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This paper examines the use of compulsory licensing as a policy to combat the monopoly problem associated with the patent system. It introduces the notion of an optimal patent—one where the patent life and the licensing royalty rate are both determined optimally. Under certain simplifying assumptions it is shown that the optimal patent will have an indefinite life, for both process and product innovations. Some preliminary calculations suggest that the use of compulsory licensing may lead to substantial welfare improvements, even if the patent life is left unchanged at 17 years.

This paper is concerned with the use of compulsory licensing as a way of dealing with the monopoly problem associated with patents.

Although several authors have recently argued that rivalrous competition could lead to excessive amounts of research spending,[1] it is still widely believed that R & D deserves government encouragement[2] and that patents are a useful way of doing this. Now it is well known that patents create monopolies,[3] but there seems to be no effective way of eliminating the associated deadweight losses.[4] Compulsory

This paper is a revised version of a chapter from my Ph.D. dissertation. I wish to thank Zvi Griliches, Kenneth Arrow, Mark Schankerman, and Tom McGuire for helpful discussions and an anonymous referee for helpful comments. All errors remain, as is usual, my responsibility.

[1] See Barzel 1968; Hirshleifer 1971; Kamien and Schwartz 1972; Tandon 1979, chap. 2; and Dasgupta and Stiglitz 1980.

[2] The classical theoretical statement of this proposition is Arrow (1962). It is underscored by the typical empirical finding that social rates of return to research tend to be higher than private rates (see, e.g., Mansfield et al. 1977).

[3] For an excellent survey of the discussion on patents, see Machlup (1958).

[4] Two obvious theoretical solutions are totally impractical. One would be to pay each inventor a lump sum equal in value to the present value of the potential revenue

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licensing of patents could serve to reduce them; opponents, however, have argued that forced licensing would reduce or even eliminate the incentive for research-performing firms.[5]

A major shortcoming of this discussion has been the assumption that compulsory licensing would take place at "reasonable" royalty rates.[6] This paper proposes the notion of royalty rates that *optimally* trade off the negative incentive effects of licensing with the positive consumer price effects. Simultaneously, it seeks to connect this discussion with the recent literature on optimal patent life, due to Nordhaus (1969).[7] What emerges is the notion of an optimal patent, whose life and royalty rate have both been determined optimally. The properties of such an optimal patent are examined; further, it is shown that introduction of such a patent scheme might have substantial welfare benefits.

The next section presents the basic model for process innovation. Section II examines a modified model of product innovation that is richer in analytical results. Section III looks at the welfare implications of compulsory licensing in the new product model. Finally, in Section IV some of the many shortcomings of the analysis are noted and some directions for future research are indicated.

I. Compulsory Licensing of Process Innovations

In order to simplify the discussion and to focus attention on the most essential characteristics of the problem, a highly simplified model of patenting is developed, similar to the one proposed by Nordhaus. Consider a perfectly competitive industry in long-run equilibrium.

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stream, and then to make the invention free for anyone to use. Aside from the difficulty of assessing ex ante the value of an invention, this would place an impossible strain on the treasury. The other solution, noted most recently by McFetridge (1977), would be the use of perfect price discrimination. Once again, this would be impossible to implement.

[5] There has been some special interest in the compulsory licensing of drug patents (see, e.g., Shifrin 1967; Whitney 1968; and Forman 1970).

[6] The only discussion of licensing at other than a "reasonable" rate is by Taylor and Silbertson (1973), who talk of a "correct" royalty rate. They suggest that "in any licensing situation, the economically desirable or 'correct' rate of royalty is such that the licensee contributes to the cost of discovery and development of the licensed product or process at the same rate per unit of output as the licensor" (p. 171). The purpose of such a policy is to try to equate the competitive situation of licensor and licensee. It can be seen, however, that they have still not departed significantly from the notion of the reasonable royalty. They have to impute a "normal" rate of return on R & D costs to determine the licensor's contribution and talk of the undesirability of "abnormal" profits on consumer welfare. No attempt is made to examine the trade-off between incentive effects on innovators and improved welfare effects to the economy.

[7] See also Nordhaus 1972 and Scherer 1972. Another approach to optimal patents has been proposed by Kitti (1973) and Kamien and Schwartz (1974, 1976).

The demand curve faced by the industry is $X = X(P)$ and average cost is constant. Without loss of generality, price and quantity may be normalized to unity in the initial equilibrium.

