RAND Journal of Economics
Vol. 23, No. 1, Spring 1992

Patent policy and costly imitation

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This article extends the theory of optimal patents to allow for costly imitation of patented innovations. With costly imitation, a rival's decision to imitate depends on the length of patent protection awarded to the patentee: the longer the patent life, the more likely it is that rivals will "invent around" the patented product. Extending patent life, therefore, may not provide the innovator with increased incentives to research or to patent the innovation. In this case, I find that optimal patent lives are sufficiently short to discourage imitation. With both patent length and breadth as instruments, the optimal policy consists of broad patents (no imitation allowed) with patent lives adjusted to achieve the desired reward. These results are in sharp contrast to recent results on the optimality of narrow, infinitely long patents.

1. Introduction

■ Two important goals underlie the patent system: to promote research and development and to encourage the disclosure of inventions so that others can use and build upon research results. The effectiveness of the patent system in achieving these goals depends in part on the ability of rival firms to imitate or "invent around" patented innovations. Most of the literature on patent life assumes that imitation of patented products is either prohibitively costly and therefore never a threat to the innovator (Nordhaus, 1969; Scherer, 1972; Kamien and Schwartz, 1974; Wright, 1984; DeBrock, 1985; and Kotowitz, 1988) or is costless and therefore always a threat to the innovator (Tandon, 1982; Gilbert and Shapiro, 1990; and Klemperer, 1990).[1] Under both assumptions the decision to imitate is independent of patent life, and consequently, an increase in patent life always promotes both research and disclosure of the innovation.

The intermediate and more common case is that imitation is costly but not prohibitively so. A study by Levin et al. (1988) reports that "patents raise imitation costs by about forty percentage points for both major and typical new drugs, but about thirty percentage points for major new chemical products, and by twenty-five percentage points for typical chemical products." Imitation costs were not prohibitive in their sample in that "the ability of competitors to 'invent around' was regarded as the most important constraint on [patent] effectiveness." Introducing imitation costs into the economic theory of patents has the effect of endogenizing rivals' imitation decisions, since the incentive to imitate depends on the length of patent protection awarded to the patentee. Parker (1974) notes: "A long period

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I am grateful to Yehuda Kotowitz, Stephen Law, Kate Rockett, Garth Saloner, Suzanne Scotchmer, Ralph Winter, Brian Wright, and an anonymous referee for insightful comments and to the Social Science and Humanities Research Council of Canada for financial support. I also gratefully acknowledge the Olin Foundation of the Yale Law School for its generous support.

[1] In these articles, imitation results in an inferior product. While imitation never occurs in equilibrium because the innovator engages in limit pricing, the potential threat of entry constrains the flow of profits to the innovator.

of legal protection may induce inventive effort to sidestep a patent. The period of [patent] protection may therefore have direct influence on the character of commercial rivalry."

This article considers optimal patent policy with costly imitation in a model that endogenizes imitation. Rivals imitate until profits from the activity are dissipated. I also analyze feedback of the rivals' decisions on the innovator's decision to patent. In the literature on patent life, beginning with Nordhaus's seminal work (1969),[2] the innovator is assumed to patent its invention, regardless of patent life.[3] Levin et al. (1988) report that innovators often choose to keep their innovation secret rather than disclose it through a patent, especially when imitation is likely.

When imitation costs are positive, I find that an increase in patent life over some range may have no effect on or paradoxically may reduce both research and development activity and the incentive to patent. Increasing the length of patent protection gives rivals a greater incentive to imitate (invent around) a patented product: the longer the patent life, the longer rivals must wait to use the technology. If imitators enter the market until profits are dissipated (as in this model), increasing patent life increases the number of competing products, thus reducing any added incentives to research and to disclose the innovation that typically result from longer patent protection.

These effects have implications for optimal patent policy. When only the length of patent protection can be controlled by patent authorities, I show that optimal patent life is generally short to discourage imitation. I extend patent policy to include both patent life and patent breadth, where the latter is measured by the flow of profits appropriated by the innovator. Patent breadth can be affected directly by changing either the costs of developing a noninfringing imitation or the flow of profits earned by imitators. I show that social surplus is maximized when patents are broad (no imitation) and patent life is adjusted to achieve the desired patent reward.

These results contrast sharply with those of Tandon (1982), Gilbert and Shapiro (1990), and, to some extent, Klemperer (1990), in which narrow, infinitely long patents are optimal. The key in our model is the increasing costly imitation that displaces the patentee's output as patent life increases. The previous literature noted here considers market situations in which imitation, while constraining the innovator's profits, never occurs in equilibrium for any patent life.[4]

In Section 2, the model's assumptions are outlined and the positive effects of patent life on the research, patent, and imitation decisions are analyzed. In Section 3, patent policy is evaluated when only patent life can be chosen, and the results are compared to those in related articles. Both patent life and breadth are direct policy instruments in Section 4. Section 5 sums up the results and suggests extensions.

