REWARDS VERSUS INTELLECTUAL PROPERTY RIGHTS*

STEVEN SHAVELL
Harvard Law School
and National Bureau
of Economic Research

and

TANGUY VAN YPERSELE
University of Namur and
Catholic University
of Louvain

Abstract

This paper compares reward systems to intellectual property rights (patents and copyrights). Under a reward system, innovators are paid for innovations directly by the government (possibly on the basis of sales), and innovations pass immediately into the public domain. Thus, reward systems engender incentives to innovate without creating the monopoly power of intellectual property rights. But a principal difficulty with rewards is the information required for their determination. We conclude in our model that intellectual property rights do not possess a fundamental social advantage over reward systems and that an optional reward system—under which innovators choose between rewards and intellectual property rights—is superior to intellectual property rights.

I. Introduction

Two basic means of stimulating innovative activity are compared in this paper. One is a system of rewards paid by the government to innovators. According to this system, innovations would pass immediately into the public domain, becoming freely available to all. The other approach is the familiar system of intellectual property rights that we employ, notably, patent and copyright protection, under which the government confers to innovators exclusive rights to market the goods and services that embody their intellectual works.

Our main conclusion is that the intellectual property rights system does not enjoy any fundamental advantage over the reward system. Indeed, an optional reward system—under which an innovator can choose between a

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reward and intellectual property rights—is superior to the intellectual property rights system in the model we examine. These findings derive from the primary virtues of reward systems: that incentives to innovate are provided without granting innovators monopoly power over price and that the magnitude of research incentives may be selected by the government. A principal difficulty with reward systems, however, concerns the government's need for information to calculate rewards (although the government might be able to base rewards on sales and other ex post data).

To motivate our analysis, we first mention a significant historical episode about the patent system and rewards. Although a fairly well articulated patent system had emerged as early as the 1400s in Venice and had spread through much of Europe and the New World by the end of the eighteenth century, the system came under strong attack in the next century, especially during the period 1850–75.[1] Criticism of the patent system reflected dislike of monopoly power, both because it harms consumers who have to pay high prices and because it can hinder improvements and subsequent innovations if patent holders disallow that.[2] Many economists disapproved of the patent system, and in some countries, such as Germany, the economics profession was virtually unanimous in its opposition to patent.[3]

Reward systems were widely discussed as an alternative method of spurring innovation (and they had been used to a not inconsiderable extent).[4] For

[1] On the history of patent, see H. I. Dutton, The Patent System and Inventive Activity during the Industrial Revolution, 1750–1852 (1984); Fritz Machlup, An Economic Review of the Patent System (1958); Christine MacLeod, Inventing the Industrial Revolution (1988); and, especially, Frank D. Prager, A History of Intellectual Property from 1545 to 1787, 26 J. Patent Office Soc'y 711 (1944). For an account of the nineteenth-century European debate about patent, see Fritz Machlup & Edith Penrose, The Patent Controversy in the Nineteenth Century, 10 J. Econ. History 1 (1950); and see also Dutton, *supra*, ch. 1 (focusing on Britain in the nineteenth century); and MacLeod, *supra*, ch. 10 (focusing on Britain in the eighteenth century). For materials relating to the patent debate, see R. A. Macfie, Recent Discussions on the Abolition of Patents for Inventions in the United Kingdom, France, Germany, and the Netherlands. Evidence, Speeches and Papers in Its Favour (1869); R. A. Macfie, The Patent Question in 1875: The Lord Chancellor's Bill, and the Exigencies of Foreign Competition (1875); and R. A. Macfie, Copyright and Patents for Inventions, Vol. 2, Patents (1883).

[2] Another criticism was that innovators did not actually receive much of the profits from patents because businesses to which they sold their rights made the lion's share; thus, it was argued, patents did not really provide a strong motive to innovate. A quite different criticism was that patents were not needed to induce innovation: on one hand, innovators could often earn enough to induce innovations merely by being first to market; on the other, innovators were frequently motivated by fame and honor, so financial incentives were not necessary to spur their efforts. On the criticisms made of patent, see Macfie, Recent Discussions, *supra* note 1; Macfie, Copyright and Patents for Inventions, *supra* note 1; and Machlup & Penrose, *supra* note 1, at 1–29.

[3] See Macfie, Copyright and Patents for Inventions, *supra* note 1, at 141; and Machlup & Penrose, *supra* note 1, at 4.

[4] See MacLeod, *supra* note 1, at 191–96, who notes that at least eight acts authorizing rewards for specific inventions were passed by Parliament between 1750 and 1825, that substantial sums were granted by Parliament to specific inventors (such as £30,000 to Edward Jenner for his smallpox vaccine), and that many organizations (especially industry groups) instituted reward schemes.

example, Robert Macfie, a member of Parliament in England and an influential champion of rewards, set out a proposal for a government-financed reward system to replace patent; the London *Economist* pressed for adoption of a reward system; and economists examined rewards in professional journals, books, pamphlets, and conferences.[5] Opinion was, however, divided on the virtues of rewards (criticism of patents did not imply endorsement of rewards). The chief argument against rewards concerned difficulties in their administration; it was typically expressed by John Stuart Mill, who maintained that patent is preferable "because it [patent] leaves nothing to anyone's discretion; because the reward conferred by it depends upon the invention's being found useful, and the greater the usefulness, the greater the reward."[6]

As a consequence of the criticism of patent and also of the possible utility of rewards as an alternative, many countries in Europe prepared to reform or abolish patent, and some actually did so: England established a series of royal commissions from the 1850s to the 1870s to investigate the patent system; Chancellor Bismarck recommended abolition of patent in Prussia in 1868; Holland repealed its patent system in 1869; and Switzerland, which had no patent law, rejected legislation to adopt it in 1863. Nevertheless, Europe ultimately embraced patent, but for reasons that may perhaps be regarded as more politically accidental than indicative of a substantive policy judgment favoring that system.[7]

In any case, today, intellectual property rights provide the principal legal financial stimulus for innovation.[8] Rewards are little employed; their payment appears to be limited to inventions in the area of atomic energy and to certain other exceptional cases, although they were provided to inventors in the former Soviet Union.[9]

[5] Macfie's proposal is reproduced in Macfie, Recent Discussions, *supra* note 1, at 84–87. Machlup & Penrose, *supra* note 1, at 19, describes the attention given to rewards by the *Economist* and states that reward proposals "were discussed in the professional journals and conferences almost everywhere."

[6] John Stuart Mill, Principles of Political Economy with Some of Their Applications to Social Philosophy 563 (1872).

[7] See Machlup & Penrose, *supra* note 1, at 3–6, which suggests that the victory of patent was associated with general events (notably, the depression of the 1870s) that led to the weakening of the free-trade movement and thus to the antipatent positions that it supported.

[8] For a description of, and materials on, intellectual property rights protection, see, for example, Paul Goldstein, Copyright, Patent, Trademark and Related State Doctrines: Cases and Materials on the Law of Intellectual Property (rev. 3d ed. 1993).

