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# Incentive mechanisms for innovation

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# Incentive mechanisms for innovation

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## Abstract

Using a simple model of innovation, I compare patents, research grants, targeted prizes, and *ex post* prizes and explore their interaction. I then introduce a new incentive mechanism for innovation, provisionally labeled optional broad rewards, or OBRs, and examine its characteristics. I explore the interaction of OBRs with the patent system and suggest some specific settings in which OBRs may be useful.

## 1. Introduction

Innovation is at the core of economic growth, and so designing incentives which will enable greater innovation should be at the core of government policy. Unfortunately, the mechanisms commonly used – patents, research grants, and prizes – are incomplete and imperfect, much like other social institutions. In particular, when patents do not enable the innovator to appropriate a significant share of the benefits of his or her invention, they cannot be an effective incentive mechanism. I introduce a new incentive mechanism for innovation, provisionally labeled optional broad rewards, or OBRs, and examine its characteristics. OBRs offer payments in place of the exclusive use of the innovation disclosed in the patent. OBRs represent an alternative way of being rewarded for an innovation, and, in combination with the patent system, OBRs may be very useful in some specific settings.

An illuminating example of incomplete appropriability under the patent system is the chemical DCA, which was recently reported to be very effective at destroying a wide set of cancers in mice (Bonnet et al, 2007). This molecule is already used to treat lactic acid buildup and cardiac ischemia in humans, so that its side effects are relatively well known. As such, it has been hailed as a very exciting prospect. The only problem is that it is already available in the marketplace. While a firm may be able to obtain a patent for the use of DCA as a treatment for cancer, it would be unable to prevent other firms from selling DCA, and as such would be unable to appropriate much (if any) of the value of the innovation. This could lead to slow or incomplete clinical trials: as a leading cancer scientist at the Canadian Institutes of Health Research asked, “But who's going to pay for the clinical trials ... it's $70 million to $100 million."[1] These trials may not be successful and there is no commercial advantage from this investment, so no company has an incentive to undertake the trials. This means that trials must be financed by government, which may lack a process for deciding whether to fund clinical trials.[2]

There are many prospective innovations for which the patent system simply does not create adequate incentives for investment in R&D. For example, malaria kills at least one million people annually, most of them under five years old, and most in sub-Saharan Africa, and there are approximately 400m clinical episodes of malaria annually, suffered mainly by poor people without health insurance (World Health Organization, 2005). These extremely poor victims have little economic power and do not represent an appealing target for most drug companies. As a result, there is little commercially funded development of new vaccines or therapies for malaria, despite the immense interest of organizations like the Gates Foundation.

In other areas of the economy, patents do not represent an effective means of securing property rights over an innovation, when patents may easily be invented around.[3] Given that the patent requires the patentee to disclose a great deal of technical information about the innovation, if the patent offers no meaningful protection, it is better not to patent. That is, patents frequently offer very low appropriability and cannot therefore be relied on as an incentive mechanism in those cases.

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[1] Joseph Hall, "Molecule offers cancer hope." *Toronto Star*, Jan. 17, 2007, citing Dr. Philip Branton.

[2] The DCA researchers are also soliciting donations, which seems a difficult way to raise the required capital.

[3] 63.5% of inventors, when asked why they didn't patent particular innovations, explained that the ease of inventing around a patent made it ineffective as protection (Cohen, Nelson and Walsh, 2000).

Because innovation might be advanced by non-patent mechanisms, there has been increasing policy interest in alternatives such as prizes. This has been encouraged by some high-profile initiatives such as the "X Prize" for re-useable spacecraft. And recently the US National Science Foundation was directed to use available funds for "innovation inducement prizes."[4] Despite this policy interest in prizes, and compared to the extensive literature on patents, economists have written little on alternatives to the patent system.

The leading paper on alternatives to patents is Wright (1983), which focuses on the racing or common pool problem that occurs when a large number of competitive researchers are all trying to achieve the same innovation. Wright explores how other mechanisms such as prizes and research grants may mitigate some of these problems, and demonstrates that for patents to be superior there must be some private information held by researchers. However, Wright's underlying assumption – many researchers targeting the same innovation – addresses exactly the opposite problem from the one I focus on in this paper: inadequate incentives for even one firm to engage in costly R&D in specific areas. Hopenhayn, Llobet and Mitchell (2006) extend Wright's analysis, focusing on the problem of sequential innovation, and compare prizes and patents. However, their model does not address the problem of incomplete appropriability of patents, except inasmuch as it relates to sequential innovation. I discuss in the text below some of the other interesting research on non-patent incentives for innovation.

In the following sections, I introduce a simple model for exploring patents, research grants, and prizes, and examine each mechanism in turn, in order to provide

[4] See National Research Council, 2007, p. vii.

some perspective on the strengths and weaknesses of each. I then introduce OBRs in the same model, exploring how OBRs interact with patents and how they might be used.

## 2. The core model

Innovating firms each have a single idea. Each idea, indexed by *i*, is characterized by $\{s_i, p_i(c), a_i, \lambda_i\}$, as described in Table 1.

Table 1

The Characteristics of an Idea

| | |
|---|---|
| $s_i$ | The social surplus in case an innovation is developed and it is made available for free (i.e. it can be produced competitively) |
| $p_i(c)$ | The function relating the investment into R&D $c$ to the probability of developing the innovation. By assumption $\frac{\partial p_i}{\partial c} \geq 0$ |
| $a_i$ | The fraction of $s_i$ which can be appropriated by an innovator under the patent system. |
| $\lambda_i$ | The ratio of deadweight loss (caused by above-cost pricing by a patentee) to $s_i$. |

In this simple model, the government establishes one or more innovation mechanisms, which are described below. Firms observe the mechanisms, and then invest $c \geq 0$ in R&D. Finally some innovations are successful, and those which are successful are exploited. Firms are then rewarded either through the exclusive use of patent rights and/or through prizes. In the case of research grants, firms or researchers seek grants, and the government awards some amount $c$ to invest in R&D. This is invested and with probability $p_i(c)$ innovation occurs and the product is sold.

I make a number of simplifying assumptions. First, the model has only one period. Second, the model assumes that $s_i$ is independent of other innovations. This assumption has bite: it means that there is no racing to the finish line for innovations. (In general, of course, innovations may be substitutes or complements. Therefore, all that is really required is that on an expected basis, the social surplus obtained from a given innovation is not affected by the number of other innovations which are developed, which implies that innovations are on average neither substitutes nor complements.)

## Optimal innovation

The net surplus obtained by investing *c* in R&D on project *i* is $p_i(c)s_i - c$, assuming that the investment is financed by distortion-free taxation. This implies that the optimal investment in each project is given by the first-order condition $\frac{\partial p_i}{\partial c}s_i = 1$. Define $c_i^* \equiv \arg\max_c p_i(c)s_i - c$. Sufficient conditions for uniqueness of $c_i^*$ are $\frac{\partial p_i}{\partial c} > 0$ and $\frac{\partial^2 p_i}{\partial c^2} < 0$. Then the total available social surplus from innovation is given by $\sum_i p_i(c_i^*)s_i - c_i^*$.