2. Innovation with costly imitation

■ **The assumptions.** In this section I outline the assumptions of a simple model. Initially, a single firm (the innovator) invests in R&D to develop a new product or process.[5] If the firm is successful in developing the innovation, it can either patent it or keep it secret.

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[2] See also Scherer (1972), Kamien and Schwartz (1974), Tandon (1982), Wright (1984), DeBrock (1985), Kotowitz (1988), Gillespie (1989), Gilbert and Shapiro (1990), and Klemperer (1990).

[3] The disclosure issue is addressed by Scotchmer and Green (1990), who analyze the effect of the novelty requirement of patent policy on disclosure. In contrast to their article, in which patenting reveals information that may be used to accelerate development of subsequent innovations, disclosure is socially beneficial in our model since it puts the innovation in the public domain in the postpatent period. Horstman, MacDonald, and Slivinski (1985) analyze the decision to patent, where patenting signals to rivals the ease of imitation of patent products and duplication of nonpatented products; they do not consider directly the effect of patent policy on disclosure.

[4] This literature is discussed in more detail in Section 3.

[5] Alternatively, if all firms know of the technology, then a patent race may take place. For an analysis of the effect of rivalry on patent policy, see Wright (1984), DeBrock (1985), Kotowitz (1988), and Gillespie (1989). In

If the new process or product is patented, the firm is awarded a monopoly over the innovation for T years, after which time the innovation is costlessly available to all firms in a competitive market. Although rivals are prevented from duplicating the patented innovation during those T years, they can invent around or develop a noninfringing imitation at cost K.[6] Free entry into "the market for imitations" implies that rivals will imitate until the profits from imitation are dissipated. The original innovator and m imitators compete simultaneously in the market, and they earn the same flow of profits, gross of research or imitation costs: $\pi(m)$. That is, imitation is assumed to be "perfect" in that imitators can, at cost K, develop either perfect, noninfringing substitutes or differentiated products with symmetric demands and incur the same production costs, $c(x)$, where x is firm output and $c'(x) > 0$, $c''(x) \geq 0$.

Alternatively, the innovator may choose not to patent the new invention. In this case, it faces the risk that some rival firms will learn about and duplicate the innovation. I assume with probability p_D that the innovation becomes available to everyone at zero cost, in which case the original innovator earns a zero return on the investment; otherwise, it enjoys an infinite monopoly.[7]

In sum, the sequence of decisions is as follows: (i) the innovator researches; (ii) if successful, the innovator chooses whether or not to patent; (iii) if the innovation is patented, then rival firms make imitation decisions; (iv) finally, production takes place. We turn now to the model.

□ **Research, patent and imitation responses to patent life.** In this section, I look for the subgame perfect equilibrium to the research-patent-imitation game outlined above. As is conventional, I consider the game in reverse, beginning with the imitation decision.

Imitation of a patented invention. Consider a rival's imitation decision when the innovator takes out a patent. Let $\beta(T) = (1 - e^{-rT})/r$, where T is the patent life and r is a common discount rate. Let $T_I(K)$ be the patent length beyond which imitation occurs when imitation costs equal K. If m is continuous, as assumed here,[8] $T_I(K)$ will be the value of T that satisfies $\beta(T)\pi(0) - K = 0$, or

$$T_I(K) = -\log(1 - Kr/\pi(0))/r. \tag{1}$$

The curve $T = T_I(K)$ is given in Figure 1 by AB.[9] As indicated in the figure, imitation is profitable for all $T > T_I(K)$. In this region, rivals will imitate until profits are dissipated; that is, for a patent life $T \geq T_I(K)$, the number of imitators that will enter the market, m, satisfies

$$\beta(T)\pi(m) - K = 0. \tag{2}$$

We turn now to the patent decision.

The patent decision. The decision to patent depends directly on patent life, T, and the (rationally anticipated) rivals' reactions to the patent decision, which in turn also depend on patent life, as shown in the previous section.

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this model, optimal patent lives would fall under a patent race relative to a single researcher in order to discourage duplicative research (see Gillespie (1989)), but the qualitative effects of costly imitation would not change.

[6] Several different products with the same end use may be patentable. For example, a British court recently ordered that Genentech could not retain exclusive marketing rights in Britain for the heart product TPA. This encouraged the other 19 companies working on their versions of TPA to continue research.

