Patents, Secrets, and the First Inventor Defense

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Abstract

We analyze optimal patent design when innovators can rely on secrecy to protect their innovations. Secrecy provides a temporary monopoly, which terminates when the secret leaks out or the innovation is duplicated. We find conditions under which the optimal policy is to induce the first innovator to patent. Furthermore, we derive the optimal scope of the rights conferred to late innovators. We show that if the patent life can be suitably set, late innovators should be allowed to patent and exclude first inventors who have relied on secrecy.

JEL Nos: L00 (Industrial organization), O31, O34 (Intellectual property rights).

Keywords: patents, trade secrets, intellectual property, prior user rights.

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1 Introduction

Trade secrets and patents are both legal means of protecting an innovator's proprietary knowledge. Although the patent system prohibits certain industries from seeking patent protection, and secrecy is infeasible in others, many inventors can choose between these forms of protection.¹ Secrecy involves a risk of leakage and of independent rediscovery of the innovation by others, but patents are limited in breadth and length, and may be costly to enforce. Based on a survey questionnaire administered to nearly 1500 R&D labs, Cohen, Nelson and Walsh (2000) report that secrecy is more highly ranked than patents as a protection mechanism for both product and process innovations.² Furthermore, secrecy is found to have increased in importance over the last decade, despite the apparent strengthening of the patent system (Gallini, 2002).

The fact that secrecy represents an available option for innovators has non-obvious implications for patent design. Should innovators be encouraged to rely on the patent system rather than trade secrets law? More specific issues arise when the first inventor opts for secrecy and the innovation is independently rediscovered. Should the second inventor be entitled to a valid patent?³ If yes, should the second-inventor patentee be allowed to exclude the first inventor from the innovation, or should the first inventor be granted a defense from infringement (i.e. a prior user right)?

Notable differences in the breadth of the legal rights assigned to first- and second-inventors are observable from nation to nation and over time. For instance, under the British 1956 Patent Act second inventors were not entitled to valid patents (but

¹However, innovators cannot benefit from both. If they choose to patent, they must disclose the innovation in the patent specification, which prevents them from extending the monopoly beyond the term of the patent. Alternatively, if they decide to rely on secrecy, they forfeit the right to patent after a short (one-year) grace period. This prevents inventors from keeping the innovation secret and applying for a patent only under the threat of impending duplication. See Friedman, Landes and Posner (1991), and Merges (1997).

²Similar findings emerge from prior empirical investigations. See, among others, Mansfield (1985) and (1986), and Levin, Klevorick, Nelson, and Winter (1987).

³Of course, the Patent Office may not be aware that the innovation had been concealed by the first inventor when granting a patent to the second inventor, but such a patent may be subsequently invalidated by the courts.

this rule was changed in 1977 to harmonize the British with the European patent law). In most European countries and the US, usually second inventors can patent.⁴ Assuming that the second inventor is entitled to a valid patent, in the US he currently has the right to exclude the first inventor. However, bills introducing a defense from infringement to first inventors have been repeatedly put on the floor in the Congress over the last decade. In November 1999, a first-inventor defense was introduced (*American Inventors Protection Act*), but limitedly to “business methods.” By way of contrast, in most European countries and Japan, good faith prior use represents a defense from infringement. In some countries, prior user rights are also assigned to individuals who are merely “preparing for use” at the time of filing or, like in France and Belgium, just have the knowledge sufficient for the use of the invention (WIPO 1988).

To summarize these legal differences, assuming that the first inventor has elected to keep the invention a secret, we can identify three main policy options:

1. the second inventor cannot patent;
2. the second inventor can patent, but cannot exclude the prior user;
3. the second inventor can patent and can exclude the prior user.

For the sake of brevity (and somewhat arbitrarily), we shall call the first system “Strict,” the second “European,” and the third “American.” The three patent systems are presented in increasing order of the protection offered to the second inventor: the Strict system provides the weakest protection, the American the strongest.

This paper has two objectives. The first, more specialized objective is to analyze the optimal scope of the rights to be assigned to the second inventor by comparing

⁴In the US, under 35 U.S.C. § 102(g), a second-inventor can claim a valid patent if the innovation was “abandoned, suppressed or concealed” by the first inventor. The second-inventor’s patent is therefore valid provided that secret use is interpreted as a form of “concealment.” This interpretation has been put forward in *Gore v. Garlock* (721 F.2d 1540, 1983), where the court held that the prior user’s secret use of a process to create a product (PTFE filament) did not invalidate the patent, despite the fact that the product had been commercially exploited. As explained by the court: “Early disclosure is a linchpin of the patent system. As between a prior inventor and a later inventor who promptly files a patent application ... the law favors the latter.” Former decisions distinguished between two cases of public use: “hidden” and “non-informing;” only the former would count as a form of concealment. See Harriel (1996) and Merges (1994).

the Strict, European and American systems on welfare grounds. The second broader objective is to ask whether society should encourage patenting and disclosure instead of secrecy. To analyze these policy issues, we develop a simple model with an innovation stage and a duplication stage. In the innovation stage, the innovator chooses her R&D effort and which type of proprietary protection to adopt. In the duplication stage, a follower decides how much effort to devote to the “catching-up” and which type of proprietary protection to adopt upon successful duplication. Patent policy influences the research efforts and the patenting decisions of both the innovator and the duplicator. The policy variables that we focus on are the patent length and the scope of the rights assigned to the second inventor.

We reach three main conclusions. First, the Strict system (where the second inventor cannot patent) is equivalent to the European system (where the second inventor can patent but cannot exclude the first inventor). Second, the American system (where the second inventor can patent and can exclude the first inventor) weakly dominates the European and Strict systems on welfare grounds because any outcome obtained in the European (or Strict) system can be replicated in the American system by a suitable patent life. The converse is not true: in the American system patenting and disclosure can be obtained with a shorter patent term and therefore, under certain conditions, the welfare dominance is strict. Finally, in a broad set of circumstances it is socially desirable to have innovators patenting; in contrast, the circumstances under which secrecy is socially preferable are rather limited and difficult to identify. We discuss their policy implications of these results more fully in the concluding section.

Although the issue of prior user rights is lively debated in the law literature, most of the economic literature assumes that innovators have no alternative to patenting.⁵

⁵The issue of prior user rights also arises when two or more individuals claim to have been the first to invent a particular innovation. Prior user rights would permit those adjudged to be subsequent inventors to continue to commercially exploit the innovation (Harriel, 1996). The work of La Manna, MacLeod, and De Meza (1989) and Maurer and Scotchmer (2002), who ask whether independent re-discoverers should be allowed to use the innovation, but posit that the first inventor always patents, is related to this issue. They focus on the implications of the patentee’s right to exclude “subsequent”

There are, however, a few notable exceptions. Horstmann, MacDonald, and Slivinski (1985) analyze the choice between patents and secrets in a signalling model where the innovator is better informed than its potential competitor on the profitability of imitation or duplication. They model information transmission as a binary choice. Anton and Yao (2000) study strategic disclosure of knowledge in patent applications in the presence of limited patent protection, and find that in equilibrium small inventions are fully disclosed whereas large innovations are protected primarily through secrecy. As the innovator has private information about the size of the innovation, a partial disclosure can be used to signal the innovator’s strength to his competitors. These papers do not focus on patent policy.

Gallini (1992) analyses the optimal patent length and breadth with respect to imitators assuming that imitation occurs only if the innovator patents and the new technology is disclosed. Thus, while competing firms can “invent around” the patent, they cannot duplicate the innovation if it is not disclosed in the patent application. She does not address the issue of prior user rights, and focuses on the optimal breadth-length mix to protect the first innovator.

The paper is organized as follows. In Section 2, we outline the game and in section 3 we solve it. Section 4 develops the welfare analysis. Section 5 concludes the paper.

