two systems. But since public disclosure of patent applications matters only when W files for a patent, we only need to consider the filing subgames.

Proposition 5: *The equilibrium investment levels and payoffs in the filing subgame under the two patent systems have the following relationships:*

(i) $\bar{q}^\ell_F \le q^\ell_F < q^w_F \le \bar{q}^w_F$ *and* $q^w_F+q^\ell_F \ge \bar{q}^w_F+\bar{q}^\ell_F$

(ii) $\pi^w_F \le \tilde{\pi}^w_F$ *and* $\pi^\ell_F \ge \tilde{\pi}^\ell_F$,

with equalities holding only when $\theta = 1$.

Part (i) of Proposition 5 is illustrated in Figure 4. Under the PD system, ℓ observes W's innovation whenever W files for a patent, whereas under the CF system, ℓ observes it only when a patent is granted. So long as $\theta < 1$, patent applications are sometimes rejected, so the expected marginal cost of q^ℓ is higher under the CF system. Consequently, $\bar{R}^\ell(q^w \mid F)$ lies below $R^\ell(q^w \mid F)$ (the two best-response functions coincide only when $\theta = 1$). Since W's best-response function is the same under the

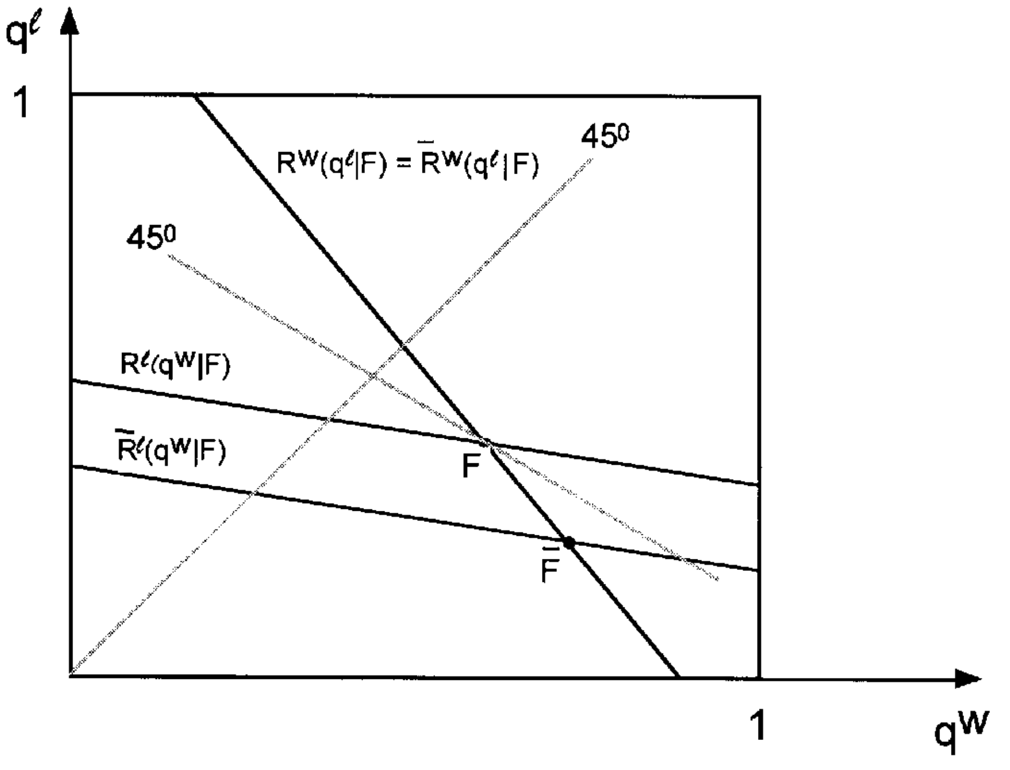

Figure 4: The best-response functions in the filing subgame under the PD and the CF systems

two patent systems, the equilibrium point under the PD system, F, is attained northwest of the equilibrium point under the a CF system, $\bar{F}$. Given Assumption A3, $\bar{F}$ 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 5 shows that in the filing subgame, public disclosure of patent applications benefits ℓ and hurts W. The result that $\bar{\pi}^w_F \geq \pi^w_F$, together with the results that $\pi^w_F > \pi^w_{NF}$ whenever $\gamma > \overline{\gamma\theta}/\theta$ (Proposition 2), and that $\bar{\pi}^w_F > \pi^w_{NF}$ whenever $\gamma > \bar{\gamma}$ (Proposition 4), implies that $\bar{\gamma}$ lies strictly below $\overline{\gamma\theta}/\theta$ in the (γ, θ) space, except when $\theta = 1$ at which point the two coincide. This has the following implication for W's filing decision:

Proposition 6: *W does not file for a patent under both patent systems if* $\gamma < \bar{\gamma}$, *files for a patent under both systems if* $\gamma > \overline{\gamma\theta}/\theta$, *and files for a patent only under the PD system if* $\bar{\gamma} \leq \gamma \leq \overline{\gamma\theta}/\theta$.

Proposition 6 is summarized in Figure 5. As the figure shows, there are three distinct cases that need to be considered, depending on the strength of patent protection. When $\gamma < \bar{\gamma}$, patent protection is weak since patents are relatively narrow and it is relatively easy to "invent around" them. Consequently, W does not file for a patent under neither patent system, so whether patent applications are publicly disclosed or kept confidential is completely 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 a strong protection, and W files for a patent under both systems. 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). The third case arises when $\bar{\gamma} \leq \gamma \leq \overline{\gamma\theta}/\theta$. Then, 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 (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 public disclosure of patent applications has several important implications. First, Proposition 6 shows that W files for a patent for a smaller set of parameters when patent applications are publicly disclosed. 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