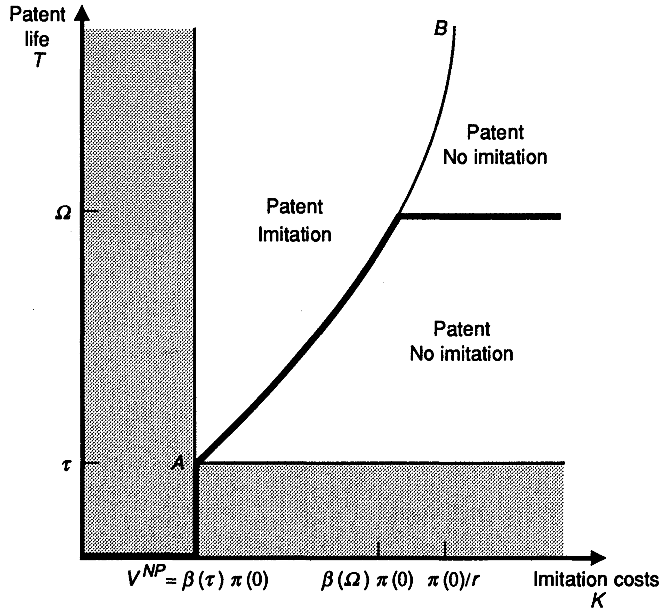
[7] Alternatively, I could assume that because of the set-up costs of duplicating the innovation, a limited number of firms duplicates, leaving the original innovator with a positive return. This assumption would not change the qualitative results of the model. I also assume that no one can patent a duplicated product; public use or knowledge of an innovation renders the innovation unpatentable, since it is no longer novel.

[8] Allowing m to be discrete makes the analysis more cumbersome, without providing additional insights.

[9] Although not shown in the figure, the curve $T = T_I(K)$ extends to the origin.

FIGURE 1

DISCLOSURE, IMITATION, AND PATENT POLICY DECISIONS



An innovator who patents (the patentee) earns a discounted return from research, $V^P(T)$, given by

$$V^P(T) = \begin{matrix} \beta(T)\pi(0) & T < T_I(K) \\ K & T \geq T_I(K). \end{matrix} \tag{3}$$

The first part of (3) gives the gross profits earned by the patentee in the absence of any imitation. Note that it increases in T. The second part gives the patentee's gross profits after imitation begins: the return is independent of patent life, since the number of imitators adjusts to changes in patent life, according to (2), until gross profits equal K.

If the innovator chooses not to patent, the return is V^{NP}, given by

$$V^{NP} = (1 - p_D)\pi(0)/r. \tag{4}$$

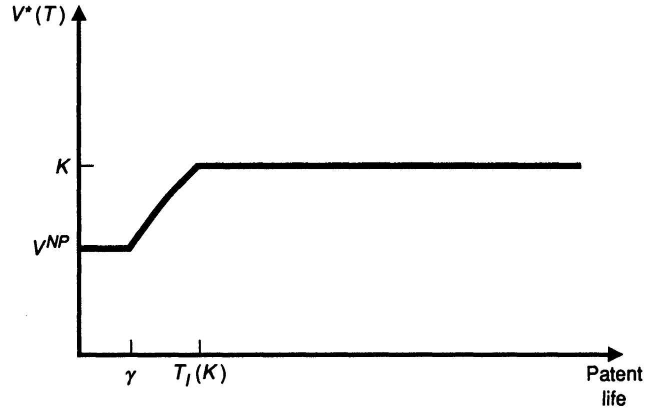
Whether the innovation is patented or kept secret depends on patent life and imitation costs, as implied by a comparison of (3) and (4). Since K is the maximum return from patenting, when $K < V^{NP}$, secrecy will be preferred to patenting for all T. For $K \geq V^{NP}$, the decision to patent depends on the length of patent protection. Let τ denote the patent life that makes the innovator indifferent between patenting and secrecy;[10] then only for $T \geq \tau$ will the innovator choose to patent. The patent decision as a function of T and K is illustrated in Figure 1. For (T, K) in the unshaded regions, defined by the intersection of the sets $\{(T, K) | K \geq V^{NP}\}$ and $\{(T, K) | T \geq \tau\}$, patenting is profitable.

Although sufficiently long patent protection encourages the innovator to disclose its innovation when imitation costs are sufficiently large, increased patent protection beyond a patent life of $T_I(K)$ does not provide further incentives for research. To see this, note that the return to the innovator as a function of patent life, $V^*(T)$, is given by

[10] From (3) and (4), $\tau = -\log p_D/r$.