2 Model assumptions

For simplicity, we assume that there are two firms, an innovator and a follower. Only the innovator can discover the original innovation, but the follower can try to replicate it once the innovator makes the initial discovery. Patent policy is a pair $\langle T, R \rangle$ where $R \in \{S, E, A\}$ is the patent system (with obvious notation, Strict, European or American) and $T \geq 0$ is the life of the patent. Although we recognize that patents are generally limited both in scope and length, here we take the life of the patent, T , as a comprehensive index of the strength of patent protection.⁶

rather than “prior” inventors.

⁶For example, narrow patents may allow imitators to use the information disclosed in the patent application to invent around the patent. This has the same qualitative effects as a reduction in the

The innovation stage. Innovation occurs with a probability, x , determined by the innovator's R&D expenditure $c_i(x)$. The innovator chooses the R&D effort so as to maximize her profit $xV_i - c_i(x)$, where V_i is the innovator's reward, to be determined presently. We assume that $c'_i(x) > 0$, $c'_i(0) = 0$, and $c''_i(x) > 0$, so that the optimal innovation effort is positive and increases with V_i .

If the innovation has been successfully developed, the innovator must decide whether to patent or keep it secret. If she patents, she reaps monopoly profit π_m for the duration of the patent, T . The patent is granted in exchange for the disclosure of the innovation: upon expiry of the patent, anybody can use it and the innovator's profits are driven to zero. Alternatively, the innovator can rely on secrecy.⁷ Here the risk is involuntary disclosure (a "leak") or successful duplication by the follower. We assume that leakage of the secret has the same effects as expiration of the patent, i.e., the innovation becomes public and profits are driven to zero. The random event of a leak occurs according to a Poisson process with arrival rate $z > 0$, which will be taken as exogenous throughout the paper. It may be seen as an index of the difficulty of concealing the innovation.

The innovator also loses her monopoly if the follower successfully duplicates the innovation. To keep this possibility into account, we next turn to the duplication stage of the model.

The duplication stage. If the innovator has made the original innovation and has concealed it, the follower can try to duplicate the innovation.⁸ To do that, he must

life of the patent. Explicit analysis of the breadth-length trade-off, as in Denicolò (1996) and the literature cited therein, would complicate matters and add little to the issues that we focus on in this paper.

⁷Of course, this is not always the case. Sometimes the commercial use of the innovation entails disclosure, e.g. when the new product can be easily reverse-engineered. This corresponds to a limit case of our model, where the parameter z defined below tends to infinity. The three patent systems are equivalent in this limiting case.

⁸We assume that the achievement of the innovation or its commercial use is observable with no time lag. This assumption is especially appropriate for the case of product innovation, but may also be reasonable with process innovations. Mansfield (1985) finds that information about innovations typically is known to rivals within 12 to 18 months of the date of the initial decision by the innovator to develop the new product or process. However, such information may be less easily obtained when the innovator is an outsider to the industry. Whether and when patent applications should be

invest in R&D. Specifically, we assume that duplication occurs with a probability, y , determined by the follower's duplication expenditure $c_f(y)$. Again, we make the regularity assumptions $c'_f(y) > 0$, $c'_f(0) = 0$, and $c''_f(y) > 0$.

If the follower has duplicated the innovation, he may in turn decide to patent it. In the American system, the follower can then obtain monopoly profit for the duration of the patent. In the European system, assuming that being innovator is verifiable, the follower will have to compete with the innovator, and both of them will earn duopoly profits π_d for the duration of the patent, with $0 < \pi_d < \pi_m$.⁹ If instead the follower does not patent, both the innovator and the follower will gain duopoly profits until the secret leaks out; this also applies to the Strict system.

In summary, the timing of actions is as follows:

- (i) the innovator decides her R&D effort;
- (ii) she decides whether or not to patent;
- (iii) if the innovator has not patented, the follower decides the effort to put into duplicative research;
- (iv) the follower decides whether or not to patent (this stage is absent in the Strict system).

All parameter values and actions are common knowledge, thus the game is one of complete information.

Discounting. All future profits are discounted at the common discount rate r .¹⁰ It is convenient to define

$$\text{"discounting-adjusted" patent length: } \tau \equiv \int_0^T e^{-rt} dt = \frac{(1 - e^{-rT})}{r} \quad (1)$$

and

$$\text{"discounting-adjusted" duration of the secret: } \Phi \equiv \int_0^\infty e^{-zt} e^{-rt} dt = \frac{1}{z + r}. \quad (2)$$

publicly disclosed then becomes a policy issue; see Aoki and Spiegel (2001) for an interesting analysis of the main options.

⁹The limiting case $\pi_d = 0$ is degenerate in that there is no duplicative effort in the European and Strict systems. However, all of our results continue to hold with minor changes.

¹⁰Throughout the paper, r may incorporate the probability that the innovation is superseded by new technology accruing exponentially with a constant hazard rate.

With no discounting, τ equals the patent life T and $\Phi = 1/z$ is the expected time before a leak occurs with an exponential distribution of the timing of leakage. For $r > 0$, delayed profits are valued less than instant profits and discounting-adjusted durations decrease: $\tau < T$ and $\Phi < 1/z$. Because there is a one-to-one relationship between τ and T , we can describe the patent policy as a pair $\langle \tau, R \rangle$. As T goes from 0 to ∞ , τ ranges from 0 to $1/r$.

3 Equilibrium

Our solution concept is subgame perfect equilibrium, so we solve the model proceeding backwards.

The follower's problem. Let us suppose that the innovator has made and secretly exploited the original innovation and that the follower has succeeded in duplicating it. Then, the follower must decide whether or not to patent. (This stage is absent in the Strict system). Intuitively, he will choose to patent if patent protection is sufficiently strong, i.e. if the life of the patent is sufficiently long. More precisely, if the follower does not patent, his expected payoff is $\frac{\pi_d}{z+r} = \Phi\pi_d$ – this is also the follower's payoff in the Strict system,

$$\mathcal{V}_f^S = \Phi\pi_d.^{11} \quad (3)$$

In the European system, if the follower patents, he has to share the market with the first innovator until the patent expires, earning $\frac{(1-e^{-rT})\pi_d}{r} = \tau\pi_d$. Thus, he will patent if and only if $\tau \geq \Phi$. (To fix ideas, we assume that a firm patents when it is indifferent between patenting and not, but our results are independent of this tie-breaking rule.) In the American system, the second-inventor patentee can exclude the first inventor and reap monopoly profits until the patent expires. Therefore, he will patent if, and only if, $\tau\pi_m \geq \Phi\pi_d$. Let $\tau_f^E = \Phi$ and $\tau_f^A = \frac{\pi_d}{\pi_m}\Phi$ be the (discounting-adjusted) patent durations that make the follower indifferent between patenting and

¹¹For simplicity, we assume that the probability of leakage is independent of the number of firms that are practicing the innovation. However, all the results of the paper immediately extend to the case where the probability of leakage is greater under duopoly than under monopoly.

not in the European and the American system, respectively. Clearly, $\tau_f^A < \tau_f^E$: the American system provides the follower with greater incentives to patent than the European system.

To summarize, the follower patents provided that $\tau \geq \tau_f^R$, $R = E, A$. Then, in the European system the follower's payoff is

$$\mathcal{V}_f^E = \begin{cases} \Phi\pi_d & \text{for } \tau < \tau_f^E, \\ \tau\pi_d & \text{for } \tau \geq \tau_f^E. \end{cases} \quad (4)$$

In the American system, we have instead

$$\mathcal{V}_f^A = \begin{cases} \Phi\pi_d & \text{for } \tau < \tau_f^A, \\ \tau\pi_m & \text{for } \tau \geq \tau_f^A. \end{cases} \quad (5)$$

Clearly, $\mathcal{V}_f^A \geq \mathcal{V}_f^E \geq \mathcal{V}_f^S$, where all of these inequalities are strict if the follower patents. Also note that under all systems $\frac{d\mathcal{V}_f}{d\tau} \geq 0$, where again the inequality is strict if the follower patents.