Innovations are assumed to be cost reducing; they can be patented, but all patents are subject to compulsory licensing. For simplicity, assume that innovations can be very easily imitated, so that it never pays firms not to get patents on their innovations. Each patent has associated with it two characteristics—a patent life, T, the number of years the patent is valid, and a royalty rate, ρ, which specifies the licensing fee per unit of output as a proportion of the cost reduction. Thus, for a cost reduction, B, the innovating firm can charge a royalty of ρB per unit of output. Note that this kind of licensing structure prohibits the first-best solution of price discrimination.

The key criticism of compulsory licensing is of course its negative impact on incentives to innovate. In order to capture this problem, assume that innovating firms can choose the size of B by varying their research outlays, R. Again, for simplicity, assume that this function $B(R)$ is known.[8] Alternatively, $B(R)$ could be thought to be the expected cost reduction and firms to be expected profit maximizers.

The basic points of the model are illustrated in figure 1. The initial equilibrium is at E_0. The cost reduction is AF and the per unit royalty CF. During the life of the patent, price is OC and quantity sold X_1. The innovator firm receives CE_1HF per year in royalties. After the expiration of the patent, price falls to OF and quantity sold rises to X_2. During the life of the patent, there is a deadweight loss of E_1HE_2. In a sense the social problem is to minimize the discounted value of the deadweight loss. However, the size of the cost reduction itself is a function of the parameters ρ and T. Thus the patent authority must choose these parameters taking into account their effect on incentives to undertake research spending.

The incentive effect can be studied by looking at how profit-maximizing innovators would choose their level of research spending. They would choose R in order to maximize the net present value of the profit stream generated by inventions, given by

$$V = \frac{\Psi}{r} \rho B X_1 - R, \tag{1}$$

where r is the constant rate of discount and

$$\Psi = 1 - e^{-rT}. \tag{2}$$

[8] This might appear an extreme assumption, since R & D is by its very nature uncertain. However, it is known that the bulk of spending on a typical R & D project occurs during the development stage, which may not be very uncertain. See also Kitch (1977) for a possible theoretical justification.

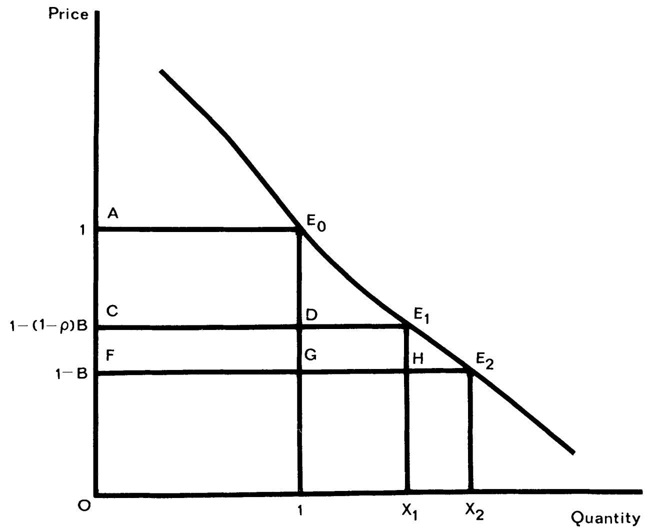

FIG. 1.—Compulsory licensing of process innovations

The term Ψ/r simply serves as the discounting factor for a stream of returns that lasts T years and is discounted continuously at the rate r.

The patent authority's problem is to maximize the present value of the stream of producers' and consumers' surplus. If A_1 represents the social benefits generated during the life of the patent (represented by area AE_0E_1HF in fig. 1) and A_2 the deadweight loss that becomes available only after the patent expires (area E_1HE_2 in fig. 1), the social problem is to maximize

$$W = \frac{1}{r}A_1 + \frac{(1 - \Psi)}{r}A_2 - R \tag{3}$$

subject to the firm's behavior.

In order to simplify the discussion of the results of the model, a further specialization is made, namely, of a linear demand schedule.[9] Thus demand may be represented as of the form $X(P) = a - \eta P$, where η is the elasticity of demand at the initial equilibrium. Implicitly, the ensuing discussion centers on "small" innovations, for which this assumption may be regarded as reasonable.

In this case, the firm's problem is to maximize

$$V = \frac{\Psi}{r}\rho B[1 + \eta B(1 - \rho)] - R; \tag{4}$$

[9] This is not necessary, but it sharpens the results and simplifies the discussion considerably. For the more general case see my thesis (Tandon 1979, chap. 3).