## 3. Innovation given a patent system

In a patent system, each innovator determines the amount of spending on its innovation, based on its own expected profitability. Suppose that innovators are well informed, and know $s_i$, $p_i(c)$, and $a_i$ in advance, and are risk neutral. The innovator's profit obtained by investing in project $i$ is $p_i(c)a_is_i - c$. Define $c_i^P \equiv \arg\max_c p_i(c)a_is_i - c$. Then the total social surplus from innovation is given by $\sum_i p_i(c_i^P)s_i(1-\lambda_i) - c_i^P$.

There are two deviations from optimality. First, there is insufficient investment into innovation, since for any $a_i < 1$, $c_i^P < c_i*$.[5] This leads to a reduction in social surplus. Second, there is a deadweight loss on those innovations which are developed because of pricing above marginal cost. The sum of social losses is $\sum_i \left([p_i(c_i*)s_i - c_i*] - [p_i(c_i^P)s_i - c_i^P] + p_i(c_i^P)\lambda_i s_i\right)$, consisting of the loss from reduced R&D investment, and the deadweight losses on those innovations which are developed.

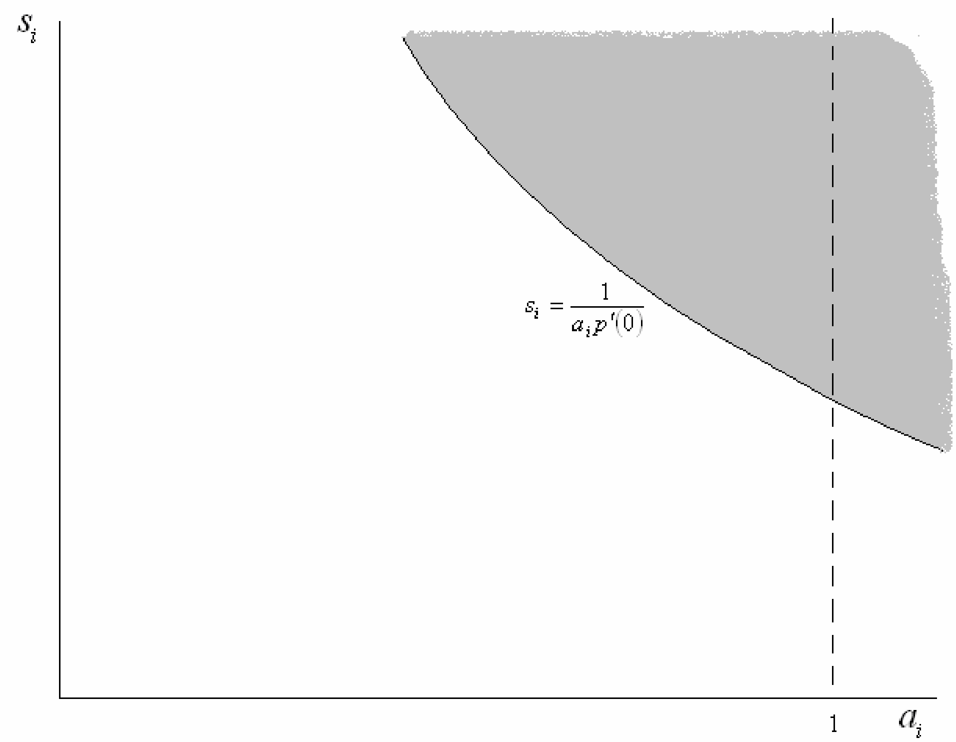
It is likely that there is a positive correlation between the appropriability $a_i$ and the deadweight loss $\lambda_i$ in case an innovation is developed. Thus, for innovations of a given $s$, those which are more likely to be developed (because of higher $a$) are also the ones which will be exploited less efficiently.

Figure 1 illustrates the distortions created by the patent system. For the purposes of the figure, it is assumed that the function $p_i(c)$ is the same for all $i$, and that $p'' < 0$. The boundary of innovations which have some investment into R&D is therefore given by $s_i = \frac{1}{a_i p'(0)}$. Notice that this means that there is a set of potential innovations with no R&D spending at all, to the left of that boundary. To the right of the boundary, there will

[5] It is also possible in some situations that $a_i > 1$, in which case there is excessive investment into R&D. Such a situation can arise if a patented innovation shifts market share (as in Mankiw and Whinston 1986) but creates little incremental value.

be inadequate R&D spending for any project with $a_i < 1$, and deadweight losses when an innovation is developed.

Figure 1




Note that innovations which are not developed because of insufficient (including zero) investment into R&D will not be observed. In general, we have no idea what innovations are possible. This is a very important problem, and seems likely to dominate the deadweight loss problem, possibly by an order of magnitude or more. Not all commentators appear to agree with me on this. For example, Suzanne Scotchmer (2004, p. 37) claims that "Deadweight loss is the main defect of intellectual property as an incentive mechanism." I compared the deadweight loss and the loss from incomplete appropriability for a particular parameterization of my model: $s \sim U[10,100]$, $a \sim U[0,0.5]$, $p = \max(1-1/c,\ 0)$, and $\lambda = a^2$. The loss from incomplete appropriability in this case is approximately 18% of surplus obtained under optimal innovation, while the deadweight loss is approximately 1.4%. Obviously the relative importance of these two effects depends on the distribution of $s$ and $a$ as well as the form of $p(c)$ and the relation between $\lambda$ and $a$. For the particular parameterization used, deadweight loss was larger only for values of $a > 0.4$, and $s$ sufficiently large. It seems unlikely that patentees are typically able to capture over 40% of potential surplus from their innovation.

Cohen, Nelson and Walsh (2000) show the results of a survey of firms on the effectiveness of "appropriability mechanisms." Strikingly, they report that most manufacturing firms find patents to be relatively ineffectual at capturing returns to innovation. Firms claimed that secrecy, lead time, complementary sales and service, and complementary manufacturing capability were on average more effective mechanisms for appropriating returns to product and process innovations. The reason that patents are so ineffectual in many contexts is that rivals can invent around patents, often with relative ease.

The importance of incomplete appropriability is largely determined by the magnitude of $c_i^* - c_i^P$ across the range of innovations. Notice that increasing appropriability, by for example increasing patent length, is not necessarily a good solution to this problem, since it creates higher deadweight losses in achieved innovations. (There are also other problems from increasing appropriability not captured in this model – for instance, excessively long patent protection may hinder sequential innovation.)

The problem of inadequate investment into R&D naturally suggests that a solution is required. There are two common solutions. First, government research grants are often used to stimulate research investment into areas of inquiry for which it is believed appropriability is particularly low. For example, much basic research requires long time periods to be turned into commercially successful products. If the time lag from investment to commercial development is too long, the 20-year time limit of patent protection may result in extremely low or zero appropriability by the innovator. Thus we often observe basic research funded by government rather than by private firms. Second, and less commonly, governments or other organizations sometimes offer prizes for attaining of specific innovation goals. I discuss the effectiveness of these solutions to the problem of inadequate R&D investment in Sections 4-6 below.