[9] The United States Atomic Energy Act (1946) established a Patent Compensation Board to grant financial rewards for innovations relating to atomic energy that are of military value (the government does not allow such innovations to be sold on commercial markets). The English patent laws allow for a patent to be infringed upon by the state if it has a "Crown use" for the patented good, in which case compensation, that is, a reward, is to be paid; see 35 Lord Hailsham of St. Marylebone, Halsbury's Laws of England 270–73 (4th ed. reissue 1994). The former Soviet Union made rewards to individual innovators; notably, an innovator might obtain a percentage (on a sliding scale, from 17 percent to .5 percent, but subject to an absolute ceiling) of the cost savings achieved by a process innovation; see 2M J. W. Baxter, John P. Sinnot, & William Joseph Cotreau, World Patent Law and Practice 44–51 (1988).

Modern economic literature reflects our reality and takes the general optimality of intellectual property rights largely as a given; the possibility of rewards is paid relatively little attention, despite the history we have summarized and despite the seeming appeal of the topic to the intellect of the economist.[10] There have been few papers written in economics journals in the past century on reward.[11] Two exceptions are those by Michael Polanvyi and Brian Wright.[12] Polanvyi recommends, in a sustained and insightful but informal argument, that rewards be adopted to foster innovation and to avoid the social losses associated with patent monopoly power; he offers reasons why informational difficulties facing the government in determining awards should not prove insurmountable. Wright is the first to consider a formal model of innovation in which innovators possess superior information to the government, and he finds that rewards are better than patents if the government's information is sufficiently good. Also, Michael Kremer, in an interesting, related paper, suggests that the government could avoid social losses associated with patents by purchasing them at a price that it obtains from an auction process.[13] (Governments have in fact occasionally purchased patents, and proposals for this to be done programmatically have sometimes been advanced.)[14] Another paper of significance is by Suzanne Scotchmer; although she does not emphasize rewards, she characterizes the optimal form of patent system under the assumption that innovators possess superior information to the government.[15]

[10] This is not to say that the possibility of rewards is entirely ignored; for example, in his classic essay, Kenneth J. Arrow, Economic Welfare and the Allocation of Resources to Invention, in Essays in the Theory of Risk-Bearing 153 (1971), mentions the intrinsic appeal of rewards. However, the lack of importance of rewards in the economic literature is indicated by how little space is devoted to the topic in the chapters on innovation in several well-known books on industrial organization: F. M. Scherer, Industrial Market Structure and Economic Performance 458 (2d ed. 1980), spends only a page on rewards; F. M. Scherer & David Ross, Industrial Market Structure and Economic Performance (3d ed. 1990), a later edition of Scherer, *supra*, does not mention rewards; and Jean Tirole, The Theory of Industrial Organization 401 (1988), discusses rewards in only half a page.

[11] We are speaking of literature on reward as an alternative to patent. There is, however, a literature on the use of prizes to spur competition among parties for the development of a specified research product, where comparison to intellectual property rights is not made; see, for example, Richard L. Fullerton & R. Preston McAfee, Auctioning Entry into Tournaments, 107 J. Pol. Econ. 573 (1999); and Curtis R. Taylor, Digging for Golden Carrots: An Analysis of Research Tournaments, 85 Am. Econ. Rev. 872 (1995).

[12] Michael Polanvyi, Patent Reform, 11 Rev. Econ. Stud. 61 (1943); and Brian D. Wright, The Economics of Invention Incentives: Patents, Prizes, and Research Contracts, 73 Am. Econ. Rev. 691 (1983).

[13] Michael Kremer, Patent Buyouts: A Mechanism for Encouraging Innovation, 113 Q. J. Econ. 1137 (1998).

[14] For example, the French government purchased the patent for the daguerrotype in 1839, as mentioned by Kremer, *supra* note 13. Another example is that in 1851, a proposal was made in the English Parliament for the government to purchase patents routinely; see Macfie, Copyright and Patents for Inventions, *supra* note 1, at 33.

[15] Suzanne Scotchmer, On the Optimality of the Patent Renewal System, 30 Rand J. Econ.

In this paper, we examine a model in which a single potential innovator knows the demand curve for the product innovation he might produce before he invests in research, whereas the government knows only the probability distribution of demand curves.[16] We first compare the patent system (for concreteness, we refer to patent rather than to copyright or to intellectual property rights in general) to the reward system, and then we investigate optional reward systems.[17] The chief contributions of the paper are that it clarifies the comparison between patent and reward systems through the use of a simple and natural model of innovation and that it considers the optional reward system and shows it to be superior to patent.[18]

The analysis of the model may be summarized as follows. Under the patent system, the innovator's incentive to invest in research is the monopoly profits he would earn; if he produces the innovation, he then sells the innovation at the monopoly price. There are two familiar deviations from first-best behavior under the patent system. First, incentives to invest in research are inadequate because monopoly profits are less than the social surplus created by an innovation.[19] Second, if an innovation results, there is a deadweight loss in social welfare because too little is sold at the monopoly price.

Under the reward system, the innovator's incentive to invest in research is the reward he would receive. If the innovator produces an innovation, it will be available to competitors and so will sell at marginal cost (perfect competition in the product market is assumed). Because there is thus no deadweight loss from monopoly pricing, the only type of deviation from first-best behavior under the reward system involves the incentive to invest

181 (1999). Her main result is that direct revelation mechanisms are equivalent to patent renewal systems—systems in which patentees are able to extend the length of their patents by paying fees (or accepting reduced patent subsidies) for renewals. Such systems have the feature that they implicitly make use of innovators' private information; notably, innovators with more valuable patents will be the ones who will tend to purchase longer patent extensions. She cites the results on rewards that we demonstrated in Steven Shavell & Tanguy van Ypersele, Rewards versus Intellectual Property Rights (Discussion Paper No. 246, Harvard Law Sch., John M. Olin Ctr. for Law, Econ. & Bus. 1998), and she solves in certain cases for optimal renewal schemes that incorporate rewards.

[16] However, as we will note, we consider a version of the model in which the government observes quantity sold in the market and makes inferences from that in formulating rewards. As this is the most plausible form of reward system, it is very important for properly interpreting the analysis here to bear it in mind. For further discussion of this issue, see Section II*H* and Section III.

[17] We restrict attention to these policies for simplicity and do not consider more general mechanisms.

[18] After the appearance of our discussion paper, Shavell & van Ypersele, *supra* note 15, a similar conclusion was independently demonstrated in Gabriela Chiesa & Vincenzo Denicolo, Patents, Prizes, and Optimal Innovation Policy (unpublished manuscript, Univ. Bologna, Dept. Econ. 1999).