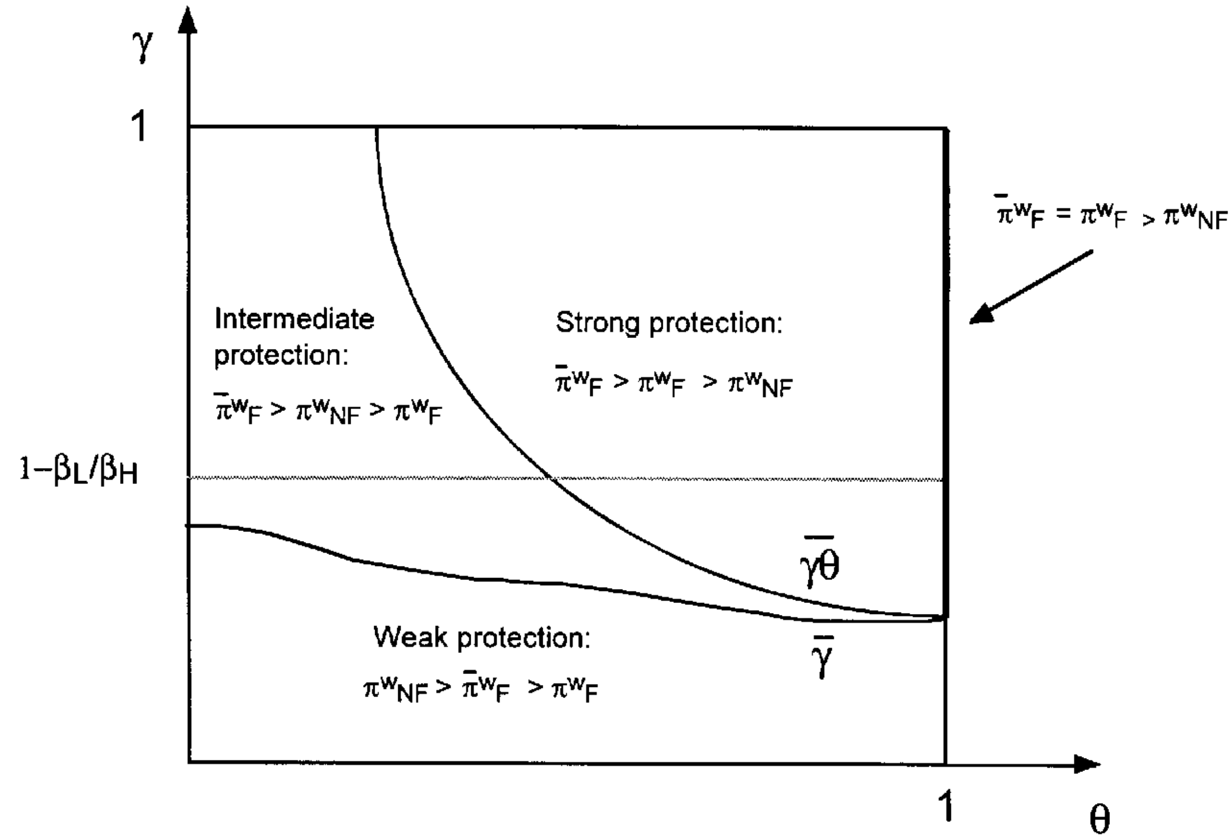

Figure 5: The equilibrium profits of W under the two filing systems. W does not file for a patent under both systems when the legal protection of patents is weak, files under both systems when the legal protection is strong, and files only under the CF system when the legal protection is intemediate.

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 6 qualifies this argument by suggesting that this will occur only in industries where patent protection is intermediate.

Second, Proposition 6 implies that under the PD system, the equilibrium levels of investments in the development phase are $q^w{}_F$ and $q^\ell{}_F$ if patent protection is strong and $q^w{}_{NF}$ and $q^\ell{}_{NF}$ otherwise, and under the CF system they are $\bar{q}^w{}_F$ and $\bar{q}^\ell{}_F$ if patent protection is either strong or intermediate and $q^w{}_{NF}$ and $q^\ell{}_{NF}$ otherwise. Using these observations, part (i) of Proposition 5 implies that in the strong protection case, public disclosure of patent applications 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, Propositions 3 implies that if $1-\beta_L/\beta_H < \gamma < \overline{\gamma\theta}/\theta$, public disclosure of patent applications leads to a decrease in q^w and an increase in q^ℓ; when $\underline{\gamma} < \gamma < 1-\beta_L/\beta_H$, the impact on the equilibrium levels of investment is ambiguous, although the aggregate level of investment increases following a transition to a PD system.

Third, noting that the equilibrium profits under the PD system are $\pi^w{}_F$ and $\pi^\ell{}_F$ if patent protection is strong and $\pi^w{}_{NF}$ and $\pi^\ell{}_{NF}$ otherwise, and under the CF system they are $\bar{\pi}^w{}_F$ and $\bar{\pi}^\ell{}_F$ if patent protection is either strong or intermediate and $\pi^w{}_{NF}$ and $\pi^\ell{}_{NF}$ otherwise, it is clear from Figure 5 that public disclosure of patent applications hurts W. This result is consistent with Putnam's (1997) estimate that publication of patent applications is associated with a \$479 decrease in the mean value of a patent. It should be noted though that in our model, W's loss from the disclosure of the patent application is even higher since Putnam's estimate is conditional on a patent being granted, while we compare the unconditional expected profits across the two patent systems. As for ℓ, then part (ii) of Proposition 5 implies that in the strong protection case, ℓ benefits from public disclosure of patent applications, and Proposition 4 implies that, at least when $\gamma > 1-\beta_L/\beta_H$, the same is true in the intermediate protection case. The fact that public disclosure of patent applications hurts W and may benefit ℓ can explain perhaps why the main opposition for the Examining Procedure Improvements Act in the U.S. comes from small and independent inventors (who in the context of our model are likely to play to role of W) while the main support for the legislation comes from large corporations that engage in products development (these corporations can in many cases play the role of ℓ).

6. Welfare implications

In this section we examine the implications of public disclosure of patent applications for consumers and for social welfare. To this end, let S_{yy} be the net present value of consumers' surplus in the product market when both firms develop the new technology, and define S_{yn} and S_{nn} similarly for the cases where only one firm, and when neither firm develop it. The measure of social welfare used in this paper is 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 make the following assumption:

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

The restriction on r ensures that Assumption A3 is satisfied. Recalling from Proposition 2 that $\overline{\gamma\theta}$ is implicitly defined $\pi^w_F = \pi^w_{NF}$, and recalling from Proposition 4 that $\bar{\gamma}$ is implicitly defined $\pi^w_F = \pi^w_{NF}$, it is straightforward to establish that, given Assumption A4, $\overline{\gamma\theta} \equiv 1 - \sqrt{\beta_L/\beta_H}$ and $\bar{\gamma} \equiv \frac{1 - \sqrt{\beta_\theta/\beta_H}}{\theta}$. Therefore, the protection of patents is strong if $\gamma > \frac{1 - \sqrt{\beta_L/\beta_H}}{\theta}$, intermediate if $\frac{1 - \sqrt{\beta_\theta/\beta_H}}{\theta} \leq \gamma \leq \frac{1 - \sqrt{\beta_L/\beta_H}}{\theta}$, and weak if $\gamma < \frac{1 - \sqrt{\beta_\theta/\beta_H}}{\theta}$.

In addition to Assumption A4, we make the following assumptions:

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

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

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,

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

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

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

Let $S_F \equiv S(q^w_F,q^\ell_F\,|\,F)$ be the equilibrium expected value of consumers' surplus under the PD system when there is filing, and define $\bar{S}_F \equiv \bar{S}(\bar{q}^w_F,\bar{q}^\ell_F\,|\,F)$ similarly for the CF system. When W does not file for a patent, public disclosure of patent applications plays no role, so the equilibrium expected value of consumers' surplus, denoted $S_{NF} \equiv S(q^w_{NF},q^\ell_{NF}\,|\,NF)$, is the same under both patent systems. Recalling that W does not file for a patent under neither system if patent protection is weak ($\gamma < \bar{\gamma}$), it is clear that consumers' surplus in this case is S_{NF} regardless of the patent system in use. Therefore we only need to consider cases where patents receive either strong or intermediate protection.