## 4. Research Grants

Research grants are paid by governments to researchers based on claims made by researchers that they are investigating an interesting topic. This is, in effect, a solution to the problem of low appropriability, since the researcher is compensated based on incurred expenses, rather than on the surplus from developed innovations. The obvious problem with such a system is that researchers who are compensated based on incurred expenses have an incentive to ensure a continuing stream of research grants: maximizing $p(c)s - c$ from among a set of possible projects – most of which are managed by other researchers – is not their objective.

The government may mitigate this problem by assessing the project in advance. However, typically granting agencies do not know either $s_i$ or $p_i(c)$ for any project: all they really know is *c*.[6] The assessment process is expensive and is typically delegated to a committee of researchers who have little incentive to determine accurately the expected benefits, since assessment is costly to them personally, while the effect of good assessment accrues to society generally. The result is that the assessment is likely to favor projects which are of personal interest to the assessors.

Despite flaws in the research grant process, it has historically been critical to the development of important innovations, especially in basic research.[7] In particular for innovations where expected appropriability through the patent system is low or zero, research grants have been the *only* way to enable research into many interesting and productive avenues of investigation.

We can model the grant process in a similar way to patents. We assume, first of all, that the excess social cost of funds is $\Lambda$. This may be thought of as the marginal deadweight loss caused by the income tax system. Second, we assume that the government funds projects based on an estimate $\sigma_i^G$ of true social value, and that it has true information on $p_i(c)$. (Obviously the government doesn't really have good

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[6] Even *c* is subject to moral hazard on the part of the grant recipient, who may receive a research grant for one purpose and spend it on another. Scotchmer (2004) shows that moral hazard problems of research grants are mitigated by fact that they are set in a repeated game context, where only "successful" researchers are able to receive grants in the future.

[7] For example, Iain Cockburn and Rebecca Henderson (2000) examined the 21 new drugs introduced between 1965 and 1992 with the highest therapeutic impact, as judged by industry experts. Among the 21, only five, or 24 percent, were developed with essentially no input from public sector research.

information on $p_i(c)$, but the effect of lack of information about probability of success is similar to the effect of lack of information about social value, so in the interest of brevity we will assume that all the ignorance is summed up in the error $s_i - \sigma_i^G$.) Define the ratio $\alpha_i^G = \frac{\sigma_i^G}{s_i}$. Then the estimate of the government is $\alpha_i^G s_i$.

Define $c_i^G \equiv \arg\max_c \left[p_i(c)\alpha_i^G s_i - c(1+\Lambda)\right]$. If the government had adequate resources allocated to this purpose, it could fund all projects for which the expected net benefits were positive. Then the total social surplus from research grants would be given by $\sum_i p_i\left(c_i^G\right)s_i - c_i^G(1+\Lambda)$. Comparing the patent system and the research grant system, it is evident that the differences relate to (a) the cost of funds (whether through the deadweight loss incurred in monopolies or through income taxes) and (b) the accuracy of the estimate of social value compared to the appropriability under the patent system. The accuracy of $\sigma_i^G$ is important since it determines which projects are chosen to be funded. We know that $a_i s_i$ is correlated with $s_i$; but if there is large variation in $\alpha_i^G$, $\alpha_i^G s_i$ may be poorly correlated with $s_i$, resulting in a poor choice of research projects.

Unfortunately, errors in the signal of the value of a project may be expected, since researchers are likely to overstate the value of the project they are working on, as well as its probability of success, in order to secure funding. In addition, it is necessary to identify both $s_i$ and $p_i(c)$ before the innovation is actually developed, which will generally entail large errors.

If $\sigma_i^G$ is much larger than $s_i$, the social surplus from investing in R&D for project $i$ will be negative at the margin and may be negative on average. If the distribution of $\alpha_i^G$ has very high variance, i.e. if there is low correlation between $s_i$ and $\sigma_i^G$, then the allocation of research funding will be poor and may even lead to losses. If, on the other hand, $\sigma_i^G = s_i \ \forall\ i$, then the grant system would work perfectly.

Even if the government believes that the signal of social value of a research projects carries little information value, there is a solution. It can limit the research grants only to those with the highest expected returns, in order to increase the average return on grants by excluding those with relatively low returns. This is in fact exactly what we observe. If the signal of project quality $\sigma_i^G$ is poor, the optimal strategy will be to restrict the amount of grants. This in turn limits the usefulness of research grants.

How do patents and research grants interact? Government can claim patent rights in any innovation developed through a funded grant. In this case, innovators with private information and a project that was profitable to invest in under the patent system would never accept government funding, since government funding is by its design only enough to pay costs.[8] This would ensure that all grants funded projects for which there was insufficient patent incentive to undertake R&D. This means that the available projects are

[8] Scherer (2006, p. 19) discusses an example of this, which he attributes to the Harbridge House Inc., Report, "Effects of Government Patent Policy on Drug Research and New Product Development" (Boston: 1967), Sections I and IV: "up to 1962, drug companies routinely screened new organic molecules synthesized by academic researchers under government grants. However, when the Department of Health, Education, and Welfare imposed new reporting requirements that threatened the exclusivity of drug companies' rights to commercialize molecules found to be therapeutically interesting, such testing ceased abruptly." The 1980 Bayh-Dole Act, in response to this, created a presumption that recipients of government grants would be entitled to patent rights, subject to as yet unused "march-in" rights retained by government. The impact on university patenting has been positive, but the overall effect on the social value of university research is less certain.

disproportionately clustered in those of low appropriability and low social value. Giving grants to those projects with low appropriability is desirable – that is, in some sense, the ideal set of projects for which research grants are suited – but giving research grants for projects with low or even negative $p_i\left(c_i^G\right)s_i - c_i^G\left(1+\Lambda\right)$ is undesirable.

## 5. Targeted "*Ex Ante*" Prizes

Prizes are another solution to the problem of creating incentives for research beyond those offered by the patent system.[9] Targeted prizes are typically offered for specific projects with an expected high social value but for which the patent system has not delivered any result, i.e., projects with high $s_i$ and low $a_i$. A difficulty in offering a targeted prize is, typically, ignorance about $p_i(c)$. How large a prize is required to induce development of the desired innovation? From the perspective of the government granting the prize, and assuming that no R&D would occur in the absence of the prize, as long as the cost of the prize is less than the estimated social value, the net effect is positive.

For a given prize, $z_i$, and assuming that the prize entails a loss of patent rights, the innovator obtains expected profits of $p_i(c)z_i - c$. At the profit-maximizing value $c_i^Z(z_i)$, expected social surplus from the prize is $p_i\left(c_i^Z\right)\left[s_i - \Lambda z_i\right] - c_i^Z$. The socially optimal prize, $z_i{*}$, will be increasing in $s_i$ and $p'_i$ and decreasing in $\Lambda$. Define

[9] For more on prizes, see National Research Council (2007), Scotchmer (2004) and Krohmal (2007).

$\alpha_i^Z = \frac{z_i}{s_i}$. Then $c_i^Z \equiv \arg\max_c p_i(c)\alpha_i^Z s_i - c$, and the expected social surplus from the prize is $p_i(c_i^Z)s_i[1 - \Lambda\alpha_i^Z] - c_i^Z$.