R will then be chosen according to the first-order condition

$$\frac{\Psi}{r}\rho B'[1 + 2\eta B(1 - \rho)] = 1. \tag{5}$$

The second-order condition to ensure that (5) yields a maximum reduces to

$$\rho B'' + 2\eta(\rho - \rho^2)(B')^2(1 - \kappa) < 0, \tag{6}$$

where

$$\kappa = -\frac{BB''}{(B')^2} \tag{7}$$

is the elasticity of B' with respect to B; thus κ is a measure of the curvature of the invention possibility function $B(R)$. Now note that if $\kappa > 1$, (6) clearly holds. This is so reasonable that it is assumed to hold.

For example, if the function B were

$$B(R) = \beta R^{\alpha}, \tag{8}$$

then it may be shown that $\kappa = (1 - \alpha)/\alpha$. In this case, the condition $\kappa > 1$ is the same as $\alpha < \frac{1}{2}$. Empirical evidence indicates that 0.10 is a reasonable value for α.[10] Thus the assumption $\alpha < 0.5$ seems highly plausible, and the solution to equation (5) may be taken as the firm's optimum.

The social problem is then to maximize (3) subject to (5) as a constraint. Solving this leads to:

PROPOSITION 1: For process innovations subject to compulsory licensing, the optimal patent has an infinite life.

Proof.—Consider the problem in two steps. For any given patent life, find the optimal royalty ρ as a function of T, and then search for the optimal T. The optimal T will be found to be infinite.

The problem is to maximize (3) subject to the constraint (5). Write the Lagrangian for this problem as

$$L = \frac{1}{r}A_1 + \frac{(1 - \Psi)}{r}A_2 - R - \lambda\left(1 - \frac{\Psi}{r}B'M\right), \tag{9}$$

where

$$M = \rho[1 + 2\eta B(1 - \rho)]. \tag{10}$$

[10] Estimates of α have ranged around 0.10. The highest estimate was 0.12 by Mansfield (1965). Other estimates have been made by Minasian (1962, 1969), Griliches (1964), and Evenson (1968). See Griliches (1973) for a discussion of some of the problems associated with these estimates.

Note that M is simply the marginal revenue product to the firm of additional cost reductions; that is, it describes the rate at which the area CE_1HF in figure 1 changes in response to changes in the size of B.

Setting $\partial L/\partial\rho = 0$, and using the fact that $\partial A_1/\partial\rho = -\partial A_2/\partial\rho$, we have

$$\lambda = \frac{\partial A_2/\partial\rho}{B'(\partial M/\partial\rho)}. \tag{11}$$

Since λ must be positive, and since B' and $\partial A_2/\partial\rho$ are both positive, it is clear that $\partial M/\partial\rho$ must be positive. This is intuitively clear also, since it simply says that the higher the proportion of any cost reduction the firm can appropriate, the greater will be the marginal revenue product of such cost reductions.

Using (11) we may show that

$$\frac{\partial L}{\partial\Psi} = \frac{\partial A_2/\partial\rho}{r}\left[\frac{M}{\partial M/\partial\rho} - \frac{A_2}{\partial A_2/\partial\rho}\right]. \tag{12}$$

Since $\partial A_2/\partial\rho$ is positive for negatively sloped demand, the sign of $\partial L/\partial\Psi$ is the same as the sign of the expression in square brackets. Further, by the envelope theorem, $dW/d\Psi = \partial L/\partial\Psi$. Also, it is obvious that T, the patent life, increases monotonically with Ψ. Thus if $\partial L/\partial\Psi$ can be shown to be positive, the optimal patent life will be infinite.

But consider the expression in square brackets. We have

$$\frac{M}{\partial M/\partial\rho} = \rho x, \tag{13}$$

where

$$x = \frac{1 + 2\eta B(1 - \rho)}{1 + 2\eta B(1 - 2\rho)}. \tag{14}$$

Since the denominator in (14), which is $\partial M/\partial\rho$, is positive, it is clear that $x > 1$. But $A_2/(\partial A_2/\partial\rho) = \frac{1}{2}\rho$. Therefore the expression in square brackets is positive, and therefore so must be $\partial L/\partial\Psi$. Hence the optimal patent life is infinite.

This completes the proof.