[19] However, in a model in which there are multiple potential innovators, there could be an excessive incentive to invest in innovation research created by the race to be first. But as we note in Section III, taking this point into account would not affect the qualitative nature of our conclusions (notably, the superiority of optional rewards over patents).

in research. This deviation could be in either direction. If the social surplus from the demand curve exceeds the reward, there will be an inadequate incentive to invest, and if the surplus from the demand curve is less than the reward, there will be an excessive incentive to invest. Either possibility may occur, as the optimal reward equals the expected surplus over the distribution of possible demand curves.

From the foregoing discussion, it is apparent that the comparison between the patent and the reward systems can be resolved into two elements. On one hand, the reward system is superior to patent in that deadweight loss due to monopoly pricing is avoided under rewards. On the other hand, the incentive to invest in research is imperfect under both systems, but in different ways. Under the patent system, the incentive to invest is always inadequate because monopoly profits are less than social surplus; but the incentive to invest is linked to actual social surplus because the innovator knows the demand for the potential innovation.[20] Under the reward system, the incentive to invest is governed by the reward and thus is not systematically inadequate; yet the incentive to invest is not linked to actual surplus but only to the reward.[21] In particular, if the innovation would be very valuable, the innovator would invest only in accordance with the reward, which will equal the expected surplus from all possible innovations.

Because patent effectively harnesses the private information of the innovator about the value of an innovation, incentives to innovate might be superior under patent to those under reward, even though the incentives under patent are always less than first best. This leads to the possibility that patent could be superior to reward, despite the deadweight loss due to monopoly pricing and the too-small incentive to innovate. Reward, however, could be superior to patent, both because of a better average incentive to innovate (as the optimal reward equals expected surplus) and because of avoidance of the deadweight loss from monopoly pricing. Analysis of patent versus reward does not lead one to think that there exists any general argument favoring the patent system over the reward system.

We next consider the optional reward system, under which an innovator may choose between a patent and a reward.[22] This system unambiguously dominates patent. The main reason is that we show that (expected) social welfare can be improved when the innovator chooses reward, for deadweight loss is then eliminated, and potential problems with overinvestment in re-

[20] This point is related to Mill's statement above, although he and other critics of reward were concerned not only about the government's lack of information but also about abuse of its authority and the rights of inventors.

[21] Note, however, that when the reward is conditioned on quantity sold (and possibly, on other ex post data), the reward will reflect surplus to the degree that quantity sold does; see Section II*H* and Section III.

[22] Such a system was proposed by Polanvyi, *supra* note 12, at 61–76. Note too that a system in which the government offers to buy patents is essentially of this type.

search can be addressed by the government's selecting an appropriately moderate level of reward. Because social welfare is improved when the innovator chooses reward instead of patent, the optional system must be superior to patent, since there is obviously no difference between the systems when the innovator chooses patent.

Although the optional reward system is superior to the patent system, and the patent system might be superior to the (mandated) reward system, when the reward system is superior to patent, we show that the reward system might also be superior to the optional reward system.

We then briefly consider the important possibility of rewards that are a function of the government's observation of quantity sold in the market. Such quantity-based rewards are obviously superior to the (unconditional) rewards we have been discussing and enhance the appeal of reward systems over patent.

After analyzing the patent, reward, and optional reward systems in our model, we discuss briefly a number of issues not considered in the model, including the government's ability to obtain information about demand for the purpose of determining rewards (especially by observation of quantity sold), the race to be first to innovate, improvements to innovations, administrative costs, the financing of rewards through income taxation and possible associated distortionary costs, and the actual potential of reward systems for raising social welfare.

II. The Model

A risk-neutral (potential) innovator may invest in research that will result in an innovation with a probability that depends positively on the research investment. Let

k = research investment, and
$p(k)$ = probability of an innovation; $p'(k) > 0$; $p''(k) < 0$.

If there is an innovation, a new product[23] can be produced at a constant per-unit cost. Let

c = unit cost of the innovation product.

Regarding the demand curve for the product, let

q = quantity of the product; and
$d(q; t)$ = (inverse) demand curve for the product; $d_q(q; t) < 0$;

where

t = parameter in $[t_a, t_b]$;
$g(t)$ = probability density of t; $g(t) > 0$ on $[t_a, t_b]$.

We assume that at t_a, monopoly profits, deadweight losses from monopoly

[23] Were we to study process innovations (see, for example, Tirole, *supra* note 10, ch. 10) instead of product innovations, the general nature of our results would not be altered.

pricing, and social surplus (these are described below) are positive[24] and that they increase with t.

We suppose that the function $p(k)$, the cost c, the family of possible demand curves $d(q; t)$, and the density $g(t)$ are common knowledge for the innovator and the government. The innovator alone knows t.[25] Also, we suppose until later that the government does not observe quantity sold. (In Section II*H* we allow the government to observe quantity and to base the reward on this.)

Social welfare is assumed to be the expected value of the utility individuals obtain from the innovation product, minus production costs, and minus research investment.

A. First-Best Outcome

If there is an innovation, the first-best quantity, denoted $q(t)$, is such that the height of the demand curve is c; that is, $d(q(t),\ t) = c$. Thus social welfare exclusive of research investment is the social surplus,

$$s^*(t) = \int_0^{q(t)} (d(q; t) - c)dq. \tag{1}$$

Consequently, the first-best research investment is that which maximizes

$$p(k)s^*(t) - k, \tag{2}$$

so that

$$p'(k)s^*(t) = 1 \tag{3}$$

identifies the first-best k. If $k(z)$ denotes the k that would be chosen if z is the payoff from an innovation,[26] then the first-best k is written $k(s^*(t))$. First-best social welfare as a function of t is thus

$$W^*(t) = p(k(s^*(t)))s^*(t) - k(s^*(t)). \tag{4}$$

Figure 1 shows $s^*(t)$ and $k(s^*(t))$.

[24] Thus, we are implicitly supposing that the government's information is good enough to screen out innovations with no value (or with no expected value). This assumption makes sense if the government devotes positive resources to screening innovations, and it is also justified if the government obtains information from sales of innovations, as discussed in Section II*H* and Section III.

[25] The assumption that the innovator has perfect information about demand (since he knows t) and that the government does not is the simplest way to reflect the idea that the innovator possesses superior information about demand. A more realistic assumption is that the innovator's information about demand is not perfect but still is better than the government's, and were this the assumption, it will be obvious that the qualitative nature of our results would not be altered.

[26] That is, $k(z)$ is determined by $p'(k)z = 1$. Note that $k(z)$ is increasing in z (implicitly differentiate $p'(k)z = 1$ with respect to z to obtain $k'(z) = -p'(k)/(zp''(k)) > 0$).