It is instructive to compare this to the patent outcome. Suppose, to assist in comparison, that $\alpha_i^Z = a_i$. Then the rewards to firms from prizes and patents are the same, so that $c_i^Z = c_i^P$. In this case, patents are superior to prizes only if $\frac{\lambda_i}{a_i} < \Lambda$. Thus, given the assumption of equal appropriation under patents or prizes, the relative effectiveness depends not only on the relationship between the social cost of funds and the deadweight loss under patents, but also on the appropriability. Since generally $\lambda_i$ will be positively correlated with $a_i$, the superiority of prizes over patents depends chiefly on $\Lambda$. If $\Lambda$ is relatively small, prizes will in this situation generally dominate patents.[10]

Of course, the assumption of equal appropriability between patents and prizes is empirically unlikely, since the chief reason for prizes is to solve the problem of inadequate appropriability under the patent system. If $\alpha_i^Z > a_i$, prizes may increase surplus through increasing investment in R&D. Thus, targeted prizes appear to be a desirable way of stimulating innovation, when the desired innovation is well understood.

If this is the case, why are prizes not used more commonly? The principal problem with targeted prizes is that it is necessary to be able to define the desired

[10] For the case of perfect monopoly created by a patent, linear demand and constant marginal cost, $\lambda = a/2$. In this case, prizes will dominate patents if $\Lambda < 1/2$. Estimates of the marginal cost of public funds are quite dispersed, since they depend on the particular method used. However, assuming that $\Lambda > 0.2$ seems justified (Warlters and Auriol, 2005).

innovation in a very tight way, and this is generally not only difficult but undesirable. For example, suppose a prize were to be offered for the development of an effective HIV/AIDS vaccine.[11] The first problem would then be in defining “effective” (effective for how long and in what proportion of the population, and against what strains of HIV/AIDS?). At the same time, one might want to include parameters defining the safety profile of the vaccine (what if it killed 1 in 10,000 recipients?) and its cost and required frequency of inoculation. Defining all these characteristics requires the prize authority to have a wealth of information about the potential vaccine before it is even developed, which is obviously problematic. In addition, having defined the prize availability to a very specific achievement, how would one treat an innovation which was close? And could one offer extra for an innovation which exceeded the technical standards? (If one offered the same prize for a vaccine which was marginally effective and one that was perfectly effective, it would distort incentives for quality downwards.)[12]

Targeted prizes also provide incentives which are not efficiently allocated across innovations, in the sense that the marginal dollar invested in a given prize is not likely to have the same expected impact on social welfare as the last dollar invested in a different prize. This problem is inevitable because of ignorance about $p_i(c)$. Thus, a fundamental and unavoidable problem of a targeted prize system is that, like a research grant system, it places investment decisions in the hands of someone other than the innovator. In the

[11] The Advanced Markets proposal espoused by, among others, Kremer and Glennerster (2004), would set aside a sum of money to pay a supplementary fee to any firm which could develop and deliver new vaccines, based on the number of units delivered, subject to meeting specific technical requirements.

[12] Another mechanism in prizes is a tournament model in which the government establishes a general goal and then awards the prize to the firm that gets closest within a given period of time. This mechanism, however, imposes considerable risk on the government, since a firm which has very low expectation of actually achieving the target, but believes that it may be able to get closest, may invest heavily.

case of research grants, investment decisions are determined by the granting authority; in the case of targeted prizes, investment decisions are directed, in that the prize authority chooses the desired projects. These projects, however, are likely to be the wrong projects, in the sense that they are not likely to be those which have the greatest average return on R&D investment. Certainly, any optimal prize system would equalize the marginal benefit of R&D in different projects.

The narrowness of a targeted prize is also troublesome: it is problematic because it requires a solution to fit into tightly defined criteria which may be difficult to define in advance of seeing a solution. At the same time, because of the narrowness, it may miss incentivizing other more valuable innovations. As Scotchmer (2004, p. 38) notes, “the most important obstacle to effective public sponsorship is in tapping ideas for invention that are widely distributed among firms and inventors.” Given the narrowness of each particular prize, it might seem suitable to offer a large number of different prizes for different possible outcomes. This, however, creates an enormous difficulty of administration and would require one to specify all kinds of contingencies in a rich environment of possible innovations.

## 6. “Ex post” prizes

A different strategy has been adopted in other situations: *ex post* prizes. In this situation, an innovation occurs and the innovator is rewarded with a prize determined after the innovation is developed. *Ex post* prizes can address two problems of the patent system. They can eliminate the deadweight loss; and they can enhance the incentive to innovate by increasing the potential reward. I first discuss prizes designed principally to eliminate deadweight loss.

Michael Polanvyi (1943) argued for the replacement of the patent system with a system of *ex post* prizes in order to reduce deadweight loss. Under his proposal, the patentee would forgo its exclusivity rights, a payment would be made by the government as compensation, and competition in the use of the innovation would be enabled. There are a number of problems with this approach. The first problem is in setting the payment made to the patentee. How large should it be? Adam Smith (1763, p. 83) noted that patents are likely to more accurately reward invention than a prize:

> Thus the inventor of a new machine or any other invention has the exclusive priviledge of making and vending that invention for the space of 14 years by the law of this country, as a reward for his ingenuity, and it is probable that this is as equall an one as could be fallen upon. For if the legislature should appoint pecuniary rewards for the inventors of new machines, etc., they would hardly ever be so precisely proportiond to the merit of the invention as this is. For here, if the invention be good and such as is profitable to mankind, he will probably make a fortune by it; but if it be of no value he also will reap no benefit.

In addition to the problem of not *knowing* how large the prize should be, once the innovation has already been developed, there is a moral hazard problem on the part of the prize-awarding body: in pharmaceuticals, for example, many countries employ schemes for reducing pharmaceutical prices. In some cases, they simply use compulsory licensing schemes in which the prize is a small royalty.[13] This, of course, will reduce incentives for innovation. This problem has resulted in some interesting work on how to construct prize schemes which would reward innovators adequately.

Michael Kremer (1998) devised an ingenious scheme for determining a suitable amount after a valuable innovation was developed: he proposed a private auction for the patent rights. The government would then, with some probability, declare the auction

[13] For example, Canada employed such a scheme between the 1950s and the 1980s, and then introduced a price control regime.

void and pay an amount equal to the winning bid. Bidders wouldn't know whether the government declare the auction void or not and would therefore have an incentive to bid honestly, thereby revealing the private value of the patent $a_i s_i$.[14] With some probability, the government would end up owning the patent and the deadweight loss $\lambda_i s_i$ could be eliminated at social cost $\Lambda a_i s_i$. Of course, this patent buyout addresses only deadweight loss and has no effect on incentives for innovation.