In the strong protection case where $\gamma > \dfrac{1-\sqrt{\beta_L/\beta_H}}{\theta}$, W files for a patent under both systems, so we need to compare S_F and $\bar{S}_F$. Given Assumption A4, the equilibrium levels of investment under the CF system are given by

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

where $\Pi \equiv \pi_{yy}+\pi_{nn}-\pi_{yn}-\pi_{ny} < 0$ by Assumption A2. Note that the assumption that $r > \pi_{yn}-\pi_{nn}$ implies that $r > -\Pi$; together with the assumption that $\beta_H > \beta_L > 1 \geq 1-\gamma\theta$, this ensures that $\bar{q}^w_F$ and $\bar{q}^\ell_F$ 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 because ℓ can observe W's innovation if W files for a patent, even if the patent application is eventually rejected. Substituting for $\bar{q}^w_F$ and $\bar{q}^\ell_F$ into (10), we get

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

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

replaces β_θ.

In the intermediate protection case where $\frac{1-\sqrt{\beta_\theta/\beta_H}}{\theta} \leq \gamma \leq \frac{1-\sqrt{\beta_L/\beta_H}}{\theta}$, W files for a patent under the CF system but not under the PD system. Therefore, now we need to compare $\bar{S}_F$ and S_{NF}, where S_{NF} is equal to $\bar{S}_F$ when it is evaluated at $\theta = 0$ (when $\theta = 0$, no information is revealed to ℓ under the CF system, exactly as if W did not file for a patent at all).

Proposition 7: *Public disclosure of patent applications does not affect consumers if $\gamma < \hat{\gamma}$ (patent protection is weak) or if $\theta = 0$, but given Assumptions A4 and A5, it enhances consumers' surplus otherwise. When patent protection is intermediate, the increase in consumers' surplus due to public disclosure of patent applications is larger the larger is γ.*

The intuition behind Proposition 7 is as follows. When patents are narrow (γ is low) or when novelty requirements are extremely stringent ($\theta = 0$), public disclosure of patent applications does not affect consumers because firms do not file for patents regardless of the patent system in use. In contrast, when patents receive a strong protection, W files for a patent under both patent systems; but as Proposition 5 shows, W invests less and ℓ invests more under the PD system. Given Assumption A4, the latter effect dominates (indeed the aggregate level of investment is larger under the PD system), so the new technology is more likely to reach the product market and this benefits consumers. Under intermediate protection, W files for a patent under a CF system but not under a PD system. To examine the implications for consumers, note that as γ increases (patents become broader and hence easier to defend in court), W is more likely to prevent ℓ from using the new technology in the product market; 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 $\gamma = \frac{1-\sqrt{\beta_\theta/\beta_H}}{\theta}$, it follows that consumers' surplus is higher under a PD system and moreover, the gain in consumer surplus from a transition from a CF system to a PD system is increasing with 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 $W_{NF} = S_{NF}+\pi^w_{NF}+\pi^\ell_{NF}$. As in Section 6.1, we only need to consider the strong and intermediate protection cases since W does not file for a patent in the weak protection case, so the type of the patent system in use is irrelevant.

When patents receive a strong protection, i.e., when $\gamma > \frac{1 - \sqrt{\beta_L/\beta_H}}{\theta}$, W files for a patent under both patent systems, so 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),

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

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

In the intermediate protection case, where $\frac{1 - \sqrt{\beta_\theta/\beta_H}}{\theta} \leq \gamma \leq \frac{1 - \sqrt{\beta_L/\beta_H}}{\theta}$, W files for a patent only under the CF system. Hence, the equilibrium expected social welfare is $\bar{W}_F$ under the CF system and W_{NF} under the PD system, where W_{NF} is equal to $\bar{W}_F$ when it is evaluated at $\theta = 0$ (under the CF system, $\theta = 0$ means that no information is revealed to ℓ, exactly as if W does not file for a patent).

In the next proposition we use the fact that $\bar{W}_F$ and W_F differ only with respect to β, and $\bar{W}_F$ and W_{NF} differ only with respect to θ to establish sufficient conditions for public disclosure of patent applications to enhance social welfare.

Proposition 8: *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 public disclosure of patent applications to enhance expected welfare when patent protection is strong is* $r \geq \bar{r}(\beta_\theta)$, *and*

(ii) *a sufficient condition for public disclosure of patent applications to enhance (lower) expected welfare when patent protection is intermediate is* $r \geq \bar{r}(\beta_\theta)$ *and* $\gamma > (<) (\beta_H-\beta_L)/(\beta_H+\beta_\theta)$.

Proposition 8 reveals that when r is sufficiently large, public disclosure of patent applications is socially desirable if patents receive a strong protection, but it may be either socially desirable or undesirable when patents receive an intermediate protection, depending on the value of γ. Intuitively, Proposition 5 shows that in the strong protection case, 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. The resulting efficiency gain increases with r which is the slope of the marginal cost of investment. Consequently, in the strong protection case, public disclosure of patent applications 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 main difference between them is with respect to the allocation of investments between W and ℓ.

In the intermediate protection case, things are more complex because the sufficient condition depends not only on r but also on the breadth of patents, γ. The reason why γ matters is that part (ii) of Proposition 3 shows that when γ is large (i.e., above $1-\beta_L/\beta_H$), the allocation of investments between W and ℓ is more even under the PD system, whereas when γ is small (i.e., below $1-\beta_L/\beta_H$), the reverse is true. 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, but more efficient under the CF system if γ is small.

To get a better sense for the welfare implications of public disclosure of patent applications we consider the following example.

□ **A Cournot example with a cost-reducing technology:** Suppose that the two firms are Cournot-competitors in the product market and face an inverse demand function $P = 6-x_1-x_2$, where x_i is the output of firm i, i = 1,2. In addition, assume that the new technology is cost-reducing in the sense that firm i's marginal cost of production is 0 if the firm 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 $r > \pi_{yn}-\pi_{nn}$ as Assumption A4 requires, let $r > 8$. This example allows us to derive the precise conditions under which public disclosure of patent applications is either welfare-enhancing or welfare-reducing (this is in contrast with Proposition 8 that reports only (overly strong) sufficient conditions).