FIGURE 2

INNOVATOR'S RETURN FROM RESEARCH



$$V^*(T) = \begin{cases} V^{NP} & \text{for} \quad T < \tau \\ \beta(T)\pi(0) & \text{for} \quad \tau \leq T < T_I(K) \\ K & \text{for} \quad T \geq T_I(K). \end{cases} \tag{5}$$

The private return from R&D is illustrated in Figure 2 for $K \geq V^{NP}$. As patent life increases in the interval $[\tau, T_I(K)]$, the reward from research increases because patent length is too low to make imitation profitable. But as T increases beyond $T_I(K)$, patent policy has no effect on the return to the innovator and thus on the incentive to innovate: while an increase in patent life extends the patentee's monopoly over the innovation, it encourages entry into the market for imitations. Consequently, the same incentive for research and disclosure can be achieved with many patent lives. The social consequences of changing patent life for $T \geq T_I(K)$, however, are not inconsequential, as shown in the next section.

3. Optimal patent length

■ Given the private decisions on innovation and imitation as a function of patent life T and imitation costs K (Figure 1), we can now examine optimal patent policy. In this section I consider the case in which patent authorities have only one policy instrument, patent length, to influence research, disclosure, and imitation activities. I search for the patent life, T^*, that maximizes discounted social surplus.

First recall that patenting is never profitable for $K < V^{NP}$; since no patent life can alter the innovator's decision to research or patent, we set $T^* = 0$ without loss of generality. For $K \geq V^{NP}$, patent policy can make a difference. The analysis in the remainder of Section 3 applies to these values of K.

For $K \geq V^{NP}$, social welfare is sensitive to the length of patent protection for patent lives sufficiently long ($T \geq \tau$); for patent lives in the interval $[0, \tau)$, the innovator has no incentive to research or to disclose the innovation, so welfare is constant. Consequently, for a given K, optimal patent life will either be equal to zero or lie in the interval $[\tau, \infty]$. In the next section I show that for a given K, T^* will never exceed $T_I(K)$, the patent life beyond which imitation takes place.

□ **Conditions for no imitation under optimal patent policy.** I identify reasonably general conditions under which optimal patent length will be sufficiently short to discourage all imitation; that is, $T^* \leq T_I(K)$. These conditions are stated in Proposition 1. Let X be market output, x firm output, and ϵ_X^n the output elasticity with respect to the total number of firms, $n = m + 1$. Then,

Proposition 1. For $K \geq V^{NP}$ and $\epsilon_X^n \leq 1$, the patent length that maximizes social surplus is no greater than $T_I(K)$; that is, no imitation takes place under the optimal patent policy.

The proof of Proposition 1 is outlined below. First, note that the result in the proposition is trivially true for $K \geq \pi(0)/r$, since $T_I(K) = \infty$ for these values of K. For the proposition to be true for $K \in [V^{NP}, \pi(0)/r)$, it is necessary that $T_I(K)$ maximize discounted social surplus in the interval $[T_I(K), \infty]$, given the innovator's and imitators' responses to changes in patent life.

To show that this is the case, note that when patent life decreases in the interval $[T_I(K), \infty]$, the innovator's incentives to research and patent are not reduced, since the number of imitators adjusts downwards: a return of K can be achieved with either a high flow of profits, π, for a short patent period or a low profit flow for a long period. (See Figure 2.) Therefore, the problem of choosing patent life alone can be solved as if the social planner had two instruments, T and π, with which to maximize social surplus, constrained by a reward to the innovator equal to K. I solve this problem below.

Denote the flow of consumers' surplus during patent life, when the innovator earns a profit flow of π, by $S(\pi)$[11] and after the patent expires, when the innovation becomes costlessly available to everyone, by S^*. Furthermore, let

$$DWL(\pi) = S^* - [S(\pi) + (m(\pi) + 1)\pi]$$

be the dead-weight loss from the output distortion due to patents, where $m(\pi)$ is the inverse of the function $\pi = \pi(m)$. Then, the social problem is

$$\max_{T,\pi} S^* - \beta(T)[DWL(\pi) + m(\pi)\pi]$$

$$\text{subject to } \beta(T)\pi = K. \tag{6}$$

The problem in (6) implies that the optimal T and π minimizes the discounted social costs of a patent—the discounted dead-weight loss plus profits lost to imitation—while generating a return to the innovator equal to K. Note that an increase in patent life has the same proportional effect on the return to the innovator and on the discounted social costs of a patent; that is, the flow of social costs per dollar of profit is the same for all T. This implies that optimal patent policy is determined by the π that minimizes this social-cost-to-profit ratio. That is, the problem in (6) reduces to

$$\min_{\pi} \frac{(DWL(\pi) + m(\pi)\pi)}{\pi}. \tag{7}$$

For the patentee to receive the monopoly profit flow from the innovation, as implied by the "no-imitation" result in Proposition 1, and for the corresponding patent life to be $T_I(K)$, the derivative of (7) with respect to π must be negative. That is,[12]

$$-DWL(\pi)/\pi^2 + [1 - \epsilon_X^n \alpha] m'(\pi) < 0, \tag{8}$$

where α is a parameter no greater than 1.[13] Since $m'(\pi) < 0$, a sufficient condition for (8) to be negative is $\epsilon_X^n \leq 1$.