Steven Shavell and Tanguy van Ypersele (2001) suggested an *optional* patent buy-out system, in which the government would offer to purchase the patent after the innovation was developed, with the price based on its best information. Suppose that the social cost of funds to the government was $\Lambda$, and suppose that the offered reward was equal to $(a_i + \phi_i \lambda_i)s_i$, with $\phi_i$ any real number. For $\phi_i < 0$, the offer would be rejected and welfare would be unchanged, and for any $\phi_i \geq 0$, the offer would be accepted. Then the change in welfare would be given by $(a_i + \lambda_i)s_i - (1+\Lambda)(a_i + \phi_i \lambda_i)s_i$, which implies that welfare would be increased only if $\phi_i < \frac{\lambda_i - \Lambda a_i}{\lambda_i + \Lambda \lambda_i}$. This inequality reveals that if the offered reward were too large (i.e. $\phi_i$ above some critical value), the mechanism would decrease welfare. At the same time, $\phi_i$ cannot be below zero, since then it is ineffectual. Consider a monopolist facing a linear demand curve, with constant marginal costs, and assume $\Lambda = 0.3$. In such a case, the critical value of $\phi_i$ is approximately 0.3, which allows little room for error on the part of the government granting the prize. For a less

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[14] There are more details involved than this: Kremer suggests that the government should pay some multiple of the third highest bid, since the highest bid might be vulnerable to collusive behavior.

effective monopolist with $a = 0.4$, still assuming constant marginal cost and linear demand, the critical value of $\phi_i$ is approximately 0.2. That is to say, unless the social cost of funds $\Lambda$ is very low, or the government is extremely accurate in evaluating $a_i$, $\lambda_i$, and $s_i$, the opportunities for use of this strategy are very limited. (However, since such prizes are to be offered *ex post*, the government has some ability to observe the innovation in action – thus there is less uncertainty about $s_i$ than with *ex ante* prizes.) Indeed, the obvious strategy in this situation is to make very low offers, since that is costless – if accepted, there is a chance of increasing welfare, and if rejected the offer does no harm. However, such a strategy can do little to increase incentives for innovation.

Scott Kieff (2001) argues that patent buy-outs will tend to be ineffectual, because of the great distance between an innovation and a commercially successful product: in the absence of the requisite additional investments to turn the innovation into a commercially available product or process, the social value may, after all, turn out to be rather small. In the pharmaceutical industry, for example, significant promotional expenditures appear to be important in turning effective drugs into profitable blockbusters. (A common observation in the pharmaceutical industry is that the sales volume of drugs tends to fall with prices after generics enter the market: the reason, of course, is that promotional expenditures are reduced sharply given the common pool problem between competitors, and doctors therefore reduce their prescriptions of that drug.) Thus, to the extent that the full exploitation of an innovation requires further investment, eliminating the patent monopoly may actually reduce, not increase, welfare.[15]

Finally, it should be observed that if innovators expect only to obtain the same revenues as they would under the patent system, prizes which replace patents ultimately do little solve the significant problem of inadequate incentives for innovation.

A second category of *ex post* prizes is designed to enhance the incentives to invent. In the Soviet Union, inventors received prizes, rather than patents, when they were successful at developing some innovation thought to be valuable. However, the prizes were relatively small and the record of invention not impressive (Scherer, 1980, p. 458). A more promising approach seems to be to award prizes along with patents. For example, the Nobel prizes or other similar awards may provide some stimulus towards innovation when patents are inadequate. However, given the uncertainty inherent in such prizes, which are awarded at the discretion of the prize authority, it seems unlikely that they resolve the problems of inadequate incentives for innovation.

## 7. Optional "Broad Rewards"

An obvious problem with the types of prizes discussed above is that they require either *ex ante* specification, narrowing the range of possible innovations which might apply, or are so general that they create at best weak incremental incentives for innovation. Targeted prizes can solve problems with inadequate incentives, but do so for only a small possible

[15] The Kieff critique can also apply to research grants, if the grants do not permit patents. It is perhaps exactly in response to the Kieff critique that the Bayh-Dole Act permitting patents on government funded research was passed.

set of innovations; while *ex post* prizes offer no commitment of increased rewards to innovation and therefore only help to solve the deadweight loss problem.

The discussion of incentive mechanisms above suggests the following criteria as desirable for incentive mechanisms:

(1) Given $p_i(c)$ unknown to the government, the prize or payment to the innovator should be as closely dependent on actual created surplus as possible, i.e. that the reward should be "precisely proportiond to the merit of the invention";

(2) Investment decisions should be made by those with the most information (unlike research grants and targeted prizes), conditional on (1);

(3) The risk of moral hazard on the part of the reward or patent administrator should be minimized (unlike *ex post* prizes);

(4) Incentives for continuing commercial development of the innovation should be maintained (unlike patent buy-outs and research grants);

(5) Deadweight losses, whether through taxation or above marginal cost pricing, should be minimized.

In this section, I examine a new incentive mechanism, which I will label "optional broad rewards" (OBR).[16] The OBR mechanism can in principle meet all of these criteria and therefore provides a potentially valuable incentive mechanism for innovation. The essence of this incentive mechanism is that rewards are offered from a fund for any

[16] This mechanism is quite new. Variations on it are described in Hollis (2005), Pogge (2005), Masters (2005) and a bill in the US congress, HR 417 (109th Congress, 2005).

patented innovation which contributes towards some general target – such as a decrease in tons of carbon emissions or a reduction in morbidity – in exchange for the innovator's relinquishing exclusivity rights under its patent. The share of the reward obtained by a given innovator is equal to his share of achieved improvements in the general target.

An OBR mechanism operates by identifying a socially desirable outcome. An example of such an outcome is additional years of life achieved by a new pharmaceutical or surgical innovation. To the extent that the value of innovations can be summarized (at least partly) by measuring some outcome, this allows a variety of unforeseen innovations all to be given prizes from the same pool. Instead of describing the technical characteristics of the innovation, as is necessary in a targeted prize, the reward describes the desired measurable outcome.

Given the government's cost of funds $\Lambda$, the optimal investment decisions require $\frac{\partial p_i(c)}{\partial c} s_i = 1 + \Lambda$ for each idea *i*. Suppose that the government could perfectly observe $s_i$ (but not $p_i(c)$), and that its budgetary constraint was not binding. Then the second-best investment decisions can be decentralized to firms by offering a prize for innovation *i* of $\alpha^B s_i$ where $\alpha^B = \frac{1}{1+\Lambda}$.