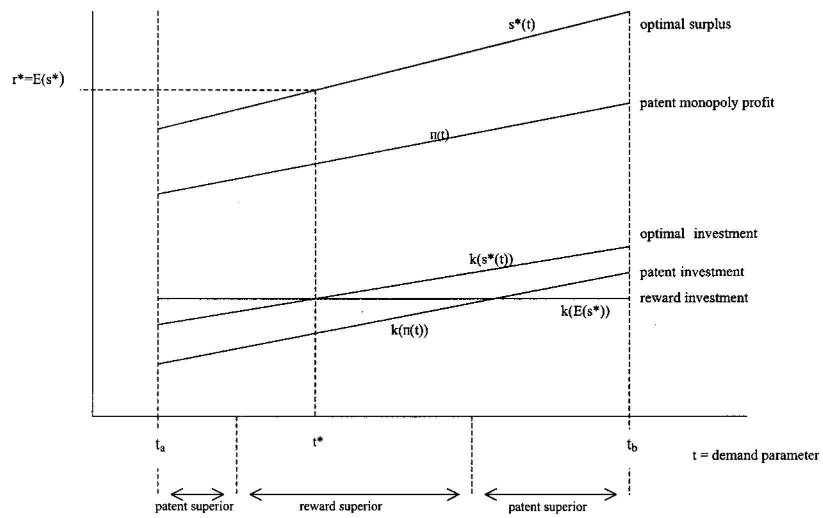

FIGURE 1

B. Patent Regime

Under the patent regime, the innovator has the exclusive right to sell the product resulting from an innovation. Hence, if he innovates, he will sell the monopoly quantity and earn monopoly profits. Specifically, let

$q_m(t)$ = monopoly quantity, and

$\pi(t)$ = monopoly profits.

Knowing that an innovation would yield $\pi(t)$, the innovator will choose k to maximize

$$p(k)\pi(t) - k \tag{5}$$

and so will choose $k(\pi(t))$.

Let us compare the outcome under patent to the first-best outcome. Now, as is familiar, $q_m(t) < q(t)$, so the social surplus under patent falls short of first-best social surplus $s^*(t)$ by the deadweight loss

$$l(t) = \int_{q_m(t)}^{q(t)} (d(q; t) - c)dq. \tag{6}$$

Hence, social welfare under the patent regime given t is

$$W_P(t) = p(k(\pi(t)))[s^*(t) - l(t)] - k(\pi(t)). \tag{7}$$

This may be compared to first-best social welfare given *t:*

$$W^*(t) - W_P(t) = \{[p(k(s^*(t)))s^*(t) - k(s^*(t))] - [p(k(\pi(t)))s^*(t) - k(\pi(t))]\} + p(k(\pi(t)))l(t). \tag{8}$$

The first term, in braces, is clearly positive and represents the welfare loss from inadequate investment in research under monopoly: because the monopolist's profit $\pi(t)$ is less than first-best social surplus $s^*(t)$, he underinvests in research, $k(\pi(t)) < k(s^*(t))$. The graph of $k(\pi(t))$ is shown in Figure 1. The second term is the expected deadweight loss due to monopoly pricing. In summary, we have the following:

PROPOSITION 1. Under the patent system, there are two sources of welfare loss relative to first-best welfare: insufficient investment in research and insufficient quantity of the innovation product sold, with accompanying deadweight loss, due to monopoly pricing.

These points are, of course, standard;[27] they are set out so that we can contrast patent to reward.

C. Reward Regime

Under the reward regime, the government gives a reward to the innovator if he succeeds with an innovation, and it is assumed that the innovation information is placed in the public domain and made available to a competitive production industry. Hence, it is assumed that the product will be sold at a price of c, so that zero profits will be made from production and total quantity produced will be $q(t)$. Let

r = reward paid by the government for an innovation.

The innovator's incentive to innovate is due entirely to the reward, since he makes no profits from sales. He will thus choose research investment to maximize

$$p(k)r - k, \tag{9}$$

and so will choose $k(r)$.

It follows that if—contrary to our assumption—the government were to possess perfect information about the demand curve t, the government could achieve a first-best outcome for each t by setting the reward r equal to $s^*(t)$: the innovator would then choose $k(s^*(t))$, the first-best investment in research; and the quantity produced is always optimal, $q(t)$, under the reward system.

Because our assumption is that the government does not know t (and does not observe quantity sold), the reward r must be fixed and independent of t. Social welfare as a function of the reward is

[27] See, for example, Tirole, *supra* note 10, ch. 10.

$$W_R(r) = \int_{t_a}^{t_b} p(k(r))s^*(t)g(t)dt - k(r) = p(k(r))E(s^*) - k(r), \qquad (10)$$

where $E(s^*)$ is the expected value of $s^*(t)$; see Figure 1. It follows that (10) is maximized if $r = E(s^*)$.[28] That is, the optimal reward r^* is the expected social surplus from an innovation.

We can now compare social welfare under the reward system to first-best social welfare. The difference between the two is that research investment is the constant $k(E(s^*))$ under the reward system, whereas investment depends optimally on t, and equals $k(s^*(t))$, in the first-best situation. Under the reward system, research investment $k(E(s^*))$ is excessive relative to the first best when $s^*(t)$ is below $E(s^*)$ and is inadequate when $s^*(t)$ exceeds $E(s^*)$.

To summarize this section, we have the following:

PROPOSITION 2. Under the reward system, the optimal reward r^* equals the expected value of social surplus, $E(s^*)$, from an innovation. There is one source of welfare loss relative to first-best welfare: incorrect investment in research, which will be excessive or inadequate depending on whether actual surplus falls below or exceeds $E(s^*)$. There is no deadweight loss due to monopoly pricing if there is an innovation.

Note that the information the government requires to calculate the optimal reward is the density $g(t)$ of the family of demand curves $d(q;t)$ and the production cost c (in order to compute the surplus for each demand curve). The government does not need to know the probability function $p(k)$.

D. Patent versus Reward

If we subtract social welfare under patent from that under reward, we obtain

$$\begin{aligned} W_R(r) - W_P &= W_R(r) - \int_{t_a}^{t_b} W_P(t)g(t)dt \\ &= \int_{t_a}^{t_b} \{[p(k(E(s^*)))s^*(t) - k(E(s^*))] \qquad (11) \\ &\quad - [p(k(\pi(t)))(s^*(t) - l(t)) - k(\pi(t))]\}g(t)dt. \end{aligned}$$

The second integrand reflects the two differences between reward and patent that we noted in Section I. First, under reward, there is no deadweight loss from insufficient production, whereas there is under patent. This constitutes an advantage of the reward system and tends to make the integrand positive (note that $l(t)$ is subtracted from $s^*(t)$ in the second term). Second, under

[28] Specifically, $p(k)E(s^*(t)) - k$ is maximized over k if $k = k(E(s^*(t)))$, so r must equal $E(s^*(t))$.

reward, the research investment is a constant $k(E(s^*))$, whereas under patent, research investment depends on t and equals $k(\pi(t))$. This difference may favor either patent or reward: when $s^*(t)$ is sufficiently close to its mean, $E(s^*)$, investment will be closer to its first-best level under reward than under patent, where it is inadequate for all *t;* nevertheless, when $s^*(t)$ is very different from $E(s^*)$, investment may be closer to first best under patent than under reward.