It is quite easy to see why this proposition holds. Essentially, for any given cost reduction, the social problem is to minimize the present value of the deadweight loss associated with the patent monopoly. This minimand varies in direct proportion with the parameter Ψ but is proportionate to the *square* of the royalty rate. Note that since the feasible range of both Ψ and ρ is zero to one, this creates a desirability from the social point of view to allow Ψ to rise as much as possible. On the other hand, the question is, What is the trade-off between ρ and Ψ

such that innovating firms have the incentive to generate the given cost reduction? Information on this trade-off is gleaned from equation (5), which shows that if Ψ is raised ρ need be lowered by a smaller proportion, while (5) is left intact. Therefore the rate at which ρ can be traded for Ψ from the social point of view is always greater than the trade-off required by firms in order to elicit the given level of research spending. Consequently Ψ is raised as much as possible, and the patent life is infinite.

It is of some interest to examine possible ranges for the value of the optimal royalty rate ρ^*. To obtain this, the original Lagrangian equation (9) must be differentiated with respect to R. Setting $\partial L/\partial R = 0$, and combining the result with (11), we obtain

$$\begin{aligned}\rho^3(6\eta^2B^2 - 2\eta^2B^2\kappa) + \rho^2[\eta B(\kappa - 5) + \eta^2B^2(2\kappa - 12)] \\ + \rho(1 + 8\eta B + 8\eta^2B^2) - (1 + 3\eta B + 2\eta^2B^2) = 0.\end{aligned} \tag{15}$$

Equation (15) is what Nordhaus would call the policymaker's equilibrium. Since it is a cubic in ρ, it is important to state the following:

LEMMA: The policymaker's equilibrium (15) has a unique solution for ρ as a function of η, B, and κ in the range $\rho \in (0, 1)$.

Proof.—Is omitted here. The interested reader could consult Tandon (1979).

The actual value of ρ^* is determined, analogous to Nordhaus's (1969) model, by the intersection of the inventor's equilibrium (5) and the policymaker's equilibrium (15). The expressions (5) and (15) are sufficiently complicated so that an easy analytical solution for ρ^* is not possible. However, it is possible to compute values of ρ that would satisfy (15) for different values of η and B. This is done in table 1, assuming a value of $\kappa = 9$, corresponding to the case $\alpha = 0.10$ if B took the functional form (8). It may be seen that the values of ρ^* may vary quite considerably for different values of η and B.

Before we leave this model, however, it is interesting to note some comparative-static results on the optimal royalty rate. Table 1 illustrates these corollaries: (i) The higher the demand elasticity η, the lower is ρ^*; (ii) the larger B, the lower is ρ^*. These are analogous to Nordhaus's findings that the patent life in his model would be shorter for higher η and for larger B. Scherer (1970, p. 388; 1972) has pointed out reasons why one might expect a shorter optimal patent life for larger cost reductions. There are basically two factors: (*a*) Large cost reductions quickly pay for themselves, and (*b*) the monopoly deadweight loss associated with a large cost reduction is large; therefore optimal social policy should call for a quick termination of these deadweight losses. The same arguments now apply to the choice of an optimal royalty rate. Further, they may be extended to

TABLE 1

ROYALTY RATES FOR DIFFERENT VALUES OF η AND B THAT SATISFY THE POLICYMAKER'S EQUILIBRIUM (15)

	VALUES OF B								
η	.001	.010	.020	.050	.100	.200	.500	.750	.900
.25	.998	.978	.958	.906	.837	.739	.584	.517	.487
.50	.996	.958	.922	.837	.739	.623	.471	.414	.392
.75	.994	.940	.891	.783	.672	.553	.414	.368	.349
1.00	.991	.922	.862	.739	.623	.506	.380	.347	.324
1.50	.987	.891	.814	.672	.553	.444	.347	.308	.297
2.00	.983	.862	.773	.623	.506	.406	.316	.291	.282
4.00	.966	.773	.661	.506	.406	.334	.277	.262	.257
10.00	.922	.623	.506	.380	.316	.277	.249	.243	.240

NOTE.—Cells to the right of the heavy line have $\eta B > 1$, which implies that they are "drastic" inventions. It may be appropriate to note at this point an error in Nordhaus's table 5.1 (1969, p. 81). Nordhaus marks the nine cells in the *upper*-right-hand corner as inapplicable because they represent drastic inventions. However, it is clear that the 11 cells noted here are the ones for which the caveat is in order—the ones in the *lower*-right-hand corner.

the case of the demand elasticity as well. In particular, a high η will imply a large deadweight loss. The optimal policy will then call for a low ρ^* so as to reduce the size of this deadweight loss.