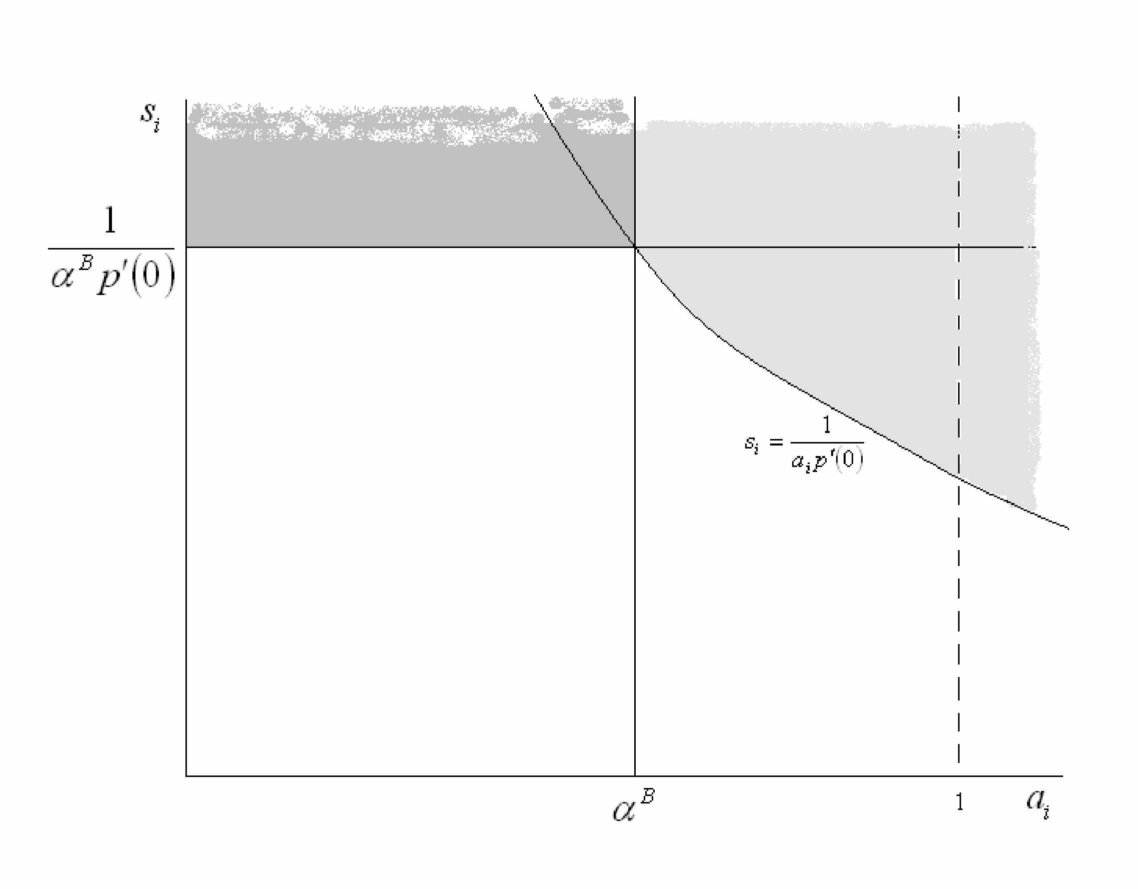
Perfect observation of $s_i$ and unconstrained budgets are not achievable, and in the following we relax these two assumptions, starting with the budget constraint. Suppose that the government has a fixed total budget *F* for rewards, which seems likely given the government's limited ability to raise money through taxation. How should it allocate it, assuming that it can only observe $s_i$ but not $p_i(c)$? Assuming that the budget is fixed, but the actual innovations arrive stochastically, the best strategy for the government is to set $\alpha^B = \frac{F}{\sum_{i \in I^B} s_i}$, where $I^B$ is the set of innovations which are actually developed and rewarded under the broad reward system (as opposed to those which retain their patent rights). This means that each innovator's reward $\alpha^B s_i = F \frac{s_i}{\sum_{i \in I^B} s_i}$ is a share of the reward fund equal to its share of the social value created by all rewarded innovations. We will relax the assumption of perfect observation of the social value in next section.

An equilibrium exists when (a) each firm's investment in R&D is privately optimal, given every other firm's investment, and (b) each firm chooses the incentive mechanism – rewards or patents – which will maximize its expected profits. Condition (a) requires that each firm chooses *c* such that $p'_i(c) \frac{s_i}{\sum_{i \in I^B} s_i} F = 1 \; \forall \; i \in I^B$. Given $p'' < 0$, this will be a unique value for any set $I^B$. Define $c_i^B(I^B)$ as this unique value. Condition (b) requires that $p_i\left(c_i^B(I^B)\right) \frac{s_i}{\sum_{i \in I^B} s_i} F - c_i^B(I^B) > p_i\left(c_i^P\right) a_i s_i - c_i^P$ for all $i \in I^B$, and the opposite for all *i* for which an ultimately successful R&D investment is rewarded through a patent monopoly. These two conditions will be satisfied for profit-maximizing firms.

## 7.1 Characteristics of OBR

The characteristics of such a reward system with a fixed reward fund can be illustrated in a simple diagram, again assuming (for the purpose of the diagram only) that that $p_i(c)$ is the same for all *i*, and that $p'' < 0$. Figure 2 shows the same range of possible innovations as Figure 1. Those ideas with $a_i > \alpha^B$ are unaffected by the reward system since a successful innovation of that type is rewarded through the patent system. For ideas with $a_i < \alpha^B$, R&D decisions will now be based on the expectation of a reward, and if successfully developed they will obtain a reward rather than patent exclusivity. The lower boundary of the innovations which are developed based on the reward system is of course given by $s_i = \dfrac{1}{\alpha^B p'(0)}$ .

Figure 2




The light shaded area shows the set of ideas in which firms will invest based on the patent system. The dark shaded area is the set of ideas in which firms will invest based on the optional broad reward system. The larger is *F*, the further down and to the right the margins of the dark shaded area move.

There are several important characteristics of such a scheme. First, the incentives for investment in R&D for those innovations rewarded in the OBR system are efficient, in the sense that incentives increase proportionally with measured social value, and with the marginal effect of investment on the probability of success, but are independent of appropriability. This is exactly the desired result. The expected profit of an innovator who chooses the reward system is $p_i(c)\frac{s_i}{\sum_{i\in I^B} s_i}F - c$, so that the choice of $c$ is determined implicitly by the first-order condition $p_i'(c)s_i = \frac{\sum_{i\in I^B} s_i}{F}$. This in turn implies that $p_i'(c)s_i = p_j'(c)s_j$ for any $i$, $j$ in the reward system. But this is simply an efficiency condition: the marginal social value of investing in R&D must be equal across innovations. Given the overall reward amount $F$ available, there is an efficient allocation of R&D between projects. This is a result not obtained under any other system of innovation incentives. Of course, this efficiency result depends on belief by the innovators that the expected rewards are proportional to the actual surplus.

Second, unlike the case of research grants, the government does not need to know anything about $p_i(c)$ – only firms need to know it. This is appealing since $p_i(c)$ can never be observed by government, either before or after the innovation is developed.

Third, a broad optional reward system increases incentives for research for any project for which $\alpha^B > a_i$. These are projects for which the patent system provides relatively weak incentives because of low appropriability.[17]

Fourth, since firms will choose the reward system over the patent system only if $\alpha^B > a_i$, the lower is $\alpha^B$, the less the reward system substitutes for patents. This means that if $\alpha^B$ is relatively low, the principal effect of the OBR system is increased incentives for innovation, not reduced deadweight loss. The degree of substitution between the patent system and the OBR system depends on the size of *F*. As *F* increases, the extent to which rewards substitute for patents increases.