Figure 1 helps to clarify the comparison. Let t^* be the t such that $s^*(t) = E(s^*)$. As shown in the figure, reward is superior to patent for t in a region around t^*. For t sufficiently close to t^* and within this region, reward is superior to patent for the double reason that investment is closer to first best than under patent and deadweight monopoly pricing loss is eliminated; elsewhere in the region, reward is superior to patent even though investment is farther from first best than under patent, because reward eliminates monopoly pricing deadweight loss. For t outside the region, patent is superior to reward because investment is sufficiently closer to first best under patent than under reward as to overcome the deadweight loss due to monopoly pricing. This makes it clear that if enough probability mass is distributed close to t^*, reward will be superior to patent, whereas if enough mass is not close to t^*, patent will be superior to reward.[29] Hence, we have the following:

PROPOSITION 3. Either the reward system or the patent system may be superior to the other.

The foregoing discussion also leads to two observations about the comparison between reward and patent.

First, if the information that the government has about demand is sufficiently good, then the reward system will dominate patent. Specifically, if the probability mass is sufficiently concentrated about $E(s^*)$, it follows from (11) that reward will dominate patent.[30] This is because the research investment under reward will tend to be superior to (and higher than) that under patent and deadweight loss from monopoly pricing will be avoided.

Second, if the need for well-calibrated incentives to invest in research is sufficiently attenuated, then the reward system will be superior to patent, because the factor of the elimination of deadweight loss from monopoly pricing will be of dominating importance. One way to make this notion precise is to consider the family of research investment functions $p(k\lambda)$, where λ is a positive parameter. Note that the need for incentives to invest

[29] We have also constructed numerical examples (see Shavell & van Ypersele, *supra* note 15) in which patent is superior to reward and in which reward is superior to patent.

[30] This follows from continuity considerations and the fact that at t^*, the integrand is positive, for at t^*,

$$p(k(E(s^*)))s^*(t) - k(E(s^*)) = p(k(E(s^*)))E(s^*) - k(E(s^*))$$
$$> p(k(\pi(t^*)))E(s^*) - k(\pi(t^*)) > p(k(\pi(t^*)))(E(s^*) - l(t^*)) - k(\pi(t^*)).$$

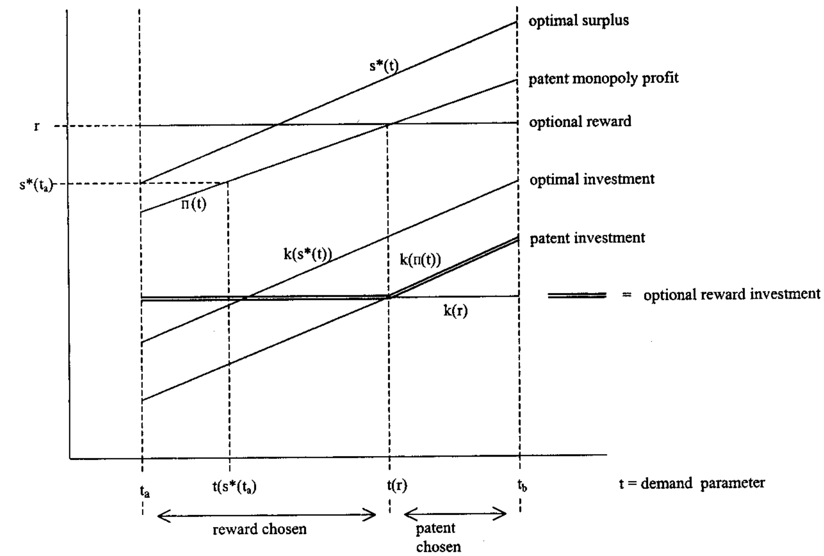

FIGURE 2

in research becomes small as λ grows large because the probability of innovation can be made high at low cost as λ grows large: for any $k > 0$, $p(k\lambda) \to \bar{p}$ as $\lambda \to \infty$, where $\bar{p} = \lim p(k)$ as $k \to \infty$. And indeed, inspection of (11) shows that reward will be superior to patent if λ is sufficiently high.[31]

Additionally, we observe that the information the government needs to make the comparison between patent and reward is not only the density $g(t)$, the demand curves $d(q; t)$, and the production cost c, but also the probability function $p(k)$.[32]

E. Optional Reward Regime

Under the optional reward regime, the innovator can choose whether to take the government reward r (in which case the innovation information is placed in the public domain) or rather to obtain a patent. Hence, the innovator will choose the reward if and only if $r \geq \pi(t)$; he will choose patent when the demand curve is such that monopoly profits would be high, as is illustrated in Figure 2. Note that if $r < \pi(t_a)$, then the innovator will always behave the

[31] It is clear that as $\lambda \to \infty$, $k(E(s^*))$ and $k(\pi(t))$ both approach 0, and $p(k(E(s^*)))$ and $p(k(\pi(t))$ both approach $\bar{p}$. Hence, the integrand in (11) approaches $\bar{p}l(t) > 0$.

[32] The government will need the same information to compute the optimal reward under the optional reward system and to make comparisons between that system and the other systems.

same way—choose patent and obtain $\pi(t)$—so that in determining the optimal reward, we can restrict attention to $r \geq \pi(t_a)$. Now let $t(r)$ denote $\pi^{-1}(r)$ for r in $[\pi(t_a), \pi(t_b)]$, and let $t(r) = t_b$ for $r > \pi(t_b)$. Then social welfare under the optional reward system is

$$W_O(r) = \int_{t_a}^{t(r)} [p(k(r))s^*(t) - k(r)]g(t)dt + \int_{t(r)}^{t_b} [p(k(\pi(t)))(s^*(t) - l(t)) - k(\pi(t))]g(t)dt. \tag{12}$$

The derivative of (12) is

$$W_O'(r) = k'(r)[p'(k(r))E(s^*|t \leq t(r)) - 1]G(t(r)) + t'(r)p(k(r))l(t(r))g(t(r)), \tag{13}$$

where G is the cumulative distribution function of g and $E(s^*|t \leq t(r))$ is the expected value of $s^*(t)$ conditional on $t \leq t(r)$. The first term in (13) reflects the inframarginal effect of raising the reward: the influence of the increase in research investment in cases where the innovator chooses the reward. Note that the term in brackets, $[p'(k(r))E(s^*|t \leq t(r)) - 1]$, is the expected net return from more investment in such cases. The second term in (13) is the marginal effect of raising the reward: just inducing the innovator to accept the reward rather than to obtain a patent. In this circumstance, the innovator, by accepting the reward, does not alter his research investment (because the reward just equals his monopoly profits); the only change is that the monopoly pricing deadweight loss $l(t(r))$ is eliminated, which explains that factor in the second term.