[11] Since the firms are symmetric, consumer surplus, which depends on industry output, can be written as a function of individual firm profits and the number of firms. In turn, m is a function of π, as given by the inverse of $\pi = \pi(m)$.

[12] $dDWL/dX = -(p(X) - c'(x))$, where $p(X)$ is price during patent life and $c'(x)$ is a firm's marginal cost, is substituted into the derivative and terms are rearranged to get the expression in (8).

[13] $\alpha = (p(X) - c'(x))/(p(X) - c(x)/x)$. Since $c''(x) \geq 0$, $\alpha \leq 1$.

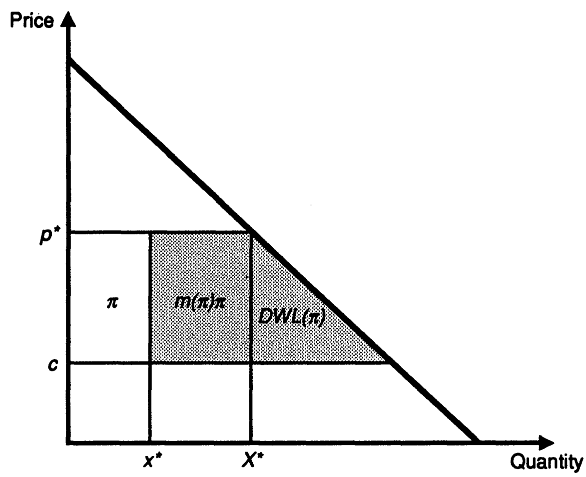
The intuition for Proposition 1 is straightforward. Consider the effect of a decrease in patent life in the interval $[T_I(K), \infty]$ and the corresponding decrease in imitation on social welfare. First, the output distortion from the innovator's market power increases according to ϵ_X^{π}; second, imitation costs decrease with the number of imitators by an elasticity of one. If the output elasticity is less than the imitation cost elasticity, then the social costs of reducing patent life will decrease. The third effect of decreasing imitation—a larger proportion of the industry profits is left with the innovator, thus requiring shorter protection to achieve the same return from research—reinforces the incentive to reduce the length of patent protection.

The result in Proposition 1 contrasts with those found in Tandon (1982), Gilbert and Shapiro (1990), and, to some extent, Klemperer (1990),[14] where an infinite patent is optimal. This difference in policy prescriptions can be attributed to the passive role of imitation in these models. To see this, consider the statement of the problem in (7). Two effects of imitation present in this model increase the social-cost-to-profits ratio. First, when $K > 0$, the social costs of patent protection will exceed the usual dead-weight loss from an output distortion by the flow of costly resources spent on the imitations (equal to $m(\pi)\pi$). Second, when $m(\pi) > 0$, imitation displaces some of the innovator's production and so the patentee captures only part of the industry profits. Both effects are illustrated in Figure 3, given a market price p^*, market quantity X^*, firm quantity x^*, and marginal production costs c.

Tandon (1982), Gilbert and Shapiro (1990), and Klemperer (1990) solve a problem similar to the one in (7), but they solve it for the case in which the effects of imitation described above are absent.[15] While potential imitation constrains the innovator's flow of profits during the patent period in these articles, imitation never takes place in equilibrium for any patent life. In Tandon's model, for example, the patentee sets the price of its innovation below that of "imitations," [16] which have higher marginal production costs. Similarly, in Klemperer's model imitations are inferior in that consumers incur a cost of travelling

FIGURE 3

SOCIAL COSTS OF PATENTS



[14] This applies to Klemperer's model in which consumers have identical travel costs.

[15] In Tandon, patent life and the compulsory licensing royalty are instruments of patent policy; in Gilbert and Shapiro, both T and π are the patent instruments; and in Klemperer, patent life and width are chosen, where patent width is the distance a consumer must travel to his/her preferred product.

[16] Tandon analyzes compulsory licensing, but the perfectly competitive licensees can be interpreted as rivals that can develop inferior imitations at zero cost.

to less-preferred varieties of the product; under the assumption of identical travel costs and price competition, the patentee sets its price so that no consumers purchase an imitation. In both cases, $m(\pi) = 0$ for all patent lives, and so the innovator captures the full industry profits.