Fifth, the OBR mechanism automatically adjusts to ensure that the reward for an innovation of a given social value is within the range of profits that would be available under the patent system. Firms at the margin will substitute between the OBR system and the patent system. If the rewards under the OBR system are relatively low, more firms will opt to exploit their patent rights, driving up the OBR reward for those who remain, and vice versa. In Figure 2, all innovations to the left of $\alpha^B$ receive a reward equal to $\alpha^B s_i$, which is, as the figure shows, within the range of the quasi-rents earned under the patent system

[17] It is important to recognize that the OBR system does not address the problem of racing. This is not necessarily a serious problem: as noted here, its principle implementation is in areas in which there is insufficient incentive for even one firm to invest in R&D. However, to the extent that racing may create inefficiencies, it is in exactly the same way as in the patent system.

Sixth, because the reward is based on a share of rewarded innovation surplus, it is not necessary for the government to know $s_i$ – all that it needs to know is the *ratio* $\frac{s_i}{\sum_{i \in I^B} s_i}$.

That is, it is only necessary for the government to be able to measure the *relative* social value of a given innovation compared to others in the reward system, not its absolute value. I discuss in Section 7.3 the implications of this requirement to be able to measure relative social value, as well as the impact of imperfect measurement.

Because of these last two properties the informational requirements of the OBR system may be much less for optional broad rewards than for the targeted prizes suggested elsewhere: relative social value determines the relative rewards within the system, while substitutability with the patent system determines the absolute scale of rewards per innovation.

Seventh, because firms compete for rewards, the moral hazard problems of the reward administrator are somewhat mitigated: if excessive rewards are granted to one innovator, other innovators are harmed. The dependence of firms' rewards on each other means that firms have an incentive to monitor other firms' rewards.

## 7.2 Implementation Issues of OBR

The mechanical implementation of OBR requires that an innovator wishing to participate in the system would obtain a patent in the usual way but would offer a zero-priced license for use of the patented innovation. The patentee would then be eligible to collect rewards during every year the innovation was protected by patents.[18] Thus the reward would be based on the total use of the innovation by anyone, not just by the innovator, during the period of the patent.

Such a broad reward system is immune from the Kieff critique, as long as the rewards were distributed on the basis of use of the innovation over a period of years: the innovator would have a continuing incentive to expand the use of its innovation, since the reward would be conditional on the realized impact of the innovation. In this respect, a reward system in which rewards were based on realized impacts is very similar to the patent system.

How should *F* be chosen? One of the important problems for other types of prizes – whether targeted or *ex post* – is that the size of the prize needs to be chosen within some optimal band. If too small, it may have no effect on innovation; and if too large, it could reduce welfare. The broad rewards system is much less vulnerable to this problem, since there is a range of innovations which could be included in the system. If *F* is small, the incentive effect on innovation will of course be smaller. In effect, the boundaries of the innovations stimulated by the optional reward will move up and to the left in Figure 2. In practice, this means that a smaller *F* will be focused on innovations with high $p'(c)s$ and low appropriability. As *F* expands, there is a larger effect on innovation, and more substitution for the patent system. The optimal size of *F* is given implicitly by

[18] Or during some other pre-determined period.

$F = \sum_{i \in I^B} \frac{s_i}{1+\Lambda}$, but it not necessary to be at the optimum. At present, $F = 0$, and so there is likely to be considerable potential gain from increasing *F*.

Note that in cases where there is little incentive for innovation under the patent system because inventing around the patented technology is too easy, the broad reward system can help, since there is no point in inventing around if the technology is freely available. Thus, such a system could not only enhance incentives for innovation but also help to eliminate wasteful duplication. The system would also work in cases such as the drug DCA. As discussed above, the patent system provides no appropriability in this case since it is not possible for the innovator to exclude other firms from selling DCA. Under the reward system, exclusion is not necessary: the innovator could obtain a patent for the use of DCA to treat cancer, and could be rewarded for the use of the drug on this basis.

An OBR system would rely on the existing patent system to resolve problems of attribution – that is to say, who has the right to claim a reward based on an innovation. Since it would rely on the structure of the patent system, OBR would suffer from some of the problems inherent in the patent system. OBR would not eliminate problems of racing and duplicative simultaneous research. However, because it is innovations with low appropriability under the patent system which would be rewarded by OBR, these are not necessarily the kind of innovations which presently have duplicative simultaneous research.

How would incremental innovation fit into an OBR system? Define an incremental innovation as an innovation which relies on two patents – one pre-existing and one new. Define the social surplus from the use of the pre-existing patent only as $s_1$ and that from combination of the two patents as $s_2$.

First suppose that the combination innovation is a superior substitute for the pre-existing innovation, and that the competitive price for both is the same. If one firm is patentee of both innovations, the total reward to the patentee would be $\frac{s_2 F}{\sum_{i \in I^B} s_i}$. However, the net reward from the second innovation only will be $\frac{(s_2 - s_1)F}{\sum_{i \in I^B} s_i}$. The incentives to undertake such incremental innovation are thus proportionate to its "merits". If the patentee of the second innovation does not own the patent on the first innovation, he will need to license it. The patentee of the first innovation will require a payment of at least $\frac{s_1 F}{\sum_{i \in I^B} s_i}$, since he will lose all sales of the unimproved product. This situation is similar to the outcome in the patent system, where one would expect licensing of existing innovations to allow improvements. Thus, there will be obstacles related to transaction costs and opportunistic behavior which may harm incentives for incremental innovation, exactly as in the patent system.

Now suppose that demand for the combination product is independent from demand for the single-patent product. The reward for the combination innovation would still be $\frac{s_2 F}{\sum_{i \in I^B} s_i}$; however, the negotiations over the licensing fee for the first innovation would presumably have a different threat-point.

An important cost of the patent system is litigation. Bessen and Meurer (2007) recently examined the costs of patents, focusing especially on the risks of infringement litigation. They concluded that "patent litigation risk was of the same order as, if not larger than, estimates of the private benefits firms receive from patents." (p. 19) The OBR system could considerably reduce the costs of litigation by reducing the frequency of infringement. Unlike the patent system, since there is no exclusion, there is no need for firms to challenge patents. Thus, particularly given the current generosity of patent offices in granting patents, it would be necessary to establish a system of bounties for successful challenges demonstrating invalidity of the patent, as in Miller (2004), in order to reduce the degree to which invalid patents were rewarded.

## 7.3 Determining Relative Social Value

An important limitation of OBR is that it can only apply to areas of innovation in which it is possible to measure the relative social value of multiple innovations without reference to prices. While economists are accustomed to thinking of measuring value in terms of prices, alternatives do indeed exist. Consumers assess value without reference to prices. Similarly, governments commonly make decisions on, for example, awarding research grants, on the basis of *expected* social surplus $p_i(c)s_i$ when $p_i(c)$ is unknown and $s_i$ still lies in the future. It is a much less ambitious task to measure social value *ex post*, as in the OBR system. Insurance companies, similarly, commonly choose which drugs to list and which to exclude, based on the therapeutic value of the drug in treating various conditions. It is necessary in all these cases to develop a non-market estimate of value. So the limitation of the broad reward system is this: the reward granting authority must be able to choose some measure of social value (not referring to prices) on which to base its rewards.