Moving one stage back, let us now consider the follower's optimal choice of duplication effort. The follower chooses y so as to maximize

$$\Pi_f = y\mathcal{V}_f - c_f(y). \quad (6)$$

Under our regularity assumptions, the optimal effort, $\hat{y}$, is (weakly) increasing in $\mathcal{V}_f$. Thus, the duplication effort depends positively on the degree of protection accorded to the second inventor, which is highest in the American system and least in the Strict system: $\hat{y}^A(\tau) \geq \hat{y}^E(\tau) \geq \hat{y}^S > 0$.¹² Furthermore, in all systems the follower's effort is non-decreasing in the patent length, $\frac{d\hat{y}(\tau)}{d\tau} \geq 0$, and is increasing if the follower patents. This is because longer patents provide a higher reward to the follower and make him more "aggressive" if he decides to patent.

The innovator's problem. Assuming that the innovation has been obtained, the innovator must decide whether or not to patent. In all systems, if the innovator patents she earns

$$V_P(\tau) = \tau\pi_m. \quad (7)$$

¹²The first inequality is strict if $\tau > \tau_f^A$, and the second is strict if $\tau > \tau_f^E$. Inequality $\hat{y}^S > 0$ follows from $\pi_d > 0$ and $c_f'(0) = 0$. Note that $\mathcal{V}_f^S$, and hence $\hat{y}^S$, are independent of τ .

If she does not patent, her payoff depends on the follower's behavior and the patent system. In the Strict system – more generally, if the follower does not patent – the innovator's payoff is

$$V_{NP}^S = (1 - \hat{y}^S) \Phi \pi_m + \hat{y}^S \Phi \pi_d \quad (8)$$

i.e., the monopoly profit for the expected duration of the secret if the follower does not duplicate and duopoly profits for the same expected period if the follower duplicates.

In the European system, the innovator's payoff if she does not patent is

$$V_{NP}^E(\tau) = \begin{cases} V_{NP}^S & \text{for } \tau < \tau_f^E, \\ [1 - \hat{y}^E(\tau)] \Phi \pi_m + \hat{y}^E(\tau) \tau \pi_d & \text{for } \tau \geq \tau_f^E. \end{cases} \quad (9)$$

When $\tau \geq \tau_f^E$ a successful follower patents and so the original innovator (who has prior user rights and therefore cannot be excluded) earns duopoly profit for the duration of the patent. Finally, in the American system the innovator's payoff by not patenting is

$$V_{NP}^A(\tau) = \begin{cases} V_{NP}^S & \text{for } \tau < \tau_f^A, \\ [1 - \hat{y}^A(\tau)] \Phi \pi_m & \text{for } \tau \geq \tau_f^A, \end{cases} \quad (10)$$

because when the follower patents, the original innovator is excluded from the innovation. Note that $V_{NP}^A(\tau)$ jumps down at $\tau = \tau_f^A$, as the follower's patenting decision deprives the innovator of duopoly profits.

Clearly, the innovator will choose to patent if patent protection is sufficiently strong. Let τ_i^R be the patent duration that makes the innovator indifferent between patenting and not in patent system R . Lower cutoffs mean that weaker patent protection suffices to induce the innovator to patent and are therefore associated with a greater propensity to patent on the part of the innovator. One can show that in each system such a cutoff value exists and is unique.¹³ Then in patent system R the value of the innovation is

$$V_i^R = \begin{cases} V_{NP}^R & \text{for } \tau < \tau_i^R, \\ V_P & \text{for } \tau \geq \tau_i^R. \end{cases} \quad (11)$$

¹³In all systems, $V_{NP}(0) > V_P(0) = 0$ and $V_P(\frac{1}{\tau}) > V_{NP}(\frac{1}{\tau})$. This means that in all systems a cutoff value exists. To show uniqueness, it suffices to note that $V_P(\tau)$ increases with τ , whereas (i) $V_{NP}^A(\tau)$ is non-increasing in τ (because $\hat{y}^A(\tau)$ is non-decreasing in τ), (ii) V_{NP}^S is independent of τ , and (iii) $V_{NP}^E(\tau)$ is continuous and weakly increasing in τ , but increases less steeply than $V_P(\tau)$. These facts imply that in any system R , with $R = E, A, S$, the cutoff τ_i^R is unique (but not necessarily the same across systems).

Moving back to the first stage of the game, the innovator chooses the R&D effort so as to maximize her profit

$$\Pi_i = xV_i - c_i(x). \quad (12)$$

Our regularity conditions on $c_i(x)$ imply that the optimal R&D effort, $\hat{x}$, is a (weakly) increasing function of the incentive to innovate, V_i .

Policy equivalence results. Our first result is that in the subgame perfect equilibrium of the model, the European system is equivalent to the Strict system.

Proposition 1 *For any $\tau \geq 0$, the subgame perfect equilibrium of the model associated with policy $\langle \tau, S \rangle$ is the same as that associated with policy $\langle \tau, E \rangle$.*

Proof. First of all, we show that in the European system the innovator has greater incentives to patent than the follower: $\tau_i^E < \tau_f^E$. If the innovator does not patent at $\tau = \tau_f^E$, she gets $(1 - \hat{y}^S)\Phi\pi_m + \hat{y}^S\Phi\pi_d$ independently of the follower's patenting decision, whereas if she patents she gets $\tau_f^E\pi_m = \Phi\pi_m$, where the equality follows from the definition of τ_f^E . Since $\pi_m > \pi_d$, the innovator strictly prefers to patent at $\tau = \tau_f^E$. This means that $\tau_i^E < \tau_f^E$, i.e. in the European system second inventors will never patent in equilibrium, and therefore the equilibrium outcome is the same as if they could not patent, as in the Strict system. ■

Proposition 1 rests on the fact that in the European system the innovator has greater incentives to patent than the follower. Thus, the follower never patents in equilibrium. The reason is that in the European system the follower patents only if the life of the patent is at least as long as the expected duration of the secret – since he cannot exclude prior users, he earns duopoly profits anyway. However, when the life of the patent equals the expected duration of the secret, the first inventor would be indifferent between patenting and not only if there were no risk of duplication; with a positive probability of duplication, the innovator definitely prefers to patent. In view of Proposition 1, in what follows we shall refer to the European system only, but it should be understood that the same results apply to the Strict system.

Our next result is that if the patent life can be freely adjusted, any achievable equilibrium in the European system can be obtained in the American system by suitable choice of the patent life, while the converse is not true.

Proposition 2 *For any policy $\langle \tau, E \rangle$ there exists a policy $\langle \tau', A \rangle$ that yields the same subgame perfect equilibrium outcome.*

Proof. First, we show that in the American system the follower has greater incentives to patent than the innovator: $\tau_i^A \geq \tau_f^A$. To show this, note that if $\tau < \tau_f^A$, the follower does not patent (i.e. $\tau\pi_m < \Phi\pi_d$). Then, we have

$$V_{NP}^A(\tau) = \Phi [(1 - \hat{y}^S)\pi_m + \hat{y}^S\pi_d] \geq \Phi\pi_d > \tau\pi_m = V_P(\tau)$$

whenever $\tau < \tau_f^A$. Thus the innovator will not patent when $\tau < \tau_f^A$, which means that $\tau_i^A \geq \tau_f^A$.