When these effects of imitation are absent, the social-cost-to-profits ratio is given by $DWL(\Pi)/\Pi$, where Π equals industry profits. Tandon shows that for linear demand, this ratio is minimized for infinite patent lives. More generally, Gilbert and Shapiro show that this result holds when social welfare is concave in Π. In Klemperer's model with identical travel costs, an infinite patent minimizes social costs per dollar of profit.

Since $K > 0$ in this model, perfect or price competition of the previous models must be replaced with market behavior that does not compete away the gross profits from imitation, for example, quantity (Cournot) competition.[17] More generally, for any market setting in which costly imitation displaces the original innovator's output for longer patent lives (for example, monopolistic competition or differentiated Bertrand), short patent lives are likely to be optimal.[18,19]

□ **Optimal patent length.** Proposition 1 notes that under optimal patent policy, no imitation takes place in equilibrium. This implies that optimal patent policy lies in the interval $[0, T_I(K)]$. In fact, it is straightforward to show that T^* will be either 0, Ω, or $T_I(K)$, where Ω is the patent life that maximizes social surplus when neither secrecy nor imitation is possible. That is, Ω is the solution to the Nordhaus model (1969), which is a special case of this model when $p_D = 1$ (no secrecy) and $K \geq \pi(0)/r$ (no imitation).

I characterize optimal patent length in Proposition 2.

Proposition 2. For $K \geq V^{NP}$ and $\epsilon_X^n \leq 1$,
(i) If $\Omega < \tau$, then $T^* = 0$.
(ii) If $\Omega \geq \tau$, then
(a) $T^* = T_I(K)$ for $K \in [V^{NP}, \beta(\Omega)\pi(0)]$; and
(b) $T^* = \Omega$ for $K > \beta(\Omega)\pi(0)$.

Recall that τ is the patent life that makes the innovator indifferent between disclosure and secrecy. Then, part (i) of the proposition simply notes that when $\Omega < \tau$, the innovator would not disclose its innovation for a patent life of Ω; this implies optimal patent length will be either zero or τ. Social surplus is identical for these two patent lives, and so patent policy is $T^* = 0$, without loss of generality.

Part (ii) of the proposition considers cases in which disclosure is profitable for a patent life of Ω. By the relationship in (1), $K \leq \beta(\Omega)\pi(0)$ (part (iia)) implies that $T_I(K) \leq \Omega$. But

[17] The condition in Proposition 1 is satisfied for Cournot firms when the Hahn-Novshek condition, $p'(X) + xp''(X) < 0$, holds, where $p(X)$ is the inverse demand function and x is firm quantity. To see this, consider the first-order condition for a Cournot firm: $p'(X)X/n + p(X) - c = 0$. Total differentiation of this condition with respect to X and n and rearranging terms gives $\epsilon_X^n = p'/(p'(n+1) + p''X)$. $\epsilon_X^n \leq 1$ if the Hahn-Novshek condition holds. This condition implies that reaction functions must be negatively sloped and so may not be satisfied for demands that are very convex, in which case long patents may be optimal. This is consistent with an example in Klemperer.

[18] These results are consistent with Klemperer's model in which consumers have identical reservation prices for the preferred variety (over buying no variety at all). In his model the original innovator sets price so that all consumers buy some variety; however, they may switch to less-preferred varieties at that price. Although less-preferred varieties (imitations) are costless to develop in his model, a transport cost is incurred when consumers purchase inferior products. To avoid this social cost, imitation is optimally prevented and patent lives are relatively short.

[19] In the model presented here, the original innovator and imitators are assumed to compete simultaneously in the market. Alternatively, if the innovator could commit to output before rivals made their imitation decisions, then if $K > 0$ it might choose a sufficiently large output to discourage imitation. In that case, an infinite patent life would be optimal.

since T^* is no greater than $T_I(K)$ under the elasticity condition (by Proposition 1), $T^* = T_I(K)$. For larger imitation costs (part (iib)), $\Omega < T_I(K)$, and so by definition of Ω, $T^* = \Omega$. That is, when K is sufficiently large, the threat of imitation is effectively absent and the Nordhaus solution results.

Optimal patent length as a function of K is given on the patent-imitation diagram of Figure 1 by the bold curve. This diagram of the innovator's, imitators', and patent authorities' decisions highlights the two main results of Propositions 1 and 2: (i) optimal patent life is sufficiently short to discourage all imitation, and (ii) optimal patent life increases in the costs of imitation for an intermediate range of K.