In the strong protection case, public disclosure of patent applications is welfare-enhancing when $W_F-\bar{W}_F > 0$. In Figure 6, we set $\beta_L = 2$ and $\beta_H = 3$ (i.e., $\beta_L/\beta_H = 0.66$, similarly to the estimate of Mansfield, Schwartz, and Wagner, 1981) and present $W_F-\bar{W}_F$ as a function of r for different combinations of γ and θ. The figure shows that public disclosure of patent applications is welfare-enhancing iff r which is the slope of the marginal cost functions in the development phase, is sufficiently large. Moreover, the figure shows that when there is a positive welfare gain, the gain is larger as θ is small (novelty requirements are weak) and as γ is small (patents are narrow). To understand why, note from equation (12) that the difference between $\bar{q}^w_F - \bar{q}^e_F$ and $q^w_F - q^e_F$ shrinks as γ and θ increase. This in turn diminishes the efficiency gain from publicly disclosing patent applications. Thus, public disclosure of patent applications 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, public disclosure of patent applications is welfare-enhancing if $W_{NF}-\bar{W}_F > 0$. In Figure 7, we set $\beta_L = 2$, $\beta_H = 18$, and $\theta = 0.25$ and present $W_{NF}-\bar{W}_F$ as a function of r for five different values of γ.[17] Since $\beta_L/\beta_H = 0.11$, patents create a relatively large informational spillover. The figure shows that when γ is relatively large ($\gamma = 0.5$ and 0.6), public disclosure of patent applications is welfare enhancing iff r is sufficiently large (above 8.241 and 8.245 respectively), whereas when γ is relatively small ($\gamma = 0.2$, 0.3, and 0.4) it is welfare enhancing iff r is small (below 8.231, 8.234, and 8.238, respectively). Moreover, the figure shows when public disclosure of patent applications is socially desirable, it generates a larger welfare gain when γ is large, i.e., when patents are relatively broad. As we explained above, this is due to the effect of γ on the allocation of investments in the development phase and hence the efficiency of R&D.

□ **Foreign patent applications and domestic welfare:** The welfare analysis in this subsection was done by taking into account the combined payoffs of consumers and firms. However, at least in the U.S., many patent applications are made by foreigners whose payoffs should be ignored if what we are interested in is 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.[18] Moreover, in 1997, 17 organizations among the top 30 organizations receiving U.S. patents

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[17] Recalling that in the intermediate protection case, $\frac{1-\sqrt{\beta_\theta/\beta_H}}{\theta} \le \gamma \le \frac{1-\sqrt{\beta_L/\beta_H}}{\theta}$, it follows that we need to restrict attention to values of γ between 0.118 and 0.667.

[18] These numbers are taken from Tables 2,6,9, and 10 in the 1997 U.S. Patent office annual report.

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

Figure 6a: gamma = 0.7

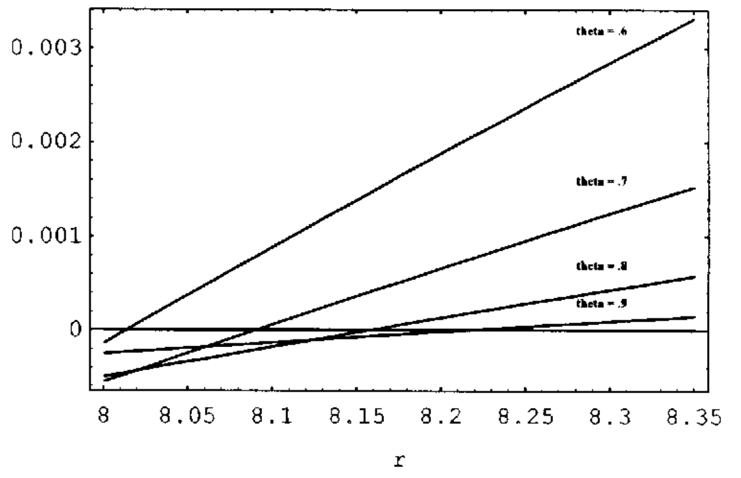


Figure 6b: theta = 0.7

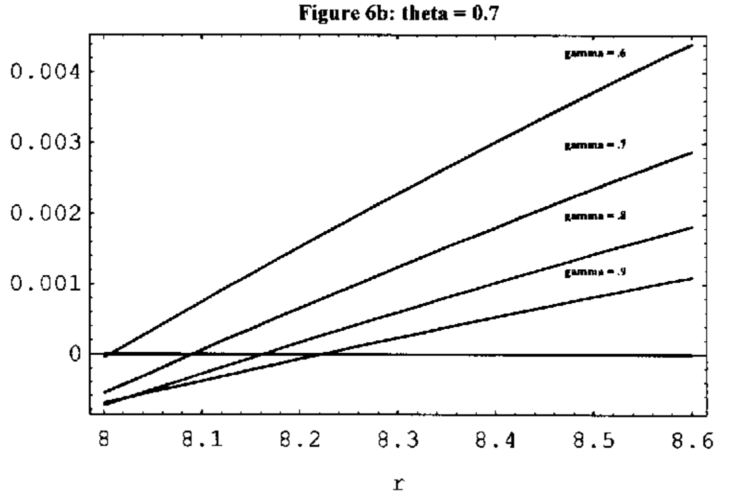
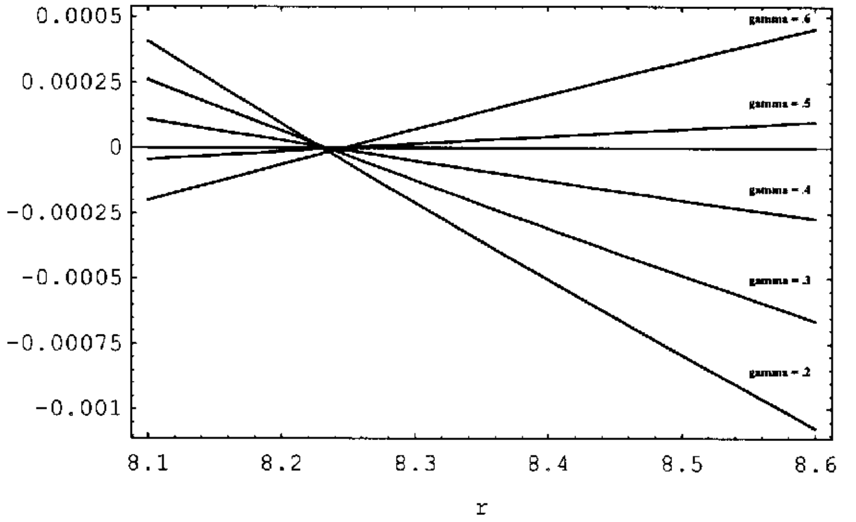


Figure 7: The change in welfare due to public disclosure of patent applications in the intermediate protection case (theta = 0.25)