A detailed examination of the extent of welfare gain from compulsory licensing is not very easy to do and is saved for the modified model of the next section.

II. A Simple New-Product Model

This section considers a very simple new-product model and examines optimal patents in this context.[11] The model is very highly simplified. Accordingly, no claim is made as to its realism. However, it has two virtues that make it seem worthwhile. One is that it is analytically more manipulable than the model of the previous section, allowing thereby a more detailed look at the comparative welfare implications of different policies. The second is that it seems to contain the beginning of a fruitful approach to the very difficult problem of new-product innovation.

Suppose the firm is working on a new product with a well-defined demand curve; we will ignore problems relating to how the firm chooses between alternative new products. Now suppose the inverse demand curve for this product may be approximated by a straight line: $P = a - bX$. Divide the research done by the firm into two

[11] A somewhat similar model was proposed by McGee (1966), although he was not concerned with optimal patent policy at all, only optimal pricing strategies for the patent owner.

components: an amount C_0 required to "reduce" the cost of production to the choke point, a, and an additional amount R that will reduce cost even further, according to a concave invention possibility function $B(R)$.[12] The average cost of production will then be $(a - B)$. Suppose the firm can obtain a patent for its new product, which thereby makes it a monopolist in this specific product. Assume that the producer does not face the direct threat of entry (once he has the patent) or the threat of antitrust action. Then if the firm were a static profit maximizer, it would set price where $X = B/2b$ and $P = a - (B/2)$.

To examine the compulsory licensing case, suppose the firm must license its patents at a royalty rate which is a fixed percentage of B. That is, suppose the firm must license at a unit royalty rate of ρB. Note that, left to itself, the firm would set $\rho = ½$; thus the Patent Office is concerned only with situations where $\rho \leqq ½$. Note also that once again it is assumed that the firm must license at a uniform rate; no price discrimination is permitted. Once the firm is forced to license its patents at a specified rate, the market will become competitive as long as there is costless entry; and thus the price will be $[a - (1 - \rho)B]$. At this price, demand will be $[(1 - \rho)B]/b$. Then the net present value to the firm of the whole research project will be $V = \int_0^T \rho B[(1 - \rho)(B/b)]e^{-rt}dt - R - C_0$, where T is the life of the patent and r is the firm's discount rate. In principle, the firm may scan V's for a whole range of possible new products and pick the one (or ones) for which the net present value is highest. We will ignore this choice for the present, concentrating instead on the choice of R for this particular product. Assume that $V > 0$ and that therefore the research project is being undertaken.

Figure 2 illustrates the salient features of this model. The key is that once again the social problem is to minimize the present value of the deadweight loss HGJ for any given cost reduction, while the innovating firm is once again choosing research spending R to maximize the present value of $KHGC$. As in the previous model, it turns out that the optimal patent has infinite life, essentially for the same reasons. We therefore state:

PROPOSITION 2: For new-product innovations subject to compulsory licensing, the optimal patent life is infinite.

Proof.—Essentially similar to that for proposition 1 and omitted here.

Once again the intuition behind it is pretty clear. The present value of the social deadweight loss is given by the expression $\Psi\rho^2B^2/2rb$. Thus the minimand of the social problem varies proportionately to Ψ but also proportionately to the square of ρ. On the other hand, the

[12] Admittedly, this division may be quite difficult to achieve in practice.

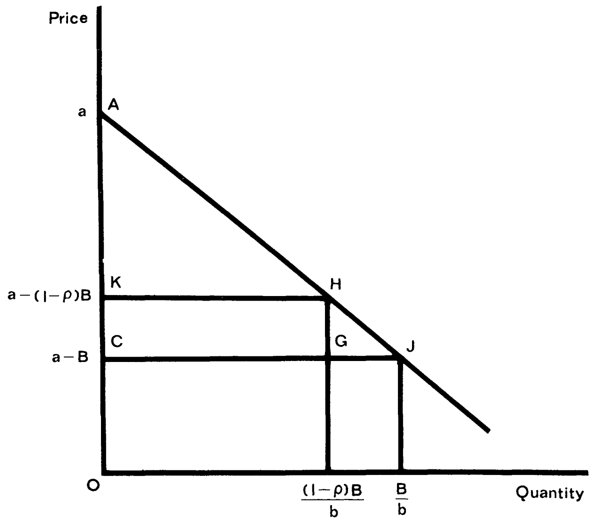

FIG. 2.—Compulsory licensing of a product innovation

firm's choice of R is guided by the equation $[2\Psi\rho(1 - \rho)BB']/rb = 1$. Consequently R can be held to any desired level by raising Ψ by a greater proportion than ρ. Quite unambiguously, then, the optimal policy calls for raising the patent life as much as possible, thereby allowing the royalty rate to be kept as low as possible.