Next, we show that the innovator's propensity to patent is greater in the American system than in the European system: $\tau_i^A \leq \tau_i^E$. In view of the previous result, we must distinguish between two cases, $\tau_i^A > \tau_f^A$ and $\tau_i^A = \tau_f^A$. In the first case, τ_i^A will be given by the condition $V_P(\tau_i^A) = V_{NP}^A(\tau_i^A)$, i.e. $\tau_i^A = [1 - \hat{y}^A(\tau_i^A)] \Phi$, whereas by Proposition 1

$$\tau_i^E = \tau_i^S = (1 - \hat{y}^S)\Phi + \hat{y}^S\Phi \frac{\pi_d}{\pi_m}.$$

Since $\hat{y}^A(\tau_i^A) > \hat{y}^S$, we have $[1 - \hat{y}^A(\tau_i^A)] \Phi < (1 - \hat{y}^S)\Phi + \hat{y}^S\Phi \frac{\pi_d}{\pi_m}$, and hence $\tau_i^A < \tau_i^E$. If $\tau_i^A = \tau_f^A$, it follows from the definition of τ_f^A that $V_P(\tau_i^A) = \Phi\pi_d$, which means that $\tau_i^A = \Phi \frac{\pi_d}{\pi_m} \leq \Phi [(1 - \hat{y}^S) + \hat{y}^S \frac{\pi_d}{\pi_m}] = \tau_i^E$.

To complete the proof it is now useful to refer to Figure 1, which illustrates the cutoff values of the patent life in the European and American systems. Consider any policy $\langle \tau, E \rangle$ with $0 \leq \tau < \tau_i^E$. Each of these policies supports the same equilibrium, in which neither the innovator nor the follower patent. Such an equilibrium can be re-produced in the American system by setting $0 \leq \tau < \tau_f^A$; for example, $\tau = 0$ would do. Next consider any policy $\langle \tau, E \rangle$ with $\tau \geq \tau_i^E$. In the ensuing equilibrium, the innovator patents and earns monopoly rents for a period of (discounting-adjusted)

length τ . Clearly, such an equilibrium can be re-produced in the American system by setting the same patent length: since $\tau_i^E \geq \tau_i^A$, for $\tau \geq \tau_i^E$ the innovator patents also in the American system earning the same monopoly rents, and hence exerting the same innovative effort, as in the European system. ■

Figure 1

Proposition 2 relies on two intermediate results that may be of independent interest. First, in the American system the innovator has a lower propensity to patent than the follower: $\tau_i^A \geq \tau_f^A$. The reason for this result, which stands in contrast to the opposite finding in the European system, is that in the American system both the first- and the second-inventor can exclude the other upon patenting, and so the monopoly rent is the same for both, but the first inventor alone can retain a monopoly if she does not patent. Therefore, whenever patent protection is so weak that the duplicator prefers not to patent, the first inventor won't patent either. However, this does not necessarily mean that $\tau_i^A > \tau_f^A$, as the innovator may want to engage in pre-emptive, or “defensive,” patenting for fear of being excluded by the duplicator, in which case we have $\tau_i^A = \tau_f^A$.¹⁴ Such a case arises when $V_{NP}^A(\tau_f^A) \leq V_P(\tau_f^A)$. If

¹⁴This is consistent with Cohen, Nelson and Walsh's (2000) finding that pre-emption of rivals' patenting is one major reason why firms patent. See also the anecdotal evidence reported in Merges (1997), where it is argued that firms' patenting decisions often resemble a prisoners' dilemma.

instead $V_{NP}^A(\tau_f^A) > V_P(\tau_f^A)$, at $\tau = \tau_f^A$ the expected profits accruing to the innovator if duplication fails are large enough to induce her to rely on secrecy even in the anticipation that a successful follower would patent, and we have $\tau_i^A > \tau_f^A$.

Second, the innovator's incentive to patent is greater in the American system than in the European system. With prior user rights, the innovator is not excluded from the use of the new technology upon duplication and is also more likely to retain a monopoly, as the follower's payoff upon duplication – and hence his duplication effort – is lower. Both effects tend to reduce the innovator's propensity to patent in that system as compared to the American system.

It appears from Figure 1 that the American system provides the policymaker with more policy options than the European system. First, when inequality $\tau_i^A \geq \tau_f^A$ is strict (the case illustrated in Figure 1), in the American system it is possible to support equilibria in which the innovator does not patent and the follower patents by setting $\tau_f^A \leq \tau < \tau_i^A$. Such equilibria cannot be re-produced in the European system for any value of the patent life. Second, those equilibria that arise in the American system for $\tau_i^A \leq \tau < \tau_i^E$ cannot be re-produced in the European system: in other words, in the American system the innovator can be induced to patent and disclose the innovation with a shorter patent length. The social value of these extra-options will be the focus of our welfare analysis in Section 4.

The incentives to innovate. Prior user rights strengthen the protection accorded to innovators and stimulate innovative effort.

Proposition 3 *For any given τ , in the American system the innovator has lower incentives to innovate than in the European system, $V_i^A(\tau) \leq V_i^E(\tau)$. Hence, the equilibrium R&D effort is lower: $\hat{x}^A(\tau) \leq \hat{x}^E(\tau)$.*

Proof. For $\tau < \tau_f^A$, irrespective of the patent system, neither the innovator nor the follower patent: $V_{NP}^A(\tau) = V_{NP}^E(\tau) = V_{NP}^S$. At $\tau = \tau_f^A$, $V_{NP}^A(\tau)$ jumps down in the American system as the follower elects to patent, whereas $V_{NP}^E(\tau)$ stays constant (nobody patents) up to τ_i^E in the European system. For $\tau_f^A \leq \tau < \tau_i^A$,

the innovator's reward in the American system is $V_{NP}^A(\tau) = [1 - \hat{y}^A(\tau)] \Phi \pi_m$. Since $\hat{y}^A(\tau)$ is increasing in τ , the innovator's reward is decreasing in τ . (If $\tau_i^A = \tau_f^A$, the interval $\tau_f^A \leq \tau < \tau_i^A$ is empty.) For $\tau_i^A \leq \tau < \tau_i^E$, the innovator patents only in the American system and $V_{NP}^A = V_P(\tau)$, which is increasing in τ but is still lower than V_{NP}^S for $\tau < \tau_i^E$. Finally, for $\tau \geq \tau_i^E$ the innovator patents and obtains the same reward in both systems. ■

Fig. 2: Innovation effort

Figure 2 illustrates the innovative effort in the two systems. It is worth noticing that in the American system patent protection may be sufficiently strong to induce the innovator to patent and yet lead to less innovative effort than secrecy. Note also, in the American system, the non-monotonicity of R&D effort in the strength of patent protection. The reason for this non-monotonicity is twofold: first, as we have already remarked, V_i^A jumps down at $\tau = \tau_f^A$ because when the follower patents the innovator is deprived of duopoly profits; second, for intermediate levels of the patent life (i.e. for $\tau_f^A \leq \tau < \tau_i^A$), the patent represents the prize to the follower rather than the innovator: a longer patent duration fosters greater investment in duplication and reduces the probability that the first inventor retains monopoly power. Non-monotonic R&D effort is also found by Horowitz and Lai (1996), Choi (1998), and Takalo (1998) but for different reasons.¹⁵

¹⁵In Horowitz and Lai (1996), long patents hurt innovators because they stimulate imitation. In

4 Welfare

In this section we analyze the socially optimal patent policy. The social problem is to choose patent policy, $\langle \tau, R \rangle$, so as to maximize expected social welfare.

For a variety of reasons, the social returns from the innovation generally differ from the private returns. Let S_m, S_d , and S_c denote the instantaneous social returns from the innovation under monopoly, duopoly, and competition, respectively. Because of the deadweight losses associated with imperfect competition, we assume that $S_m \leq S_d \leq S_c$.