(and 7 out of the top 10) were foreign.[19] To examine how public disclosure of patent applications made by foreigners will affect domestic welfare, we shall now assume that W is a foreign firm. Given this assumption, domestic welfare in the strong protection case is $\bar{S}_F+\bar{\pi}^\ell_F$ under the CF system and $S_F+\pi^\ell_F$ under the PD system. Since Propositions 7 and 5, respectively, imply that $S_F \geq \bar{S}_F$ and $\pi^\ell_F \geq \bar{\pi}^\ell_F$, it is clear that when the patent application is disclosed, domestic welfare increases. In the intermediate protection case, domestic welfare continues to be $\bar{S}_F+\bar{\pi}^\ell_F$ under the CF system, although under the PD system it becomes $S_{NF}+\pi^\ell_{NF}$. Now, Proposition 7 implies that $S_{NF} \geq \bar{S}_F$, while Proposition 4 implies that $\pi^\ell_{NF} > \bar{\pi}^\ell_F$ whenever $\gamma > 1-\beta_L/\beta_H$. Hence, whenever $\gamma \geq 1-\beta_L/\beta_H$ (i.e., the patent is sufficiently broad), public disclosure of patent applications surely enhances domestic welfare. When $\gamma < 1-\beta_L/\beta_H$, the comparison between π^ℓ_{NF} and $\bar{\pi}^\ell_F$ is ambiguous, so we cannot determine the resulting impact on domestic welfare without imposing further structure on the model.

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

Comparing Propositions 8 and 9 reveals that public disclosure of patent applications is more likely to enhance domestic welfare if W is a foreign firm. The reason for this is that public disclosure always hurts W, so if we exclude W's payoff from social welfare we get a more positive picture of the welfare implications. 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 when patents are broad, there is a high chance that if the foreign firm, W, files for a patent, it will prevent the domestic firm, ℓ, from using the new technology in the product market if the latter succeeds to develop such a technology. But, in the intermediate protection case, public disclosure of patent applications induces W to stop filing for patents, so there is a higher chance that ℓ will be able to introduce the new technology in the product market.

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[19] 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

7. The incentives to innovate

Thus far we have focused on the implications of public disclosure of patent applications, assuming that one firm has already made an innovation. In this section, we ask how public disclosure affects the incentives to innovate in the research phase. To this end, we assume that by investing in the research phase, a firm can increase its chances to make a discovery. Moreover, we assume that the outcome of the research phase is binary: either a firm makes a discovery or else it learns nothing. Given these assumptions, the benefit from investment in the research phase is given by $B \equiv \pi^w - \pi^\ell$, which is the difference between the expected profits of being the winner and being the loser in the research phase. We will argue that the patent system that gives rise to a higher B, provides firms with stronger incentives to innovate. As before, we study only the strong and intermediate protection cases since in the weak protection case, W does not file for a patent under neither system, so public disclosure of patent application is completely irrelevant.

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 $\bar{B}_F = \bar{\pi}^w{}_F - \bar{\pi}^\ell{}_F$ under the CF system. The comparison between B_F and $\bar{B}_F$ is straightforward since part (ii) of Proposition 5 implies that when W files for a patent, public disclosure of patent applications hurts W and benefits ℓ. Hence, $B_F - \bar{B}_F < 0$, so firms have weaker incentives to innovate in the research phase and try to assume the role of W.

Things are more complex in the intermediate protection case. Now public disclosure of patent applications induces W to stop filing for patents and this has an adverse effect not only on W but on ℓ too. To study this case further, we shall impose Assumption A4. Given this assumption, the benefit from investing in the research phase under the CF system is

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

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 the expression for B_{NF} is identical to $\bar{B}_F$ when $\theta = 0$. The impact of public disclosure of patent applications, then, depends on the sign of the following expression:

$$B_{NF} - \bar{B}_F = \frac{(\pi_{yn} - \pi_{nn})(\pi_{yn} + \pi_{nn} - 2\pi_{ny})\, r\,(r^2 - \Pi^2)\big(\beta_H (1-\gamma\theta)^2 - \beta_\theta\big)}{2\big(r^2 \beta_H - \Pi^2\big)\big(r^2 \beta_\theta - (1-\gamma\theta)^2 \Pi^2\big)}, \tag{16}$$

where $\beta_H(1\text{-}\gamma\theta)^2 - \beta_\theta \leq 0$, since in the intermediate protection case, $\gamma \geq \frac{1 - \sqrt{\beta_\theta/\beta_H}}{\theta}$. Hence, public disclosure of patent applications hurts W by more than it hurts ℓ, and therefore, it weakens the incentives to innovate. We summarize this discussion as follows:

Proposition 10: *Public disclosure of patent applications diminishes the benefit from investment in the research phase when patent protection is strong, and given Assumption A4, it also diminishes the benefit from investment in the research phase when patent protection is intermediate.*

Proposition 10 supports the concern of the opponents of the Examining Procedure Improvements Act in the U.S. that public disclosure of patent application might discourage innovative activity. Given the importance of this activity to the performance of the economy as a whole, this aspect of public disclosure of patent applications should be given a serious consideration.

8. Conclusion

In this paper, we analyzed the consequences of patent disclosure of patent applications. This analysis can potentially contribute to the 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.[20] Our analysis suggests that the legislation will discourage firms from filing for patents in industries where patents receive an intermediate protection against imitation. Moreover, the analysis suggests that the legislation may have an adverse effect on the incentives of firms 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."

[20] 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.

At the same time, our analysis also shows that, holding the number of innovations fixed, public disclosure of patent applications may raise the likelihood that new technologies will reach the product market by either raising the aggregate level of investment in developing new technologies or by lowering the legal hurdles for introducing such technologies by firms who do not own patents on the underlying innovations. Consequently, the legislation benefits consumers and, depending on the breath of patents and the shape of the cost functions of R&D, it may also enhance social welfare. And, if we restrict attention to domestic welfare, the legislation is even more likely to be desirable if some innovations are made by foreign firms.

Although our model is quite general (we do not assume a particular type of competition 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 the impact of public disclosure of patent applications. 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 explore this possibility and examine how public disclosure of patent applications 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 public disclosure of patent application is relevant) and licensing is 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:

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

and

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

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). These functions cross one another 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) if (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 the best-response functions cross 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 now $\beta_\theta \equiv \theta\beta_L+(1-\theta)\beta_H$ replaces β_L. 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 Proposition 1: (i) 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 $\partial R^{\ell}(q^w \mid F)/\partial(\gamma\theta) < 0$. Since q^w and q^{ℓ} are strategic substitutes, this implies that q^w_F increases and q^{ℓ}_F decreases with $\gamma\theta$.