Now the second term in (13) is nonnegative (it is clear that $t'(r)$ is nonnegative). Hence, if the first term in (13) is positive, (13) will be positive. The first term will be positive if $[p'(k(r))E(s^*|t \leq t(r)) - 1]$ is positive, and that will be so if and only if $r < E(s^*|t \leq t(r))$. This in turn certainly will be true for $r \leq s^*(t_a)$, because $s^*(t_a) < E(s^*|t \leq t(r))$ for any r. Thus (13) must be positive for $r \leq s^*(t_a)$, which implies that the optimal r, denoted r^{**}, must exceed $s^*(t_a)$. We therefore have the following:

PROPOSITION 4. Under the optional reward system, the innovator chooses the reward when monopoly profit would be lower; otherwise he chooses patent. The optimal optional reward, r^{**}, exceeds the minimum social surplus, $s^*(t_a)$.

We observe that if $r^{**} \geq \pi(t_b)$, then the optional reward will always be chosen, so the outcome is equivalent to that if r^{**} were a mandatory reward.

F. Optional Reward versus Patent

We can immediately show the following:

PROPOSITION 5. The optional reward system is superior to the patent system.

This result is really a corollary of Proposition 4. In particular, as we observed, the patent system is equivalent to an optional reward system with $r = \pi(t_a)$, because then the patent would always be chosen (except on a set of measure zero, when $t = t_a$). But since $r^{**} > s^*(t_a)$, we know that r^{**} exceeds $\pi(t_a)$; hence, the optimal optional reward system must be superior to the patent system.

Although the above paragraph demonstrates the result, it is perhaps best understood by considering informally why the optional reward system with a reward slightly above $\pi(t_a)$ is superior to patent (and a fortiori why the optional reward system with the *optimal* reward must be superior to patent). If the reward is slightly above $\pi(t_a)$, then the reward will be chosen only by innovators with the lowest monopoly profits $\pi(t_a)$ and slightly more. The research investment of these innovators will be essentially unchanged—it will be approximately $k(\pi(t_a))$—because they are essentially indifferent between a patent and the reward. Thus, the only factor that changes in regard to these lowest profit innovators is that, because they select the reward, the deadweight loss due to monopoly is eliminated. Therefore, social welfare rises when the lowest profit innovators choose rewards, and social welfare is unchanged for all other innovators, as they choose patents. Hence, social welfare must have risen.

G. Optional Reward versus Reward

We have yet to compare the optional reward system to the reward system, which is of a mandatory nature. We have the following:

PROPOSITION 6. Either the optional reward system or the reward system may be superior to the other.

That the optional reward system may be superior to reward is clear: the patent system may be superior to reward, according to Proposition 3; and whenever the patent system is superior to reward, the optional reward system must be superior to reward, for optional reward is superior to patent, according to Proposition 5.[33] The explanation is essentially that under optional reward, when the demand curve is high, patent will be chosen and incentives to invest will thus not be dulled by a too-low-under-the-circumstances reward. This investment-incentive advantage of optional reward may be more important than the disadvantage of deadweight loss from patent monopoly pricing.

[33] It is also possible for optional reward to be superior to reward when reward is superior to patent.

That the reward system may be superior to optional reward is possible for related reasons. When the demand curve is high and patent is chosen under optional reward, the investment-incentive advantage of optional reward may be less important than the disadvantage of deadweight loss from patent monopoly pricing. Reward, being mandatory, prevents the potential problem that patent would be chosen when the demand curve is high.[34]

H. Rewards Conditional on Quantity Sold

Suppose now that the government can observe quantity q sold and base rewards on this; and suppose too that, in general, the government cannot infer the demand curve t from q because many different demand curves may pass through the observed price-quantity point (c, q). Our analysis would then be modified in straightforward ways. In Section II*C*, the reward would not be a constant r but instead a function $r(q)$. The innovator would then choose $k(r(q(t)))$: the innovator knows t, and so can calculate what the equilibrium quantity sold $q(t)$ would be, and thus the reward $r(q(t))$ he would receive. (We assume for simplicity that the innovator cannot influence the equilibrium $q(t)$.)[35] Hence, social welfare (10) given the function $r(q)$ would become

$$\begin{aligned} W_{\mathrm{R}}(r(q)) &= \int_{t_{\mathrm{a}}}^{t_{\mathrm{b}}} [p(k(r(q(t)))s^*(t) - k(r(q(t)))]g(t)dt \\ &= \int_{q_{\mathrm{a}}}^{q_{\mathrm{b}}} [p(k(r(q)))E(s^*|q) - k(r(q))]f(q)dq, \end{aligned} \tag{10$'$}$$

where $E(s^*|q)$ is the mean of $s^*(t)$ given that $q(t) = q$, $f(q)$ is the density of q derived from $g(t)$ (that is, $f(q)$ is the density of the set of t such that $q(t) = q$), and $q_i = q(t_i)$. It is evident from (10′) that, for any q, the socially optimal $r(q)$ is $E(s^*|q)$; the optimal reward function is the mean social surplus conditional on the demand curve being such that the quantity sold at price c was the observed quantity.

Clearly, the comparison between reward schemes and the patent system

[34] We have constructed a numerical example in which reward may be superior to optional reward; see Shavell & van Ypersele, *supra* note 15.

[35] The innovator might well wish to increase production so that q is above $q(t)$ in order to raise his reward, as $r(q)$ presumably would be rising in q. The government could prevent such strategic increases in q by forbidding the innovator from selling below the competitive price c or directly by forbidding the innovator from producing. A closely related problem is that the innovator might have an incentive to buy the innovation product to increase q and his reward. For example, the reward for each pill sold of a new drug might exceed its production cost, in which case the innovator would have an incentive to make large purchases of the pill. The government could police purchases in such a case. If the government is unable to prevent strategic manipulation of q, then the optimal $r(q)$ would be different from what is described below.

would be qualitatively unchanged from that discussed above. However, because the quantity-based optimal reward is generally different from the unconditional optimal reward (because $E(s^*|q)$ is generally different from $E(s^*)$) and thus is superior to it, the quantity-based reward would more often be superior to patent than the unconditional reward is superior to patent. Likewise, the quantity-based optional reward would be superior to the unconditional optional reward and would thus be more advantageous relative to the patent system than would the unconditional optional reward.

III. Discussion

We comment here on a number of issues that were omitted from the model and on its interpretation.