Expected social welfare is defined as the expected value of the discounted social returns from the innovation less innovation and duplication costs. If the innovator patents, assuming that the social discount rate equals r , in all patent systems expected social welfare is¹⁶

$$W = x \left[\tau S_m + \left(\frac{1}{r} - \tau \right) S_c \right] - c_i(x), \quad (13)$$

i.e., with probability x the innovation is achieved and society obtains a flow of S_m for the duration of the patent plus a flow of S_c thereafter (with probability $1 - x$ the innovation is not achieved and so there are no social benefits from innovative activity), less the innovation cost.

If instead neither the innovator nor the duplicator patent, we have¹⁷

$$W = x \left\{ (1 - y) \left[\Phi S_m + \left(\frac{1}{r} - \Phi \right) S_c \right] + y \left[\Phi S_d + \left(\frac{1}{r} - \Phi \right) S_c \right] - c_f(y) \right\} - c_i(x). \quad (14)$$

If the innovator succeeds, with probability $(1 - y)$ the innovation is not duplicated and society obtains a flow of S_m for the expected duration of the secret plus a flow of S_c thereafter. With the complementary probability, y , the innovation is duplicated

Choi (1998), the length of the patent affects the innovator's incentive to litigate and hence the entry decision of outsiders. In Takalo (1998), as in the present paper, longer patents increase the duplication effort. However, the mechanism is different: in Takalo longer patents reduce the duplicator's profit in case he does not succeed, whereas in our model longer patents increase the duplicator's profit if he succeeds.

¹⁶ $\frac{1}{r} - \tau = \int_T^\infty e^{-rt} dt$ is the discounted value of a unit flow earned from time T onwards.

¹⁷ $\frac{1}{r} - \Phi = \int_0^\infty (1 - e^{-zt}) e^{-rt} dt$ is the expected value of a unit flow which starts to be earned when a leakage occurs.

which means that duopoly rather than monopoly will prevail until the secret leaks out. In both cases, society now also pays the duplication cost $c_f(y)$.

Finally, consider the case in which the innovator does not patent and the follower patents upon successful duplication. Proposition 1 implies that such a case can only arise in the American system, when $\tau_f^A \leq \tau < \tau_i^A$. Social welfare is then

$$W = x \left\{ (1-y) \left[\Phi S_m + \left(\frac{1}{r} - \Phi \right) S_c \right] + y \left[\tau S_m + \left(\frac{1}{r} - \tau \right) S_c \right] - c_f(y) \right\} - c_i(x), \quad (15)$$

which differs from (14) in that successful duplication now entails monopoly for the duration of the patent and competition thereafter. However, it is never optimal to set patent life so as to encourage patenting by the second inventor only.

Lemma 1 *In the American system, the optimal patent life never lies in the interval $\tau_f^A \leq \tau < \tau_i^A$.*

Proof. The Lemma is trivially true if $\tau_f^A = \tau_i^A$. Thus, suppose that the interval $\tau_f^A \leq \tau < \tau_i^A$ is not empty – the case illustrated in Figures 1 and 2.

To prove the Lemma, let us take any policy $\langle \tau_1, A \rangle$ with $\tau_f^A \leq \tau_1 < \tau_i^A$ and we compare it to the policy $\langle \tau_2, A \rangle$, with $\tau_2 \geq \tau_i^A$, such that $\hat{x}^A(\tau_2) = \hat{x}^A(\tau_1)$. In other words, we choose $\langle \tau_2, A \rangle$ so as to generate the same incentive to innovate as $\langle \tau_1, A \rangle$. To show that such a patent life τ_2 exists, note that $V_i^A(\tau)$ reaches its minimum at τ_i^A , it is continuous for $\tau \geq \tau_i^A$, and $V_i^A(\frac{1}{r}) > V_i^A(0)$ (see Figure 2).

Then, let $\bar{x}$ be any research effort that may be achieved in the interval (τ_f^A, τ_i^A) , say at $\tau = \tau_1$, and let $\tau_2 \geq \tau_i^A$ be the patent life that generates the same R&D effort $\bar{x}$. Since the R&D effort at τ_1 and τ_2 is the same, from (13) and (15) we get

$$W^A(\tau_2) - W^A(\tau_1) = \bar{x} \left\{ -\tau_2 + [1 - \hat{y}^A(\tau_1)] \Phi + \hat{y}^A(\tau_1) \tau_1 \right\} (S_c - S_m) + \bar{x} c_f(\hat{y}^A(\tau_1)).$$

By construction, at τ_1 and τ_2 the reward for the innovator has to be the same:

$$\tau_2 = [1 - \hat{y}^A(\tau_1)] \Phi.$$

This implies that

$$W^A(\tau_2) - W^A(\tau_1) = \bar{x} \left\{ \hat{y}^A(\tau_1) \tau_1 (S_c - S_m) + c_f(\hat{y}^A(\tau_1)) \right\} > 0.$$

This shows that any patent length τ_1 in the interval $\tau_f^A \leq \tau_1 < \tau_i^A$ is welfare dominated by another feasible policy, and therefore cannot be optimal. ■

The intuition for this result is that duplication and patenting by the second inventor involves wasteful duplication effort and a longer expected duration of monopoly, which results either from secret use of the first inventor or from the patent right of the follower.

The proof of Lemma 1 is based on the comparison of policy options that lead to the same innovative effort. This approach, which we adapt from the patent breadth-length literature started by Gilbert and Shapiro (1990), will be applied repeatedly in what follows. By eschewing the determination of the optimal innovative effort, this approach is informatively less demanding but fails short of providing a complete characterization of the optimal policy. Accordingly, we shall focus on the following issues:

- (i) Should society encourage innovators to rely on patents or trade secrets?
- (ii) What is the best patent system?

We start from the latter question.

American system v. European system. Proposition 2 has a simple corollary: if the patent life can be freely adjusted, the American system weakly dominates the European system.

Corollary 1 *For any τ there exists a τ' such that $W^A(\tau') = W^E(\tau)$.*

Any welfare level achieved in the European system can also be obtained in the American system by a suitable choice of the patent length. This means that in the search for the optimal patent policy we can restrict our attention to the American system and focus on the optimal patent length in that system, τ^* .

Note, however, that the Corollary does not necessarily imply that the American system is *strictly* better than the European system. Indeed, if the optimal policy entails secrecy, i.e. if $\tau^* < \tau_f^A$, the choice of the patent system is a matter of indif-

ference.¹⁸ Thus, a necessary condition for the American system to strictly dominate the European system on welfare grounds is that it is socially preferable to have first inventors patent rather than let firms rely on secrecy (i.e., $\tau^* \geq \tau_i^A$). We next turn to this issue.

Patents v. secrets. Having found that we can restrict our attention to the American system without loss of generality and that the optimal patent life in that system, τ^* , never lies in the interval $\tau_f^A \leq \tau < \tau_i^A$, our next goal is to ascertain whether it is socially preferable to have first inventors patent (i.e., $\tau^* \geq \tau_i^A$) or else let firms rely on secrecy (i.e., $\tau^* < \tau_f^A$). We shall show that in a broad set of circumstances it is socially desirable to have innovators patenting.

To begin with, we introduce a condition on the nature of competition in the product market.