(ii) First, suppose that $\gamma\theta = 0$. Then, equations (5) and (7) show that $R^w(q^\ell | F) = R^w(q^\ell | NF)$. Since $\beta_L < \beta_H$, it follows from equations (6) and (8) that $R^\ell(q^w | F) > R^\ell(q^w | NF)$ for all q^w. Together with the fact that q^w and q^ℓ are strategic substitutes, this implies 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 $\beta_L = 1$, equation (5) and (6) are symmetric and therefore admit a symmetric solution. Since the best-response functions of the two firms cross only once, this solution is unique. As β_L increases from 1, $R^\ell(q^w | F)$ decreases while $R^w(q^\ell | F)$ stays the same (note that β_L does not appear in equation (5)). Since $R^w(q^\ell | F)$ is steeper than $R^\ell(q^w | F)$, the best-response functions must now cross in the (q^w, q^ℓ) space below a 45 degrees line passing through the origin, so $q^\ell_F < q^w_F$.

Next, suppose that $\gamma\theta \geq 1-\beta_L/\beta_H$. We can rewrite equation (6) as

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

Here the first two terms are the same as the first two term in equation (8) whereas the third term is larger since $\gamma\theta \geq 1-\beta_L/\beta_H$. Hence, $R^\ell(q^w | F) \leq R^\ell(q^w | NF)$. Together with the fact that equations (5) and (7) imply that $R^w(q^\ell | F) > R^w(q^\ell | NF)$ for all $\gamma\theta > 0$, it follows that $q^w_F > q^w_{NF}$ and $q^\ell_F < q^\ell_{NF}$. To prove that $q^\ell_{NF} < q^w_{NF}$, note that if $\beta_H = 1$, equations (8) and (9) are symmetric so $q^\ell_{NF} = q^w_{NF}$. As β_H increases from 1, $R^\ell(q^w | NF)$ decreases while $R^w(q^\ell | NF)$ stays the same. Since $R^w(q^\ell | NF)$ is steeper than $R^\ell(q^w | NF)$, the best-response functions must cross in the (q^w, q^ℓ) space below a 45 degrees line passing through the origin, so $q^\ell_{NF} < q^w_{NF}$.

(iii) Suppose that $\gamma\theta = 1-\beta_L/\beta_H$. Then, $R^\ell(q^w | F) = R^\ell(q^w | NF)$, 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 $\partial R^\ell(q^w | F)/\partial q^w = -(1-\gamma\theta)\Pi/\beta_H C''(q^\ell_F)$. Given Assumption A3, $C''(q) > -\Pi$ for all $q \in [0, 1]$, so $\partial R^\ell(q^w | F)/\partial q^w > -1$, 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 $\gamma\theta < 1-\beta_L/\beta_H$, $\bar{R}^\ell(q^w | F)$ shifts upward, reinforcing the result. *Q.E.D.*

Proof of Proposition 2: (i) Equations (3) and (4) indicate that π^w_{NF} and π^ℓ_{NF} are independent of γ and θ. Using the envelope theorem, it follows from equation (1) that

$$\frac{\partial \pi_F^w}{\partial(\gamma\theta)} = -q_F^\ell\left[q_F^w(\pi_{yy}-\pi_{yn}) + (1-q_F^w)(\pi_{ny}-\pi_{nn})\right] + \frac{\partial \pi_F^w}{\partial q^\ell}\frac{\partial q_F^\ell}{\partial(\gamma\theta)}. \tag{A-4}$$

Assumption A1 ensures that the expression inside the square brackets and $\partial\pi^w_F/\partial q^\ell$ are both negative. Since $\partial q^\ell_F/\partial(\gamma\theta) < 0$ by Proposition 1, it follows that $\partial\pi^w_F/\partial\gamma\theta > 0$. Similarly, it follows from equation (2) that

$$\frac{\partial \pi_F^\ell}{\partial(\gamma\theta)} = -q_F^\ell\left[q_F^w(\pi_{yy}-\pi_{ny}) + (1-q_F^w)(\pi_{yn}-\pi_{nn})\right] + \frac{\partial \pi_F^\ell}{\partial q^w}\frac{\partial q_F^w}{\partial(\gamma\theta)}. \tag{A-5}$$

Assumption A1 ensures that the expression inside the square brackets and $\partial\pi^\ell_F/\partial q^w$ are both positive. Since by Proposition 1, $\partial q^w_F/\partial(\gamma\theta) > 0$, it follows that $\partial\pi^\ell_F/\partial\gamma\theta < 0$.

(ii) To prove the existence of $\overline{\gamma\theta} \in (0, 1-\beta_L/\beta_H)$, note that $\overline{\gamma\theta}$ is defined implicitly by the equation $\pi^w_F = \pi^w_{NF}$. 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 $\pi^w(q^w,q^\ell\,|\,F) = \pi^w(q^w,q^\ell\,|\,NF)$. Consequently,

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

where the strict inequality follows because $\partial\pi^w(q^w,q^\ell\,|\,F)/\partial q^\ell < 0$ and because by Proposition 1, $q^\ell_F > q^\ell_{NF}$ when $\gamma\theta = 0$, and the weak inequality is implied by revealed preferences (i.e., by the definition of q^w_{NF}). Next suppose that $\gamma\theta = 1-\beta_L/\beta_H$. Then Proposition 1 indicates that $q^\ell_F < q^\ell_{NF}$. Moreover, 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 $\gamma,\theta > 0$. Hence,

$$\pi_F^w \ge \pi^w(q_{NF}^w,q_F^\ell\,|\,F) > \pi^w(q_{NF}^w,q_F^\ell\,|\,NF) = \pi_{NF}^w, \tag{A-7}$$

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 find out 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

$$\frac{\partial\overline{\gamma\theta}}{\partial\beta_L} = \frac{(1-\gamma\theta)\dfrac{\partial q_F^{\ell}}{\partial\beta_L}}{q_F^{\ell} - (1-\gamma\theta)\dfrac{\partial q_F^{\ell}}{\partial\gamma\theta}}, \qquad \textbf{(A-8)}$$

where $\partial q^{\ell}_F/\partial(\gamma\theta) < 0$ by Proposition 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, noting that π^w_{NF} is independent of $\gamma\theta$ and π^w_F is independent of β_H, and using the envelope theorem, we obtain

$$\frac{\partial\overline{\gamma\theta}}{\partial\beta_H} = \frac{-\dfrac{\partial q_{NF}^{\ell}}{\partial\beta_H}}{q_F^{\ell} - (1-\gamma\theta)\dfrac{\partial q_F^{\ell}}{\partial\gamma\theta}}, \qquad \textbf{(A-9)}$$

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_L. Hence, $\overline{\gamma\theta}$ increases with β_H.