4. Optimal patent length and breadth

■ Section 3 focuses on optimal length of patent protection. I extend the analysis to analyze a second dimension of patent policy: patent breadth or scope. As in Gilbert and Shapiro (1990), I define patent scope by the flow of profits earned by the innovator during patent life.

The analysis in the previous section shows that when imitation is costly, changes in patent life indirectly affect patent breadth by affecting imitation decisions. In this section, patent authorities are given a second, more direct instrument for controlling the breadth of a patent. Two types of "scope" instruments considered are ones that change either (i) the cost of imitation or (ii) the flow of profits to the imitators.

Patent instruments for increasing the costs of imitation might be a filing fee for patent applications, lump-sum damages that must be paid if an imitation is found to infringe, or court decisions that raise the cost of imitation by making infringement easier to prove. To affect the flow of profits from imitating, an annual fee to develop a noninfringing patent could be imposed, or as in Klemperer's (1990) analysis, the "distance" between an imitation and the original innovation could be specified. For example, suppose technically feasible imitations could be characterized by a parameter σ, representing their substitutability (in demand) with the original innovation, and that an imitator's profit increased in σ. Then, patent policy could be defined by a σ above which imitations would infringe. That is, only "imperfect" imitations would be allowed.

We turn now to the problem of optimal patent design with multiple instruments.

□ **Imitation costs.** Proposition 3 characterizes optimal patent policy when patent authorities can choose both patent length and imitation costs.

Proposition 3. When both patent length and imitation costs are patent instruments and $\epsilon^n_X \leq 1$, then the optimal patent is broad (K is set sufficiently high to discourage imitation) with patent length adjusted to achieve the desired reward for the innovator.

The result in Proposition 3 is easily understood from Figure 4. Recall from Proposition 1 that for any K, optimal patent life is sufficiently short to discourage all imitation; that is, $T^* \leq T_I(K)$. This implies that if optimal patent design induces disclosure, then T^* must lie along AB; that is, optimal patent length will maximize social surplus in the absence of imitation. But recall that this is precisely the definition of Ω, when $\Omega \geq \tau$.[20] So $T^* = \Omega$ and imitation is optimally discouraged by setting imitation costs at any $K \geq K^*$.

Under optimal patent design, K is a direct instrument for eliminating the threat of imitation; T is used to achieve the correct incentives for research. In comparison, note that when patent life is the single instrument (as in Section 3), it must balance both innovation and imitation objectives, resulting in a lower patent life (possibly equal to zero) for sufficiently low imitation costs.

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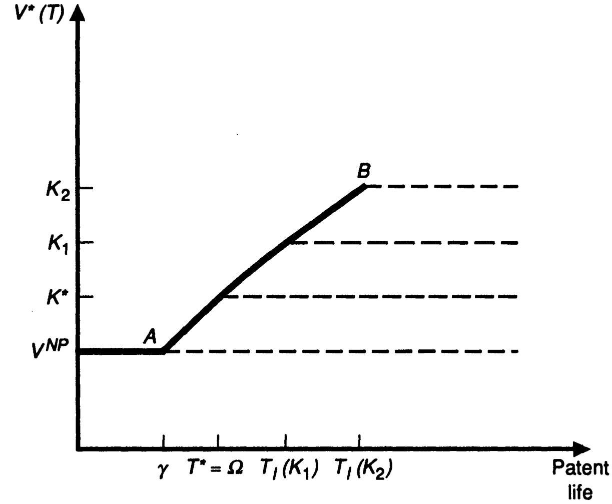
[20] If $\Omega < \tau$, then the innovator would want to keep the innovation secret at Ω. In this case, optimal patent policy would be to set $T^* = 0$, as in Proposition 2.

FIGURE 4

OPTIMAL PATENT DESIGN: LENGTH *(T*)* AND SCOPE *(K*)*



□ **Imperfect imitation.** Next consider the case in which patent policy can reduce the flow of profits from imitating relative to that received by the innovator. I illustrate this case with the simplest form of the profit difference: imitations incur a fixed production cost. In particular, suppose technologically feasible imitations are characterized by fixed costs of production F; that is, the flow of profits from an imitation are $\pi(m) - F$, where $F \geq 0$. Patent authorities can affect scope by specifying an F below which imitations will be found to infringe.[21]

This instrument changes the dynamic profile of the patentee's return. In contrast to the return in (5) for $F = 0$, the payoffs to the innovator increase in all patent lives that encourage disclosure. To see this, consider the zero-profit entry condition:

$$\beta(T)(\pi(m) - F) = K. \tag{9}$$

Note that the patent life for which imitation becomes profitable, $T_I(K, F)$, is a function of both F and K. Then, the return from R&D is

$$V^*(T) = \begin{cases} V^{NP} & \text{for} \quad T < \tau \\ \beta(T)\pi(0) & \text{for} \quad \tau \leq T < T_I(K, F) \\ K + \beta(T)F & \text{for} \quad T \geq T_I(K, F). \end{cases} \tag{10}$$