This explanation raises a provocative question: If social welfare is relatively more sensitive to the royalty rate rather than to the patent life, is it possible that the welfare implications of compulsory licensing are more substantial than those of setting the patent life optimally? It turns out that is indeed the case; in order to demonstrate it, however, the model must be laid out more fully and the several cases analyzed. In the process, interesting results on the range of optimal values for ρ are generated.

The social problem in this model is to maximize

$$W = \frac{B^2}{2rb} \cdot (1 - \rho^2\Psi) - R - C_0 \tag{16}$$

subject to

$$\frac{2\Psi\rho(1 - \rho)BB'}{rb} = 1. \tag{17}$$

Solving this problem yields $\Psi^* = 1$ (infinite patent life), and ρ^* is given by the solution to

$$-(\kappa - 3)\rho^3 + (\kappa - 6)\rho^2 + 4\rho - 1 = 0, \tag{18}$$

where κ is defined as in equation (7). It can be shown that (18) possesses a unique solution for ρ in the range (0, ½).[13]

An interesting point to note is that the value of ρ^* is independent of the rate of discount. The effect of our optimal policy is to keep the price above the average cost of production in perpetuity, thereby giving up forever a triangle of consumer's surplus represented by the area HGJ in figure 2. It could be argued that if the discount rate were sufficiently low, there might be a case for a finite patent life since society would not want to lose this triangle of welfare forever. The explanation is that reducing the patent life would also reduce the amount of research done. If the royalty rate ρ were raised enough to keep R and B unchanged, there would be a higher price and a lower quantity demanded, with consequently lower welfare gain, during the life of the patent.

It is possible to examine some approximate values of the optimal royalty rate, ρ^*, for representative values of κ. Column 2 in table 2 lists the optimal royalty rates for different κ values, assuming that patent life is infinite. Note that the optimal royalty rate falls as κ rises. This is intuitively plausible. It is perhaps best illustrated by consideration of the Cobb-Douglas form for the invention possibility function (8). Recall that κ rises as α falls. Thus as α rises, ρ^* rises. That is, for research that is more productive, the optimal royalty rate is higher.[14] This procedure will encourage productive research.

A related question is: What is the optimal royalty rate for a finite patent? To answer this question it is necessary to repeat the maximization exercise for a given value of Ψ. When this is done, the optimal royalty rate is the solution to the equation

$$-\Psi(\kappa - 3)\rho^3 + \Psi(\kappa - 6)\rho^2 + (2 + 2\Psi)\rho - 1 = 0. \qquad (19)$$

Note that, when $\Psi = 1$, (19) reduces to our previous equation (18).

For illustrative purposes, consider the case where $T = 17$ years. Then, at a discount rate of 10 percent, $\Psi = 0.82$; and if $r = 0.20$, $\Psi = 0.97$. The optimal royalty rates were computed for $\Psi = 0.82$ and are shown in column 3 of table 2. The effect of a finite patent life, as would be expected, is to raise the optimal royalty rate. Somewhat surprisingly, however, the increases in the royalty rate are not very substantial even at a 10 percent discount rate; they would be quite small if the discount rate were 20 percent. Thus even if lengthening

[13] For proof, see Tandon (1979).

[14] The use of the term "productive" here is not exactly the same as Nordhaus's "ease of invention." His model did not allow a detailed examination of the effect of α (or κ) on the optimal policy. Thus his "easier invention" could in principle be generated by higher α or higher β in eq. (8). However, the implications of "more productive" research opportunities are substantially the same.

TABLE 2

OPTIMAL ROYALTY RATES

κ (1)	ρ^* With Ψ = 1.0 (2)	ρ^* With Ψ = .82 (3)
4	.302	.333
6	.265	.292
9	.229	.254
12	.205	.228
15	.190	.210
18	.177	.196

the patent life were politically infeasible or undesirable from some other point of view, compulsory licensing at royalty rates considerably below the implicit rate of 0.5 exercised by monopoly patent holders might still be useful.