(iii) Using equations (2) and (4) we get,

$$\pi^{\ell}(q_F^{w},q_F^{\ell}|NF) - \pi_F^{\ell} = \gamma\,\theta\, q_F^{\ell}\left[q_F^{w}(\pi_{yy}-\pi_{ny}) + (1-q_F^{w})(\pi_{yn}-\pi_{nn})\right] - (\beta_H-\beta_L)C(q_F^{\ell}). \qquad \textbf{(A-10)}$$

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

$$\begin{aligned}\pi^{\ell}(q_F^{w},q_F^{\ell}|NF) - \pi_F^{\ell} &= \frac{\gamma\,\theta\,\beta_L\, q_F^{\ell}\, C'(q_F^{\ell})}{1-\gamma\theta} - (\beta_H-\beta_L)C(q_F^{\ell}) \\ &> \frac{\beta_H\, C(q_F^{\ell})}{1-\gamma\theta}\left[\gamma\,\theta - \left(1-\frac{\beta_L}{\beta_H}\right)\right] > 0.\end{aligned} \qquad \textbf{(A-11)}$$

Using this inequality, we have

$$\pi_{NF}^{\ell} \geq \pi^{\ell}(q_{NF}^{w},q_F^{\ell}|NF) > \pi^{\ell}(q_F^{w},q_F^{\ell}|NF) > \pi_F^{\ell}, \qquad \textbf{(A-12)}$$

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 because by Proposition 1, $q^w_F > q^w_{NF}$ for all $\gamma\theta >$

$1\text{-}\beta_L/\beta_H$. *Q.E.D.*

Proof of Proposition 3: (i) First recall that q^w_{NF} and q^ℓ_{NF} are defined implicitly by the solution to equations (7) and (8). Since γ and θ do not appear in these equations, it is clear that q^w_{NF} and q^ℓ_{NF} are independent of γ and θ. Second, recall that $R^w(q^\ell \mid F)$ and $\bar{R}^\ell(q^w \mid F)$, respectively, are defined implicitly by equations (5) and (9). These equations indicate that $\partial R^w(q^\ell \mid F)/\partial\gamma > 0$ and $\partial\bar{R}^\ell(q^w \mid F)/\partial\gamma < 0$. Since q^w and q^ℓ are strategic substitutes and since $R^w(q^\ell \mid F)$ is steeper than $\bar{R}^\ell(q^w \mid F)$, it follows that $\bar{q}^w_F$ increases and $\bar{q}^\ell_F$ decreases with γ. Third, from equation (5) it is clear that $\partial R^w(q^\ell \mid F)/\partial\theta > 0$. Using equation (9), we get:

$$\frac{\partial \bar{R}^\ell(q^w \mid F)}{\partial\theta} \overset{s}{=} -\gamma\left[q^w_F(\pi_{yy}-\pi_{ny}) + (1-q^w_F)(\pi_{yn}-\pi_{nn})\right] - (\beta_L-\beta_H)C'(\bar{q}^\ell_F), \tag{A-13}$$

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

$$\frac{\partial \bar{R}^\ell(q^w \mid F)}{\partial\theta} \overset{s}{=} \frac{\beta_H}{\beta_\theta}\left[\bar{q}^w_F(\pi_{yy}-\pi_{ny}) + (1-\bar{q}^w_F)(\pi_{yn}-\pi_{nn})\right]\left[\left(1-\frac{\beta_L}{\beta_H}\right)-\gamma\right]. \tag{A-14}$$

Since the expression outside the square brackets is positive, it follows that $\partial\bar{R}^\ell(q^w \mid F)/\partial\theta \gtreqless 0$ as $\gamma \lesseqgtr 1\text{-}\beta_L/\beta_H$. Thus, when $\gamma > 1\text{-}\beta_L/\beta_H$, $\partial\bar{R}^\ell(q^w \mid F)/\partial\theta < 0$. Together with the fact that $\partial R^w(q^\ell \mid F)/\partial\theta > 0$ and the fact that q^w and q^ℓ are strategic substitutes and $R^w(q^\ell \mid F)$ is steeper than $\bar{R}^\ell(q^w \mid F)$, this implies that $\bar{q}^w_F$ increases and $\bar{q}^\ell_F$ decreases. When $\gamma < 1\text{-}\beta_L/\beta_H$, $\partial\bar{R}^\ell(q^w \mid F)/\partial\theta > 0$. Since $\partial R^w(q^\ell \mid F)/\partial\theta > 0$ 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 $R^w(q^\ell \mid F) = R^w(q^\ell \mid NF)$ and $\bar{R}^\ell(q^w \mid F) = R^\ell(q^w \mid NF)$. To prove that $\bar{q}^w_F > \bar{q}^\ell_F$, note when $\theta = 0$, equation (5) and (9) are symmetric if $\beta_H = 1$, so the equilibrium is symmetric. As β_H increases from 1, $\bar{R}^\ell(q^w \mid F)$ decreases while $R^w(q^\ell \mid F)$ remains the same. Since $R^w(q^\ell \mid F)$ is steeper than $\bar{R}^\ell(q^w \mid F)$, the best-response functions intersect in the (q^w, q^ℓ) space below a 45 degrees line passing through the origin, so $\bar{q}^w_F > \bar{q}^\ell_F$.

The proof for the case where $\theta > 0$ is similar to the proof of part (ii) of Proposition 1 and hence is omitted.

(iii) The proof is similar to the proof of part (iii) of Proposition 1 and hence is omitted. *Q.E.D.*

Proof of Proposition 4: The proof that $\bar{\gamma}$ exists and it decreases with β_L and increases with β_H is similar to the proof of part (ii) of Proposition 2 and is therefore omitted.

To establish the sufficient condition for $\bar{\gamma}$ to decrease with θ, note that $\bar{\gamma}$ is defined implicitly by the equation $\bar{\pi}^w{}_F = \pi^w{}_{NF}$. Differentiating this equation with respect to $\bar{\gamma}$ and θ, using the envelope theorem, and recalling that $\pi^w{}_{NF}$ is independent of γ and θ, yields

$$\frac{\partial \bar{\gamma}}{\partial \theta} = \frac{-\bar{\gamma}\bar{q}_F^\ell + (1-\bar{\gamma}\theta)\dfrac{\partial \bar{q}_F^\ell}{\partial \theta}}{\theta \bar{q}_F^\ell - (1-\bar{\gamma}\theta)\dfrac{\partial \bar{q}_F^\ell}{\partial \gamma}}. \quad \text{(A-15)}$$

The denominator here is positive since part (i) of Proposition 3 ensures that $\partial \bar{q}^\ell{}_F/\partial\gamma < 0$. As for the numerator then,

$$-\bar{\gamma}\bar{q}_F^\ell + (1-\bar{\gamma}\theta)\frac{\partial \bar{q}_F^\ell}{\partial \theta} = \frac{(1-\bar{\gamma}\theta)\bar{q}_F^\ell}{\theta}\left[\bar{\eta}_F^\ell(\theta) - \frac{\bar{\gamma}\,\theta}{1-\bar{\gamma}\,\theta}\right], \quad \text{(A-16)}$$

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, $\partial\bar{\gamma}/\partial\theta > 0$ iff $\bar{\eta}^\ell{}_F(\theta) > \bar{\gamma}\theta/(1-\bar{\gamma}\theta)$.