Soft Competition: *The ratio of duopoly deadweight loss to per-firm profit is at least as large as the ratio of monopoly deadweight loss to monopoly profit:*

$$\frac{S_c - S_d}{\pi_d} \leq \frac{S_c - S_m}{\pi_m}. \quad (16)$$

To illustrate, consider a homogeneous good industry, with linear demand function $P(Q) = a - Q$ and constant marginal costs. Suppose that there is a drastic cost-reducing innovation, and normalize to zero the post-innovation marginal cost. Denoting by Q_d aggregate duopoly output, we let Q_d range from monopoly output $\frac{1}{2}a$ to competitive output a as product market competition increases, without making any specific assumption on the nature of product market competition. In this linear demand case, condition (16) holds as an equality when firms compete *à la* Cournot and as a strict inequality if duopoly output is lower than under Cournot competition;

¹⁸Strict welfare dominance also requires $\tau^* < \tau_i^E$; if $\tau^* \geq \tau_i^E$, optimality would involve patenting by the first inventor in all systems and again the choice of the patent system would be a matter of indifference.

it is violated if duopoly output is greater than under Cournot competition.¹⁹ In general, the ratio $(S_c - S_d)/\pi_d$ tends to $2(S_c - S_m)/\pi_m$ when Q_d tends to monopoly output (as $S_d \rightarrow S_m$ and $\pi_d \rightarrow \frac{1}{2}\pi_m$ for $Q_d \rightarrow Q_m$), implying that condition (16) tends to be satisfied when product market competition is not too intense, whence the name *Soft Competition*.²⁰

Proposition 4 *Under Soft Competition, the optimal patent life in the American system is long enough to encourage immediate disclosure of the innovation, i.e. $\tau^* \geq \tau_i^A$.*

Proof. We compare expected social welfare in case both firms rely on secrecy with that associated with the patent life that induces the innovator to patent and generates the same R&D effort as secrecy, namely τ_i^E (see Figure 2). That is, we take any policy $\langle \tau_1, A \rangle$ with $0 \leq \tau_1 < \tau_f^A$, say $\tau_1 = 0$, and we compare it to the policy $\langle \tau_i^E, A \rangle$. Because all of these policies generate the same incentive to innovate and so the same R&D effort, from (14) and (13) we get

$$W^A(\tau_i^E) - W^A(0) = \hat{x}^S \{ [-\tau_i^E + (1 - \hat{y}^S)\Phi](S_c - S_m) + \hat{y}^S\Phi(S_c - S_d) + c_f(\hat{y}^S) \},$$

where we have used the fact that $\hat{x}^A(\tau_i^E) = \hat{x}^A(0) = \hat{x}^S$ and $\hat{y}^A(0) = \hat{y}^S$. Next, recall that:

$$\tau_i^E = (1 - \hat{y}^S)\Phi + \hat{y}^S\Phi \frac{\pi_d}{\pi_m}.$$

This implies that

$$W^A(\tau_i^E) - W^A(0) = \hat{x}^S \left\{ \hat{y}^S\Phi \left[(S_c - S_d) - \frac{\pi_d}{\pi_m}(S_c - S_m) \right] + c_f(\hat{y}^S) \right\}.$$

Under *Soft Competition* the term inside square brackets is non-negative and therefore $W^E(\tau_i^E) > W^E(0)$. This means that the optimal patent life in the American system

¹⁹In the linear demand case we have $(S_c - S_m)/\pi_m = 1/2$ and $(S_c - S_d)/\pi_d = (a - Q_d)/Q_d$. Clearly, the ratio $(S_c - S_d)/\pi_d$ is decreasing in Q_d , i.e. in the intensity of product market competition. It tends to 1 when Q_d tends to monopoly output and to 0 when Q_d tends to competitive output a . With Cournot competition, $Q_d = \frac{2}{3}a$ and thus $(S_c - S_d)/\pi_d = 1/2 = (S_c - S_m)/\pi_m$.

²⁰When the demand function is concave, as Q_d increases the ratio $(S_c - S_d)/\pi_d$ decreases more rapidly – starting from $2(S_c - S_m)/\pi_m$ – than in the linear case, while it decreases less rapidly (it may even increase, in which case inequality (16) always holds) with convex demand functions.

is not shorter than τ_f^A . By Lemma 1, it does not lie in the interval $\tau_f^A \leq \tau < \tau_i^A$ and so it must be $\tau^* \geq \tau_i^A$, such that the innovator patents. ■

The intuition is as follows. With patents, the innovator benefits from monopoly profits, while under secrecy she earns a combination of monopoly and duopoly profits. The condition *Soft Competition* ensures that the deadweight loss per unit of the innovator's profit is lower under monopoly than under duopoly. Thus, comparing patent policies that lead to the same R&D effort, i.e. to the same expected reward for the innovator, *Soft Competition* implies the expected deadweight loss is lower with patents than with secrets.

■ **The linear-quadratic case.** An additional advantage of having innovators patenting is that in this case society does not pay the duplication cost $c_f(y)$. This means that patents may be better than secrets even when *Soft Competition* fails. To illustrate, consider again the linear demand example illustrated above, and suppose that $c_f(y) = \frac{1}{2}\beta y^2$. Provided that β is sufficiently large relative to $\mathcal{V}_f$ to yield interior solutions, the optimal duplicative effort is $\hat{y} = \frac{\mathcal{V}_f}{\beta}$. In this linear-quadratic example, it turns out that it is always desirable to induce innovators to patent and disclose the innovation.

Proposition 5 *In the linear-quadratic example with interior solutions ($\hat{y}^S < 1$), in the American system the optimal patent length is always such as to induce innovators to patent and disclose the innovation: $\tau^* \geq \tau_i^A$.²¹*

Proof. Proceeding as in the proof of Proposition 4, we get

$$W^A(\tau_i^E) - W^A(0) = \hat{x}^S \frac{\Phi^2 \pi_d}{\beta} \left[(S_c - S_d) - \frac{\pi_d}{\pi_m} (S_c - S_m) + \frac{1}{2} \pi_d \right].$$

With a linear demand function and zero marginal costs we have $\pi_d = \frac{1}{2}Q_d(a - Q_d)$, $S_c - S_m = \frac{1}{8}a^2$, and $S_c - S_d = \frac{1}{2}(a - Q_d)^2$. Thus, the term inside square brackets reduces to

$$(S_c - S_d) - \frac{\pi_d}{\pi_m} (S_c - S_m) + \frac{1}{2} \pi_d = \frac{1}{2}(a - Q_d)^2 > 0,$$

²¹As is clear from the proofs, Propositions 4 and 5 also hold in the European system: the optimal patent life in that system is always at least as large as τ_i^E under the stated assumptions.

and $W^A(\tau_i^E) > W^A(0)$. The conclusion then follows like in the proof of Proposition 4. ■

■ **The contract theory of patents.** Condition *Soft Competition* can be weakened in the special case in which we have $\hat{x} = 1$ for any possible patent policy. (Because V_i is bounded away from zero when secrecy is an option, it is clear that this case obtains if the marginal R&D cost is sufficiently low.)²² In this special case we can ignore the effect of patent policy on the innovator’s R&D effort, and we can focus on the patent system as a means for the *diffusion* of innovative knowledge. This approach formalizes the “contract theory” of patents, a theory that maintains that the function of the patent system is to grant monopoly in exchange for disclosure of innovative knowledge, rather than remunerate R&D effort.²³

Consider the following weakening of *Soft Competition*:

$$\hat{y}^S \leq \frac{(S_c - S_m)}{(S_d - S_m)} \frac{(\pi_m - \pi_d)}{\pi_m}. \quad (17)$$

Under *Soft Competition*, the right hand side of inequality (17) is greater than 1 and so the inequality is always satisfied. More generally, inequality (17) tends to be satisfied when marginal duplication costs are large.²⁴

Proposition 6 *If marginal R&D costs are low (and $\hat{x} = 1$ for any patent length) and inequality (17) holds, the optimal patent life in the American system is just long enough as to encourage immediate disclosure of the innovation, i.e. $\tau^* = \tau_i^A$.*

²²For instance, when $c_i(x) = \frac{1}{2}\alpha x^2$ the optimal innovative effort is always $\hat{x} = 1$ provided that $\alpha \leq V_i^A(\tau_i^A)$, as V_i is minimized at policy $\langle \tau_i^A, A \rangle$.