Finally, for purposes of welfare comparisons, let us define a Nordhaus optimum as one where the patent life alone is set optimally. This is the problem of (16) and (17) with the value of ρ set equal to ½, since that will be the "royalty" charged by patent holders not subject to compulsory licensing. Solving this problem leads to optimal patent lives, depending on the elasticity of the invention possibilities function $B(R)$. Table 3 shows the value of T^* for a range of values for κ. Column 2 lists, as an illustrative device, the values of α in (8) corresponding to the respective κ values. The table shows that, for a range of reasonable values of κ and r, the optimal patent life is considerably shorter than the existing period of 17 years. Once again, the optimal life is longest for situations where α is highest, just as in table 2 high α

TABLE 3

OPTIMAL PATENT LIFE, T^*, WITH NO COMPULSORY LICENSING FOR THE NEW PRODUCT MODEL

κ (1)	α (2)	T^* With r = 10% (3)	T^* With r = 20% (4)
4	.200	21.97	10.99
6	.143	12.99	6.50
9	.100	8.47	4.24
12	.077	6.36	3.18
15	.063	5.11	2.55
18	.053	4.27	2.14

values were accompanied by high optimal royalty rates. The reason again is that more productive research opportunities (characterized by higher values of α) should receive greater encouragement from the patent authority. Note, however, that the values of T^* generated by this model are likely to be underestimates of the true optima because of the assumption of complete appropriability. In fact, firms would find it difficult to appropriate revenues throughout the industry, particularly toward the end of the patent life.

III. Welfare Implications of Compulsory Licensing

It is now possible to examine explicitly the dimensions of the possible welfare effects of compulsory patent licensing. Recall that Nordhaus found only a small welfare advantage from setting patent life optimally. In the present model, however, the greater sensitivity of social welfare to appropriate pricing decisions results in significant welfare differences. Four cases will be analyzed here: (i) where $T = 17$ years and $\rho = \frac{1}{2}$ (no compulsory licensing), (ii) where T is optimal and $\rho = \frac{1}{2}$ (the Nordhaus optimum), (iii) where $T = 17$ years and ρ is optimal, and (iv) where T is infinite and ρ is optimal (the full optimum). In all cases, assume that $C_0 = 0$, or rather that the welfare measure used is a gross measure that does not account for C_0 as a cost. This does not diminish the usefulness of the comparative exercise. Further, assume, as does Nordhaus, that the function B takes on the special form (8).

Case i.—Since there is no compulsory licensing in this case, we know that net welfare gain is given by (16) with $\rho = \frac{1}{2}$ and C_0 excluded:

$$W = \frac{B^2}{2rb}\left(1 - \frac{\Psi}{4}\right) - R.$$

Further, the firm's maximizing condition is (17) with $\rho = \frac{1}{2}$: $\Psi BB' = 2rb$. Then $W_1 = R[(1/\alpha\Psi) - (1/4\alpha) - 1]$. Using (8) and knowing that $\rho = \frac{1}{2}$, we may substitute for R to get

$$W_1 = \left(\frac{\beta^2\alpha\Psi}{2rb}\right)^{1/(1-2\alpha)}\left(\frac{1}{\alpha\Psi} - \frac{1}{4\alpha} - 1\right).$$

Let

$$A = \left(\frac{\beta^2\alpha}{2rb}\right)^{1/(1-2\alpha)}. \tag{20}$$

Then

$$W_1 = A \cdot \Psi^{1/(1-2\alpha)}\left(\frac{1}{\alpha\Psi} - \frac{1}{4\alpha} - 1\right). \tag{21}$$

We know that when $T = 17$ and $r = 0.10$, $\Psi = 0.82$. Thus from (21) we can calculate W_1 for different values of α, as a multiple of an unspecified A.

Case ii.—The welfare level in this case may be shown to be the same as (21), with the exception that now there will be a different value of Ψ for each α. These correspond to the optimal patent-life figures in table 3.

Case iii.—If the patent life is left at 17 years, the optimal royalty rate is the solution to (19) for $\Psi = 0.82$. These royalty rates were presented in column 3 of table 2. In the presence of compulsory licensing, however, the welfare index is no longer given by (21). Welfare will be given by (16): $W = (B^2/2rb)(1 - \rho^2\Psi) - R$, where B is chosen according to (17). Then, recalling (20), we may rewrite the welfare gain as

$$W_3 = A[4\Psi(\rho - \rho^2)]^{1/(1-2\alpha)}\left[\frac{1 - \rho^2\Psi}{4\alpha\Psi(\rho - \rho^2)} - 1\right]. \tag{22}$$

Knowing $\Psi = 0.82$ and the ρ^* corresponding to each value of β, we may easily compute values of W_3.