Given the incentives for imitation and innovation as a function of T and F in (9) and (10), respectively, optimal patent design can be determined. Note that any return to the innovator greater than K can be generated with an infinite number of patent policy combinations (F, T). Any reward less than K can be achieved with the single instrument of patent life. As in the previous literature, I solve for the optimal design of the patent (F, T), holding constant the innovator's reward at some value (greater than K). The solution is described in Proposition 4.

[21] Alternatively, inventions may differ by the marginal costs of production. For example, if the marginal costs of producing with the original innovation is c, then only imitations with a marginal cost no less than c_I, where $c_I > c$, would be allowed.

Proposition 4. When both patent length and scope (F) are patent instruments and $\epsilon_X^n \leq 1$, then the optimal patent is broad (F is set sufficiently high to discourage imitation) with patent length adjusted to achieve the desired reward for the innovator.

Proof. The proof of Proposition 4 follows along the lines of the proof of Proposition 1. The optimal policy pair (T, F) maximizes social surplus, subject to the patentee's return of V: $\beta(T)\pi(m) = V$. From (9) note that the constraint can be written as $V = \beta(T)F + K$. Let $T(F)$ be the patent life, as defined by the constraint, that is required to achieve the return V when the second patent instrument is set at F. Differentiation of the constraint implies

$$dT/dF = -\beta(T)/(\beta'(T)F). \tag{11}$$

Let $m(F, T(F))$ be the number of imitators, as defined by (9), as a function of F and $T(F)$. Differentiation of (9) with respect to F and substitution of (11) into the expression gives

$$dm/dF = \pi(m)/(\pi'(m)F). \tag{12}$$

Social surplus, as a function of F, is given by

$$S^* - \beta(T(F))(DWL(m(F)) + m(F)F) - m(F)K. \tag{13}$$

Differentiation of (13) with respect to F gives

$$-\beta'(T)(DWL(m) + mF)dT/dF$$
$$- [\beta(T)(DWL'(m) + F) + K]dm/dF - \beta(T)m. \tag{14}$$

Finally, substitution of (11) and (12) into (14) and rearranging terms gives

$$[DWL(m) - (1 - \alpha\epsilon_X^n)\pi(m)^2/\pi'(m)]\beta(T)/F. \tag{15}$$

If the derivative in (15) is positive, then the optimal policy calls for a sufficiently high F to discourage imitation for any patent life. Since $\pi'(m) < 0$, this will be the case if $1 \geq \epsilon_X^n$.

Proposition 4 supports a broad patent that prevents all imitation, with patent life adjusted to generate the desired return from research: increasing F broadens patent protection, allowing the innovator to displace production from inefficient imitators, whose profits are dissipated by the costs of making the imitations. As before, this result contrasts with the optimality of narrow, infinitely long patents found in the previous literature.

5. Conclusions

■ In this article I analyze optimal patent design when costly imitation displaces a patentee's output as the length of patent protection increases. The policy prescription implied by this model differs sharply from that in the literature on optimal patent policy. In particular, optimal patent design under costly imitation is given by (i) a patent life that discourages all imitation (when only patent length can be set) and (ii) a broad patent (no imitation) with patent life adjusted to generate the desired return from research (when both patent life and a scope instrument can be chosen). The model presented is admittedly simple, but it illustrates considerations that must be understood before a successful patent policy can be prescribed.

Several extensions remain. One would be to examine alternative instruments for committing to a shorter patent life; for example, the innovator could license its innovation to discourage imitation,[22] or it could choose technologies that are relatively costly to imitate, as suggested by Horstman, MacDonald, and Slivinski (1985). Second, this model could be extended to examine a sequence of improvements of the original innovation (Scotchmer

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[22] For example, see Gallini (1984) and Gallini and Winter (1985).

and Green, 1990) or a sequence of applications of the original innovation in distinct markets (Matutes, Regibeau, and Rockett, 1991); here we consider imitators that compete contemporaneously with the original innovator in the same market. If a sequence of improvements is possible, then, as shown by Scotchmer and Green (1990), a narrow patent may accelerate innovation by allowing future generations of the innovation to be developed. Finally, the framework developed here could be used to examine optimal patent policy when a single uniform policy must apply to a variety of innovations with different social values. Kotowitz's (1988) analysis of a uniform patent life could be extended to allow for costly imitation.

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