²³The “contract theory” is customarily adopted by the courts, along with the “reward theory,” to justify the patent system. In *Universal Oil Products v. Globe Oil & Refining* (1944), for instance, the Supreme Court couched the view that: “As a reward for inventions and to encourage their disclosure, the United States offers a seventeen-year monopoly to an inventor who refrains from keeping his invention a trade secret. But the quid pro quo is disclosure of a process or device in sufficient detail to enable one skilled in the art to practice the invention once the period of the monopoly has expired; and the same precision of disclosure is likewise essential to warn the industry concerned of the precise scope of the monopoly asserted.”

²⁴For instance, when $c_f(y) = \frac{1}{2}\beta y^2$ we have $\hat{y}^S = \frac{\Phi\pi_d}{\beta}$ and so it is clear that if β is sufficiently large inequality (17) is satisfied.

Proof. If marginal R&D cost are sufficiently low that $\hat{x}^A(\tau) = 1$ for all τ , for $\tau \geq \tau_i^A$ we have

$$W^A(\tau) = \left[\frac{S_c}{r} - \tau(S_c - S_m) \right] - c_i(1),$$

which is obviously maximized at $\tau = \tau_i^A$. By Lemma 1, τ^* cannot lie in the interval $\tau_f^A \leq \tau < \tau_i^A$. To complete the proof, it suffices to show that $W^A(\tau_i^A) > W^A(\tau)$ for any $\tau \leq \tau_f^A$, say $\tau = 0$.

When inequality $\tau_i^A \geq \tau_f^A$ is strict, τ_i^A is given by the condition $V_P(\tau_i^A) = V_{NP}^A(\tau_i^A)$, i.e. $\tau_i^A = [1 - \hat{y}^A(\tau_i^A)] \Phi$. It follows that

$$W^A(\tau_i^A) - W^A(0) = \Phi \{ [\hat{y}^A(\tau_i^A) - \hat{y}^S] (S_c - S_m) + \hat{y}^S(S_c - S_d) \} + c_f(\hat{y}^S) > 0.$$

When instead $\tau_i^A = \tau_f^A = \frac{\pi_d}{\pi_m} \Phi$, we have

$$W^A(\tau_i^A) - W^A(0) = \Phi \left[(S_c - S_m) \frac{(\pi_m - \pi_d)}{\pi_m} - \hat{y}^S(S_d - S_m) + c_f(\hat{y}^S) \right].$$

If inequality (17) holds, the term inside square brackets is positive and so $W^A(\tau_i^A) > W^A(0)$, whence the result follows. ■

When the research effort is not a concern, the goal of the patent policy is to minimize the deadweight loss associated with the use of the innovation. If inequality $\tau_i^A \geq \tau_f^A$ is strict, at $\tau = \tau_i^A$ the expected duration of the innovator's monopoly as secret user equals the patent length. A reduction in the patent length below τ_i^A *de facto* lengthens the expected duration of monopoly, since the follower becomes less aggressive and duplication is less likely to occur. If instead $\tau_i^A = \tau_f^A$, the expected duration of the innovator's monopoly if she does not patent is lower than the (discounting-adjusted) patent length, and so reducing τ below τ_i^A does not lead to prolonged monopoly. However, shorter monopoly will be accompanied by duopoly with probability $\hat{y}^S$, and unless duopoly is much more "efficient" than monopoly in providing the innovator with incentives to innovate, patents will still be preferable to secrets.

Propositions 4-6 substantiate our claim that in a broad set of circumstances it is socially desirable to have innovators patenting. Such a policy avoids wasteful dupli-

cation costs and under certain conditions minimizes the deadweight loss associated with the rewarding of innovators. In addition, by varying the patent life the policymaker can control the equilibrium innovative effort to a certain extent, whereas with secrets the R&D effort is fully determined by exogenous parameters. The role of this greater flexibility is downplayed by our approach of comparing different policy options that lead to the same equilibrium innovative effort, but in many cases it may be important. Nevertheless, there are circumstances under which secrecy is socially preferable. For instance, consider again the linear-quadratic example where $c_i(x) = 1/2\alpha x^2$ and $c_f(y) = 1/2\beta y^2$, but now assume that α and β are sufficiently small as compared to V_i and $\mathcal{V}_f$ to yield corner solutions, i.e. $\hat{x} = 1$ and $\hat{y} = 1$ for any feasible patent policy. In this special case, $\tau_i^A = \tau_f^A = \tau_i^E$ and W^A is piecewise constant in τ , with a jump at $\tau = \tau_i^E$. Proceeding as in the proof of Proposition 4, one calculates

$$W^A(\tau_i^E) - W^A(0) = \left\{ \Phi \left[(S_c - S_d) - \frac{\pi_d}{\pi_m} (S_c - S_m) \right] + \frac{1}{2}\beta \right\}.$$

If Soft Competition fails (i.e. duopoly output is greater than under Cournot competition) the term inside square brackets is negative. If, in addition, the marginal duplication costs β is sufficiently low, we have $W^A(0) > W^A(\tau_i^E)$, i.e., social welfare jumps down at $\tau = \tau_i^E$. In this special case, were both research and duplication costs are very low and Soft Competition fails, secrets turn out to be socially better than patents.

5 Extensions

In this section we briefly report on various extensions of the basic model. First, although in the basic model we have assumed that innovation is uncertain but instantaneous, nothing substantial changes if innovation and duplication are assumed to occur in time according to Poisson processes with hazard rates determined by firms' inventive and duplicative efforts, as in the first version of this paper (Denicolò and Franzoni, 2001).

Second, we have assumed that there is no competition in R&D. However, it should be clear from the preceding analysis that all that matters for our results is that there exists a positive relationship between equilibrium aggregate innovative effort and the innovator's reward. Generally speaking, the introduction of competition in R&D does not destroy such a relationship, which is exhibited, for example, by most patent race models: see e.g. Reinganum (1989).²⁵

Third, in the basic model leakages are necessary to have the follower patenting in the European system: with no leakage, i.e. $z = 0$, the equivalence between the European and the Strict system is trivially true (but note that all of our results continue to hold). However, the choice between patenting and secrecy is non trivial with many potential duplicators, even with $z = 0$ – except for the last duplicator. To illustrate, suppose there are two potential duplicators and extend the basic game by assuming that if the first duplicator succeeds and in turn conceals the innovation, the second duplicator can invest to re-obtain the innovation and, if he succeeds, can choose to patent or keep it secret. With $z = 0$, in the European system the second duplicator would never patent. However, the first duplicator patents provided that

$$\tau\pi_d \geq (1 - y_2)\Phi\pi_d + y_2\Phi\pi_t$$

where y_2 is the second duplicator's effort and π_t is the individual profit with three active firms. Thus, $\tau_f^E = (1 - \eta)\Phi + \eta\Phi\frac{\pi_t}{\pi_d}$. Proposition 1 continues to hold under the weak condition $\frac{\pi_m}{\pi_d} \geq \frac{\pi_d}{\pi_t}$, which is satisfied in many oligopoly models.²⁶ To show

²⁵However, there is a caveat. Suppose there are two firms racing for the innovation, and the loser has the possibility of duplicating the innovation (i.e. becomes the follower). Then, equilibrium investment in R&D depends not only on the profits to the winner of the patent race, but also on those of the loser. Propositions 1 and 2 continue to hold, but the function $\hat{x}(\tau)$ may now jump down at certain points. This implies that for certain patent policies such that the first inventor does not patent, it may not be possible to find a corresponding policy that induces the first inventor to patent and leads to the same R&D effort. In these cases, we can no longer proceed by comparing patent policies that generate the same incentive to innovate. However, the problem would disappear if there is free entry in the duplication stage, such that the prize to the loser of the patent race is driven to zero.