Case iv.—The overall optimum is attained when the patent life is infinite ($\Psi = 1$) and ρ is set as the solution to (18). The optimal royalty rates were presented in column 2 of table 2. Using these figures and (22) we may compute values of W_4.

The results of the welfare computations are presented in table 4. The welfare levels associated with cases i–iv are compared for different values of the research productivity parameter κ (or α). The parameter A was eliminated by taking index numbers. Since A contains terms in α, this procedure does not allow us to compare welfare levels for different levels of α.[15] Accordingly the index is set to 100 in case i for each value of α.

Table 4 suggests that merely changing the patent life to some optimal length may not greatly increase welfare. This is in accordance with Nordhaus's finding. However, compulsory licensing, even with patent life unchanged at 17 years, may result in fairly substantial welfare gains (here of the order of 11–19 percent). An optimal readjustment of the patent life would help raise welfare further, but again the increase may not be appreciable.

Note that the welfare indices have not been computed net of the "break-in cost," C_0. If this were allowed for, the percentage gains in welfare would be substantially higher as welfare increased. For example, consider the case where $\kappa = 9$. The W_1 index is 100. Suppose of

[15] We would of course expect welfare to rise as α rises. I am indebted to an anonymous referee for pointing out an error in my earlier presentation of these comparisons.

TABLE 4

LEVELS OF WELFARE UNDER ALTERNATIVE POLICIES

κ	α	CASE i (T = 17, ρ = ½)	CASE ii (T = T*, ρ = ½)	CASE iii (T = 17, ρ = ρ*)	CASE iv (T = T*, ρ = ρ*)
4	.200	100.00	100.34	111.81	119.50
6	.143	100.00	100.43	113.91	118.30
9	.100	100.00	102.51	115.81	118.49
12	.077	100.00	104.50	117.02	118.96
15	.063	100.00	106.11	117.87	119.41
18	.053	100.00	107.53	118.56	119.83

this, C_0 = 50. Then net W_1 = 50. The corresponding W_2 would be 52.51 (a 5 percent increase), W_3 would be 65.81 (a 31.6 percent rise), and W_4 would be 68.49 (up 37 percent). It is clear from this example how a substantial welfare gain occurs in case iii, magnified when C_0 is netted out of the welfare index.

It should be pointed out as a final note here that the main reason for the substantial welfare gain effect is the reduction in deadweight losses associated with the patent monopoly. The use of consumer's surplus to measure such gains may in fact be problematic, as pointed out recently by Hausman (1981).

IV. Conclusion

Traditional discussions of compulsory licensing have assumed that licensing would occur at reasonable royalty rates. Scherer believes that, at reasonable royalties, "technical progress would not grind to a halt if a uniform policy of compulsory licensing . . . were introduced" (1977, p. 85). The models here suggest that compulsory licensing may, at least in theory, lead to increased welfare. Further, it was suggested that although the optimal life is theoretically infinite this step may not be crucial. Of course, the models here are highly stylized and, admittedly, quite impractical. Further work is needed to suggest practical approaches to realizing the potential welfare gains which have been discussed.

The theoretical conclusions must be approached with considerable caution, however. For example, most of the analysis was based on linear demand. Although some results hold for more general specifications (see Tandon 1979), it is not possible to infer that the welfare comparisons will be true in general. The assumption of perfect appropriability may have created considerable bias. Problems relating to uncertainty—both technological and economic—have been ignored. No allowance has been made for the possibility that firms introducing new or modified products have a wide range of choice; the shifting of policy parameters may well cause them to alter their choice of product. The list could undoubtedly go on.

The approach, however, seems promising enough to propose some possible extensions. Both models assume that firms are static profit maximizers. Allowance should be made for alternative pricing strategies, particularly if explicit account were taken of rival firms that also perform research. The effect of altering the patent life might be quite different in such cases. Another possible extension would allow firms to choose between different new products.

Two other points deserve notice. Firms spend large sums of money on efforts to "invent around" the patents of their competitors. Under generalized compulsory licensing, these expenditures would be unnecessary, which might increase the welfare benefits. On the other hand, compulsory licensing is likely to reduce firms' propensity to patent. Firms might try to keep their inventions secret instead. This would defeat one of the principal aims of the patent system: disclosure.

Finally, there is the problem of estimating B. It should be possible to develop incentive structures that would elicit the required information from the innovating firms themselves, who presumably would be the best ones to know. Devising such incentive structures would be another task for future research.

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