An Alternative System: Patent and Reward. A policy that we did not consider is one in which an innovator obtains a patent and is also given a reward. This system is superior to patent, because the problem of underinvestment is alleviated by payment of a reward. (The optimal reward would equal the expected value of the difference between social surplus and monopoly profits at the monopoly quantity—the social surplus not captured by the patent holder.) The system might or might not be superior to reward (for reasons analogous to those relating to the comparison between patent and reward) but is inferior to optional reward.[36]

Government's Ability to Obtain Information about the Value of Innovations. As we stressed in the analysis, the government's knowledge about the social value of innovations, embodied in its probability distribution over demand curves, is important to the performance of the reward system and to that of the optional reward system (even though the latter dominates patent no matter how poor the government's knowledge). In fact, one supposes that the government could obtain significant information about demand. Most obviously, the government can base its rewards on sales data, which should be relatively easy to obtain; thus, the version of rewards discussed in Section II*H* is the most relevant one to consider. (Note that if rewards are based on sales, the government should not fear that it would be flooded by claimants for rewards with inferior or meaningless innovations—they would not generate products that would pass the market test.) The government could also attempt to measure more about the demand curve than sales at the market price; it could estimate demand elasticities and undertake surveys to determine the character and frequency of use of, for example, computer software,

[36] To explain why the system of patent and reward must be inferior to optional reward, suppose that the reward that accompanies patent is r. Now let the optional reward equal $r + \pi(t_a)$. Then, by the logic sketched at the end of Section II*F*, social welfare must rise: innovators with the lowest monopoly profits will accept this reward, and not alter their research investment, but deadweight loss will be eliminated, raising social welfare. No other innovators will change their behavior. Hence, social welfare is higher under this optional reward and must therefore be higher under the optimal optional reward.

musical recordings, and cinematic and television productions. As events unfold and information flows to the government, it could appropriately supplement rewards, perhaps on an annual basis. In past proposals for reward systems, payments based on sales and other information that the government receives have sometimes been discussed.[37] It would be a gross mistake to envision the reward as having to be premised on the government's estimate of valuation at the time an innovation is registered.

Government's Information versus Innovators'. We have just mentioned the ability of the government to obtain information about demand, but we have not considered how good innovators' information is and its relation to the government's. In this regard, two comments should be made, which together suggest that the factor of innovators' superiority of information may be less important than it initially appears to be. First, innovators' information will often be substantially imperfect ex ante, at the time when they are deciding on research investment—the crucial period for assessment of innovators' information. Second, the government's information will often be reasonably good ex post, which is the pertinent period for assessment of government information when rewards are based on sales and other indicia of worth. Thus, when rewards are based on ex post data, the informational comparison that bears on the choice between rewards and intellectual property rights is that between innovators' ex ante information and the government's ex post information. (That innovators' ex ante information may be superior to the government's ex ante information would be irrelevant to the choice between rewards and property rights.) This point can be put more sharply. Suppose, as is not implausible, that the government's ex post, sales-related information about demand is as good as innovators' ex ante information, when they are deciding on research investment. Then innovators enjoy no informational advantage that favors intellectual property rights, and mandatory rewards (not just optional rewards) are unambiguously superior to intellectual property rights.[38]

Race to Be First. The optimal magnitude of the reward would be affected in practice by a consideration that we did not study in our model: the race among potential innovators to be the first to innovate. As is emphasized in the literature on patent, this race leads to the possibility of overinvestment in research because the private return to being first may exceed its social value.[39] Likewise, under a reward system, there would be a race to be first, and it might lead to excessive investment in research, lowering the optimal

[37] See especially Polanvyi, *supra* note 12, at 67–69.

[38] To amplify, let the innovator's ex ante information be z, which can be written $z(q)$, because the assumption is that q is at least as informative as z. Then it is clear that the social optimum given the constraint that the innovator knows only z when he chooses k can be achieved under the reward system if the reward equals $E(s^* \mid q)$, whereas under the patent system, k will be suboptimal, and the amount sold will be too low.

[39] See Tirole, *supra* note 10, ch. 10.

reward. Because the race to be first is a factor that afflicts both systems, and because the information needed to address it under either seems to be of the same character, consideration of the race to be first does not seem to bear on the comparison between reward and patent.[40]

Subsequent Innovations. We did not discuss the issue of subsequent innovations, that is, improvements to innovations or new innovations depending on past ones. In this regard, two points are of interest. First, under the intellectual property rights system, subsequent innovations may be stymied by the refusal of holders of property rights to allow improvements; there may be breakdowns in bargaining between the holders and innovators due to asymmetry of information.[41] A famous example of this occurred when James Watt, holder of an early steam engine patent, denied licenses to improve it to Jonathan Hornblower and Richard Trevithick, who had to wait for Watt's patent to expire in 1800 before they could develop their high-pressure engine.[42] Under a reward system, this would not have been the case, for Watt's steam engine would have been in the public domain, and Hornblower and Trevithick would have been free to improve it immediately. (Indeed, as noted in Section I, this was one of the arguments in favor of the reward system emphasized in the nineteenth-century debates.)[43] The second point of note is that the government's problem of determining rewards is made more difficult when the value of an innovation is in part that it leads to subsequent innovations. However, the government's problem in administering the patent system is also made more difficult by the possibility of subsequent innovations (notably, in determining issues of patent scope—which subsequent innovations will be considered infringing) and for closely related informational reasons. Hence, it is not clear the extent to which, or whether, the added informational difficulty presented by subsequent innovations favors patent over reward.

Administrative Costs. Under a reward system, administrative costs would be incurred by the government in deciding upon rewards, and these costs

[40] Notably, optional reward is superior to patent regardless of the level of research investment induced by the race to be first. This is apparent from reviewing the argument given at the end of Section II*F*. In particular, if a reward of $\pi(t_a)$ is offered, then the lowest profit innovators do not alter their level of investment—whatever that level may be, however it may be affected by the race to be first—and deadweight loss due to patent is eliminated; thus social welfare rises.

[41] To some degree, this problem can be addressed by legal rules that force the right holder to allow an innovator to make and sell an improved product; this is what compulsory licensing rules of patent law do.

[42] See Scherer, *supra* note 10, at 452.

[43] See, for example, Macfie, Patent Question in 1875, *supra* note 1, at 5, which states, "[W]hen an invention is patented, the reward being monopoly, a stop is put to improvement. . . . If we substituted for monopoly a sensible system of grants in money, thus preserving a pecuniary stimulus to publish inventions, I predict that almost every new machine or process would be studied, scrutinized, and subjected to such an amount of diversified and intelligent thought that . . . it would be greatly perfectionated."

presumably would exceed those associated with deciding on the granting of patents. There would also be litigation costs borne in relation to disputes about rewards between innovators and the government, as well as between different innovators. However, under a reward system, there would be a savings in administrative costs relative to under the patent or copyright systems: under these systems, intellectual property rights have to be protected by the state, parties often make efforts to determine if their rights have been violated and also to ascertain if they are violating someone's else's rights, and litigation costs are expended in disputes over rights; but under the reward system, there are no intellectual property rights to generate such costs. On a priori grounds, one cannot say whether these administrative cost savings of the reward system would outweigh the added administrative costs that the reward system would entail.[44]

Tax-Financing Cost of a Reward System. Reward systems have to be financed, and we presume through income taxation, but that involves a labor supply–related distortionary cost, something that was not considered in our model.[45] Hence, the potential case for reward is less strong than is suggested by our analysis.