²⁶For example, in a Cournot model with linear demand and constant marginal costs, $\frac{\pi_t}{\pi_d} = \frac{9}{16}$ and $\frac{\pi_d}{\pi_m} = \frac{4}{9}$. With conjectural variations and under the same assumptions, inequality $\frac{\pi_m}{\pi_d} \geq \frac{\pi_d}{\pi_t}$ holds for any value of the conjectural variations parameter.

this, note that if the innovator does not patent at $\tau = \tau_f^E$, she gets

$$(1 - y_1)(1 - y_2)\Phi\pi_m + [y_1(1 - y_2) + y_2(1 - y_1)]\Phi\pi_d + y_1y_2\Phi\pi_t < \tau_f^E\pi_m$$

where $\tau_f^E\pi_m = (1 - y_2)\Phi\pi_m + y_2\Phi\frac{\pi_t}{\pi_d}\pi_m$, and the inequality follows by condition $\frac{\pi_m}{\pi_d} \geq \frac{\pi_t}{\pi_i}$. Therefore, the innovator prefers to patent at $\tau = \tau_f^E$; in other words, we have $\tau_i^E < \tau_f^E$, whence the equivalence between the European and Strict systems follows. The intuition is that the loss due to (further) replication is higher for the innovator than for the first duplicator (and, more generally, is higher for the k -th duplicator than for the $k + 1$ -th). Thus, even apart from any intrinsic descriptive value, a positive probability of a leakage may be seen as a shortcut for keeping into account the possibility of multiple duplications.

Fourth, in the basic model we have posited that being the first inventor is verifiable so that in the European system the innovator can continue to practice the innovation even if duplication occurs. Suppose instead that the innovator is adjudged to be the first inventor with probability μ . If the follower patents he now gets $\tau[\mu\pi_d + (1 - \mu)\pi_m]$, and so

$$\tau_f^E(\mu) = \frac{\Phi\pi_d}{\mu\pi_d + (1 - \mu)\pi_m}.$$

The basic model corresponds to $\mu = 1$. However, all of our results continue to hold provided that $\mu \geq \bar{\mu}$, where $\bar{\mu}$ is implicitly defined as the solution to $\tau_f^E(\bar{\mu}) = \tau_i^S$, or

$$\frac{\pi_d}{\bar{\mu}\pi_d + (1 - \bar{\mu})\pi_m} = \frac{\hat{y}^S\pi_d + (1 - \hat{y}^S)\pi_m}{\pi_m}.$$

If $\mu < \bar{\mu}$, Propositions 1 and 2 no longer hold as $\tau_f^E(\mu) < \tau_i^E(\mu)$. However, it remains true that for any policy $\langle \tau, S \rangle$ there exists a policy $\langle \tau', A \rangle$ that yields the same subgame perfect equilibrium outcome. Moreover, it is easy to see that for all values of μ we have $\tau_f^E(\mu) \geq \tau_f^A$ and $\tau_i^E(\mu) \geq \tau_i^A$, with equality holding for $\mu = 0$, in which case the European system collapses to the American system. One can also show, proceeding as in the proof of Lemma 1, that in the European system the optimal patent life never lies in the interval $\tau_f^E(\mu) \leq \tau < \tau_i^E(\mu)$. These facts imply that for any τ there exists a τ' such that $W^A(\tau') = W^S(\tau)$, and a τ'' such that

$W^A(\tau'') \geq W^E(\tau)$. This means that there is still no loss of generality in focusing on the American system in the search for the optimal patent policy, and the rest of our welfare analysis continue to apply.

Finally, the analysis could be extended to take into account the costs of enforcing patents and secrets. The high administrative and legal costs of the patent system are well documented in the empirical literature. However, secrecy is also costly, because of the direct costs of enforcing trade secret laws, and because holders of concealed inventions may be induced to use inefficient marketing or production strategies to protect the secret. There is little evidence on the relative costs of patents and secrets. For instance, in an empirical investigation on civil litigation case files, Lerner (1994) finds that patent and trade secret issues are commonplace and occur with about the same frequency. However, he also finds that small firms tend to rely on secrecy more often than big firms; one possible explanation is that secrecy is less costly than patenting. Then, let us normalize to zero the costs of secrecy and suppose that the innovator must pay a lump-sum cost $\Psi \geq 0$ to obtain the patent and a flow cost $\psi \geq 0$ to renew and enforce it (that is, we interpret Ψ and ψ as the difference in costs between patents and secrets), so that the discounted total cost of the patent is $\Psi + \tau\psi$. One can easily show that all the results in Section 3 continue to hold with this more general formulation.²⁷ Obviously, however, if Ψ and ψ are large, the welfare comparison between patents and secrets becomes more ambiguous.

6 Concluding remarks

This paper provides an analysis of the optimal degree of patent protection (captured by patent length) and the scope of the rights conferred to second inventors when innovators can resort to secrecy to protect their innovations. We have compared three patent systems, which differ in regard to the breadth of the second inventor's patent rights. We have shown that the Strict system, where second inventors cannot patent,

²⁷This is not true if either Ψ or ψ are negative, i.e. if secrets are more costly to enforce than patents.

is equivalent to the European system where they can patent but cannot exclude the first inventor. Provided that the patent length can be suitably chosen, is it optimal to offer broad protection to second inventors (as in the American system), so as to more easily induce first innovators to disclose their innovation. Patents are superior to trade secrets in a broad set of circumstances, because they allow for greater flexibility in the reward to innovators (which can be greater or lower than under trade secrets), prevent wasteful duplication effort, and imply smaller deadweight losses (provided that product market competition is not too strong).

Our findings shed some light on recent proposals to introduce a first inventor defence in the American system. Presuming that the degree of patent protection is currently at the optimal level, such a move would not enhance welfare (Corollary 1). However, this presumption is not unassailable. For an arbitrarily given patent length, not necessarily the optimal one, the welfare comparison of the American and European systems is generally ambiguous. In the American system the innovators' propensity to patent is greater, but the incentive to innovate is lower (Proposition 3). A more highly structured model is needed to make further progress on this issue.

One major reason why the current level of patent protection is unlikely to be at its (first-best) optimal level is that the optimal policy typically varies across industries, and even across innovations within the same industry. While some differences in the strength of patent protection are observable from industry to industry, incomplete information and administrative costs make it difficult to tailor patent policy to specific industries and innovations. In these circumstances, our result that patents are broadly superior to secrets also needs qualification. If the policymaker is restricted to choose the same strength of patent protection in all sectors, it is clear that the (second-best) optimal policy may well entail that certain sectors – for instance, those in which the risk of leakage is lowest – prefer to rely on secrecy. In such a framework, the social cost of decreasing patent protection is not necessarily that innovation is discouraged, as in the standard Nordhaus trade-off, but rather that more innovations will be kept secret. The analysis of optimal patent policy in this framework again requires a more

highly structured model.

Finally, there is the issue of cumulative innovation. Green and Scotchmer (1990) analyze a two-stage model of R&D in which, by patenting an intermediate result, a firm gains interim profits but helps its rival achieve the final innovation. Licensing agreements in a similar framework are analyzed by Battacharya, d'Aspremont and Gerard-Varet (2000). This literature has highlighted the role of disclosure of innovations in generating technological spillovers and spurring further progress, and the role of licensing agreements to ensure the appropriate division of the profits from successive innovations among all firms that concurred to the discoveries (see also Scotchmer 1999). Because secrecy makes it more difficult for inventors to license their innovations to others, there is a presumption that secrecy is particularly costly with sequential innovation, but a proper analysis of these dynamic issues must await future research.

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