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

$$\pi^\ell(\bar{q}_F^w,\bar{q}_F^\ell \mid NF) - \bar{\pi}_F^\ell = \theta\gamma\bar{q}_F^\ell\left[\bar{q}_F^w(\pi_{yy}-\pi_{yn}) - (1-\bar{q}_F^w)(\pi_{yn}-\pi_{nn})\right] - \theta(\beta_H-\beta_L)C(\bar{q}_F^\ell). \quad \text{(A-17)}$$

Substituting for the square bracketed term from equation (9) and using the fact that by Assumption A3, C(q) is strictly convex,

$$\begin{aligned}\bar{\pi}^\ell(\bar{q}_F^w,\bar{q}_F^\ell \mid NF) - \bar{\pi}_F^\ell &= \theta\left[\gamma\,\beta_\theta\,\bar{q}_F^\ell C'(\bar{q}_F^\ell) - (\beta_H-\beta_L)C(\bar{q}_F^\ell)\right] \\ &> \frac{\theta\,\beta_H C(\bar{q}_F^\ell)}{1-\gamma\theta}\left[\gamma - \left(1-\frac{\beta_L}{\beta_H}\right)\right] > 0.\end{aligned} \quad \text{(A-18)}$$

Using this inequality, we have

$$\bar{\pi}^{\ell}_{NF} \geq \pi^{\ell}(q^{w}_{NF},\bar{q}^{\ell}_{F}\,|\,NF) > \pi^{\ell}(\bar{q}^{w}_{F},\bar{q}^{\ell}_{F}\,|\,NF) > \bar{\pi}^{\ell}_{F}, \tag{A-19}$$

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 $\gamma > 1-\beta_L/\beta_H$. *Q.E.D.*

Proof of proposition 5: (i) Equations (6) and (9) and the assumption that $\beta_H \geq \beta_L$, imply that $\bar{R}^{\ell}(q^{w}\,|\,F) \leq R^{\ell}(q^{w}\,|\,F)$, with equality holding when $\theta = 1$. Since W's best-response function is the same under both systems and since q^{w} and q^{ℓ} are strategic substitutes, it follows that $q^{w}_{F} \leq \bar{q}^{w}_{F}$ and $q^{\ell}_{F} \geq \bar{q}^{\ell}_{F}$, with equality holding when $\theta = 1$. To prove that $q^{\ell}_{F} < q^{w}_{F}$, note that when $\beta_\theta = 1$, equation (5) and (9) are symmetric and since the best-response functions of the two firms cross only once, $q^{\ell}_{F} = q^{w}_{F}$. As β_θ increases from 1, $\bar{R}^{\ell}(q^{w}\,|\,F)$ decreases while $R^{w}(q^{\ell}\,|\,F)$ remains the same. Hence, the best-response functions cross in the (q^{w}, q^{ℓ}) space below a 45 degrees line passing through the origin, so $\bar{q}^{\ell}_{F} < \bar{q}^{w}_{F}$.

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 $(q^{w}_{F}, q^{\ell}_{F})$ lie on the same curve in the (q^{w}, q^{ℓ}) space, with $(\bar{q}^{w}_{F}, \bar{q}^{\ell}_{F})$ being southeast of $(q^{w}_{F}, q^{\ell}_{F})$. Using equation (3), the slope of this curve is given by $\partial R^{w}(q^{\ell}\,|\,F)/\partial q^{\ell} = (1-\gamma\theta)\Pi/C''(q^{w}_{F})$. 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 $(q^{w}_{F}, q^{\ell}_{F})$. Consequently, $\bar{q}^{w}_{F}+\bar{q}^{\ell}_{F} \leq q^{w}_{F}+q^{\ell}_{F}$.

(ii) First, note that

$$\pi^{w}_{F} \leq \pi^{w}(q^{w}_{F},\bar{q}^{\ell}_{F}\,|\,F) \leq \bar{\pi}^{w}_{F}, \tag{A-20}$$

where the left inequality follows since $\partial\pi^{w}(q^{w},q^{\ell}\,|\,F)/\partial q^{\ell} < 0$ and since $q^{\ell}_{F} \geq \bar{q}^{\ell}_{F}$, 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 $\pi^{\ell}(q^{w},q^{\ell}\,|\,F) \geq \bar{\pi}^{\ell}(q^{w},q^{\ell}\,|\,F)$, with equality holding for $\theta = 1$. Hence,

$$\pi^{\ell}_{F} \geq \pi^{\ell}(q^{w}_{F},\bar{q}^{\ell}_{F}\,|\,F) \geq \pi^{\ell}(\bar{q}^{w}_{F},\bar{q}^{\ell}_{F}\,|\,F) \geq \bar{\pi}^{\ell}_{F}, \tag{A-21}$$

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 $q^{w}_{F} \leq \bar{q}^{w}_{F}$. *Q.E.D.*

Proof of Proposition 7: 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,

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

So long as $\theta < 1$, this expression is strictly positive, implying that public disclosure of patent applications makes consumers better-off. When $\theta = 0$, $\beta_\theta = \beta_L$, so $S_F = \bar{S}_F$.

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, $\gamma \geq \frac{1 - \sqrt{\beta_\theta/\beta_H}}{\theta}$, we get $\beta_\theta - \beta_H(1-\gamma\theta)^2 \geq 0$, so the first line of (A-23) is positive. As for the second line, then the expression inside the square brackets is increasing with γ and it vanishes at $\gamma = \frac{1 - \sqrt{\beta_\theta/\beta_H}}{\theta}$; 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 increase in consumers' surplus is larger the larger is γ. *Q.E.D.*

Proof of Proposition 8: (i) Since 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 (17), we get

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

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

where

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

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, $Z(r,\beta)$ is surely positive 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) Since expected social welfare under the CF system, $\bar{W}_F$, and under the PD system, W_{NF}, differ only with respect to θ, it follows that public disclosure of patent applications is welfare-reducing, i.e., $W_{NF} < \bar{W}_F$, if $\partial\bar{W}_F/\partial\theta > 0$ for all $\theta \in [0, \overline{\gamma\theta}/\gamma)$. Using equation (17) we get

$$\frac{\partial \bar{W}_F}{\partial \theta} = \frac{(\pi_{yn}-\pi_{nn})r(1-\gamma\theta)(r+\Pi)\big(\beta_H-\beta_L-\gamma(\beta_H+\beta_\theta)\big)}{2\big(r^2\beta_\theta-(1-\gamma\theta)^2\Pi^2\big)^3} \times \Big[(\pi_{yn}-\pi_{nn})Z(r,\beta_\theta) \tag{A-27}$$

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

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 $(\beta_H-\beta_L)-\gamma(\beta_H+\beta_\theta)$. *Q.E.D.*

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