Further Merits of the Optional Reward System. The optional reward system not only has the theoretical advantage that it is superior to intellectual property rights, it has the practical, political advantage that industry should not object to it, as it can only raise firms' profits. Moreover, the fear that the government would act suboptimally, and give unduly conservative rewards, would be less of an issue under an optional reward scheme because innovators can always obtain intellectual property rights. Indeed, just because of innovators' option, the government's temptation to pay too little might be checked under an optional reward system.[46] Thus, were there an interest in actual adoption of a reward scheme, an optional version might be the best type to propose initially. (As noted earlier, the plan set out by Polanvyi was mainly optional in nature, as are schemes for the government to offer to purchase patents.)

Importance of the Advantages of Reward Systems. To appreciate the

[44] In considering this paragraph, the complicating factor that administrative costs are really endogenous and depend on the type of reward system should be borne in mind. We can, for instance, imagine an intellectual property rights system that is less expensive than the one we have, and we can imagine a reward system that involves low administrative costs because it determines rewards using a simple formula. Also, the cost of administering an optional reward system would likely be lower than that of a mandatory reward system, especially if rewards are, as is realistic, based on ex post data.

[45] See, however, Louis Kaplow, The Optimal Supply of Public Goods and the Distortionary Cost of Taxation, Nat'l Tax J. 513–33 (1996), which emphasizes that there need not be any distortionary cost associated with raising greater income tax revenues to finance a government program if the income tax is optimally adjusted rather than mechanically increased.

[46] That is, a problem the government might have in being able to commit to a policy of relatively high rewards might be mitigated under the optional reward system.

possible advantages of reward systems, it is helpful to consider areas of innovation where the social losses due to intellectual property rights are likely to be high, namely, where the difference between price and production cost (after innovation) is large. Such areas of innovation may be exemplified by development of pharmaceuticals, computer software, and recorded music and visual products. Here, prices are often substantial in relation to production cost; drugs may sell for many times their marginal production cost, the price of computer software is generally nontrivial even though its marginal production cost is essentially zero (it can be downloaded from the Internet), and similar statements can be made about compact disc recordings, cable television broadcasts, and first-run movies. In a regime with rewards, drugs would be far cheaper and more widely used, all computer software would be free, and electronically recorded materials would be inexpensive, arguably engendering significant increases in consumer welfare. Moreover, there would also be potential gains from enhanced incentives to innovate, as profits from patent and copyright may fall considerably short of consumer surplus. For example, Kremer suggests that studies of the social versus the private returns from research indicate that private profits from research might well be only one-third of the social returns. Because optimal rewards would reflect the social returns, rewards would increase overall incentives to invest.

IV. Conclusion

Reward systems, or optional reward systems, and especially those based on sales-related information, appear on reflection to hold promise as alternatives to our system of intellectual property rights, because there is no necessity to marry the incentive to innovate to conferral of monopoly power in innovations. As such, serious study of the possibility of reward systems, with a view toward their implementation at least on an experimental, partial basis, is worth contemplating.

Bibliography

Arrow, Kenneth J. “Economic Welfare and the Allocation of Resources to Invention.” In *Essays in the Theory of Risk-Bearing,* pp. 144–63. Chicago: Markham Publishing Co., 1971.

Baxter, J. W.; Sinnot, John P.; and Cotreau, William Joseph. *World Patent Law and Practice.* Vol. 2M. New York: Matthew Bender, 1988.

Chiesa, Gabriella, and Denicolo, Vincenzo. “Patents, Prizes, and Optimal Innovation Policy.” Unpublished manuscript. Bologna: University of Bologna, Department of Economics, 1999.

Dutton, H. I. *The Patent System and Inventive Activity during the Industrial Revolution, 1750–1852.* Dover, N.H.: Manchester University Press, 1984.

Fullerton, Richard L., and McAfee, R. Preston. “Auctioning Entry into Tournaments.” *Journal of Political Economy* 107 (1999): 573–605.

Goldstein, Paul. *Copyright, Patent, Trademark and Related State Doctrines: Cases and Materials on the Law of Intellectual Property*. Revised 3d ed. Westbury, N.Y.: Foundation, 1993.

Kaplow, Louis. "The Optimal Supply of Public Goods and the Distortionary Cost of Taxation." *National Tax Journal* 49 (1996): 513–33.

Kremer, Michael. "Patent Buyouts: A Mechanism for Encouraging Innovation." *Quarterly Journal of Economics* 113 (1998): 1137–67.

Lord Hailsham of St. Marylebone. *Halsbury's Laws of England.* 4th ed. reissue. Vol. 35. London: Butterworths, 1994.

Macfie, Robert Andrew. *Recent Discussions on the Abolition of Patents for Inventions in the United Kingdom, France, Germany, and the Netherlands. Evidence, Speeches and Papers in Its Favour.* London: Longmans, Green, Reader, and Dyer, 1869.

Macfie, Robert Andrew. *The Patent Question in 1875: The Lord Chancellor's Bill, and the Exigencies of Foreign Competition.* London: Longmans, Green, 1875.

Macfie, Robert Andrew. *Copyright and Patents for Inventions.* Vol 2. *Patents.* Edinburgh: T&T Clark, 1883.

Machlup, Fritz. *An Economic Review of the Patent System.* Washington, D.C.: U.S. Government Printing Office, 1958.

Machlup, Fritz, and Penrose, Edith. "The Patent Controversy in the Nineteenth Century." *Journal of Economic History* 10 (1950): 1–29.

MacLeod, Christine. *Inventing the Industrial Revolution.* Cambridge: Cambridge University Press, 1988.

Mill, John Stuart. *Principles of Political Economy with Some of Their Applications to Social Philosophy.* Boston: Lee & Shephard, 1872 (1848).

Polanvyi, Michael. "Patent Reform." *Review of Economic Studies* 11 (1943): 61–76.

Prager, Frank D. "A History of Intellectual Property from 1545 to 1787." *Journal of the Patent Office Society* 26 (1944): 711–60.

Scherer, F. M. *Industrial Market Structure and Economic Performance.* 2d ed. Boston: Houghton Mifflin, 1980.

Scherer, F. M., and Ross, David. *Industrial Market Structure and Economic Performance.* 3d ed. Boston: Houghton Mifflin, 1990.

Scotchmer, Suzanne. "On the Optimality of the Patent Renewal System." *Rand Journal of Economics* 30 (1999): 181–96.

Shavell, Steven, and van Ypersele, Tanguy. "Rewards versus Intellectual Property Rights." Discussion Paper No. 246. Cambridge, Mass.: Harvard Law School, John M. Olin Center for Law, Economics, and Business, 1998.

Taylor, Curtis R. "Digging for Golden Carrots: An Analysis of Research Tournaments." *American Economic Review* 85 (1995): 872–90.

Tirole, Jean. *The Theory of Industrial Organization.* Cambridge, Mass.: MIT Press, 1988.

Wright, Brian D. "The Economics of Invention Incentives: Patents, Prizes, and Research Contracts." *American Economic Review* 73 (1983): 691–707.