This limitation means that a reward fund cannot apply to innovations which have effects which cannot reasonably be compared: for example, a single reward fund could hardly be applied to innovations in surgical techniques *and* television technology. However, a single reward fund might apply to one of those areas. I discuss in Section 8 a number of areas in which an OBR system seems plausible.

In most situations, the reward-granting authority will obtain at best an imperfect signal of relative social value. Define $g(s) \rightarrow \sigma$, mapping social value into signals. Suppose that $g(s)$ takes the form $\sigma_i = gs_i + \varepsilon_i$, where $g \geq 0$ and error term $\varepsilon_i$ has some density $G(\varepsilon_i)$ with mean zero. Then the reward for innovation $i$ will be $\alpha^B \sigma_i = F \frac{\sigma_i}{\sum_{i \in I^B} \sigma_i} = F \frac{s_i + \varepsilon_i / g}{\sum_{i \in I^B} s_i}$. This implies, in turn, that the *expected* reward for innovation with social value $s_i$ is simply $F \frac{s_i}{\sum_{i \in I^B} s_i}$, leading to the same incentives for innovation as when the government's signal is perfect.

Suppose, however, that the distribution of possible innovations includes many with zero social value and $p(\underline{c}_i) = 1$. For those innovations, the signal will strictly consist of the error term $\varepsilon_i$. If $\underline{c}_i$ were sufficiently low, and the error term had a sufficiently large range, it would be profitable for a firm to develop such innovations. It could claim a reward as long as the error term was positive, obtaining reward $F \frac{\varepsilon_i}{\sum_{i \in I^B} \sigma_i}$, but creating no social value. Then a firm would find it profitable to invest in this sort of "innovation" if the expected reward was greater than the certain cost, i.e. if $F\int_0^\infty \frac{\varepsilon_i}{\sum_{i\in I^B}\sigma_i} G(\varepsilon_i)d\varepsilon_i > \underline{c}_i$.

Note that if this condition held, the reward fund could be swamped with applications for rewards for worthless "innovations", which could, in a variation of Gresham's Law, drive out the valuable innovations.[19]

The potential problem of worthless innovations suggests two possible responses. First, the quality of the signal matters. If $\varepsilon_i$ is the dominant component of $\sigma_i$, the proposed reward system cannot function effectively. Thus, as discussed above, it is essential that such a system be used only in an industry where the signal is informative. Second – assuming the signal is imperfect – it may be possible to prevent worthless innovation by setting a minimum value of $\sigma_i$ when granting the reward, or requiring applicants to pay a fee at the time their innovation was assessed. This kind of approach would keep small innovations out of the system, but would also deter firms from pursuing worthless or almost worthless innovations in the hopes of getting a lucky draw of $\varepsilon_i$.[20]

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[19] It is arguable that the patent office issues many patents with low value. Notably, in pharmaceuticals, there is a high rate of patents which are found invalid in court when they are used to try to stop generic competition (Boyce and Hollis, 2007).

[20] Excluding small innovations has other attractive properties. First, it would reduce administrative costs. Second, it would enable scrutiny of claims by other firms. While very large reward claims are likely to receive scrutiny from other innovators, small reward claims might attract little attention, leading to possible misappropriation of reward funds.

## 8. Applications of Optional Broad Rewards

I describe in this section some possible applications of optional broad rewards. Even relative social value is in general difficult to measure, particularly when comparing across different types of products, without reference to prices. So, as observed in the previous section, the OBR system can apply only to innovations whose value can be compared. I describe a few such innovation areas below.

Medical Innovations

The purpose of medical innovations, in general, is improved health and longer lives. Health economists routinely quantify the effects of new drugs by estimating the number of QALYs (quality-adjusted life years) they provide.[21] Thus, a rewards authority could use the number of QALYs generated by a given medicine or surgical procedure as a measure of $s_i$. In implementing such a reward system, innovations would only become eligible for such a reward if they offered a zero-priced license of their innovation for use in the patented medicine. Then the innovator would obtain a reward based on the estimated number of QALYs the patented innovation created during the period of the patent.

There are good reasons for thinking that this might be attractive. First, there is a continuing stream of new medical innovations which are patentable. Second, it appears that there are many potential innovations which are not developed because of inadequate appropriability to justify clinical trials. The case of DCA, mentioned in the introduction, is just one of many such cases. Third, the market for pharmaceuticals may be thought to

[21] See, for example, Krupnick (2004).

work exceptionally poorly, since in many countries it is normal that consumers consume but do not pay or choose which drugs to consume, doctors choose but do not pay, and insurers pay but do not choose. This means that the profit under the patent system is likely to be relatively poorly correlated with social value, since prices are likely to be poorly correlated with social value. Thus, the optional reward system might work much better than the patent system for drugs.

The reward system is similar, in some respects, to the patent system plus government funded drug insurance, where the government sets the reimbursement price equal to some fraction of $s_i$ per unit. In countries with government-funded drug insurance, typically the reimbursement price is set according to demonstrated health effects, often using QALY-type measures. Thus the reward system described is not radically different from current practice in countries such as Canada and Australia. However, there are important differences. First, there is typically incomplete drug insurance. Second, appropriability in these countries under the patent system suffers from the usual problems: some innovations are simply not well protected; and other innovations are over-rewarded. (Over-rewarded drugs would include those which are very similar to existing patented drugs but which are rewarded with the same price as the first-in-class.)

Drugs for Developing Countries

Markets for drugs for developing countries might well be suitable for such a system. Many of the same arguments apply in this case as for medical innovations generally. However, there is a special urgency for the development of drugs for poorer countries, as well as significant problems of access. In addition, it is clear that funding for such development is in any case likely to come from outside the patent system. Thus, the alternative funding sources are (a) research grants, (b) narrow prizes and (c) optional broad rewards. Within this set of choices, OBRs appear to have some significant advantages.

Carbon capture or reduction

Another area in which the principal object of innovation can be measured without prices is reduction in $CO_2$ in the atmosphere. An innovator who develops a new technology for reducing carbon emissions must currently obtain his reward under the patent system, but this implies first that there will be deadweight losses, i.e. that there will be less reduction in $CO_2$ than would be efficient. Second, it seems likely that the appropriability of some types of innovations which reduce carbon emissions – or sequester carbon – may be very low, because of the externalities involved. An innovator who was rewarded for use of his innovation might even be willing to subsidize its adoption.

Newell and Wilson (2005) discuss a number of different approaches to targeted and *ex post* prizes for climate change mitigation technologies, recognizing many of the problems with targeted and *ex post* prizes noted above. They conclude with a suggestion that an interested corporation or individual might "be inspired to offer a climate technology prize." (p. 37) And indeed Richard Branson's company Virgin recently offered a $25m prize, to be awarded for "a commercially viable design … to achieve the net removal of significant volumes of anthropogenic, atmospheric greenhouse gases each year for at least 10 years without countervailing harmful effects."[22] A broad reward based on actual removal volumes, for technologies which were patented and offered at zero or negative license rates, could have a variety of advantages over this narrow prize for exactly the reasons discussed above in Sections 5 and 6.

Scientific Research

There have been repeated calls for open access to scientific journal articles, particularly those which are the product of research funded by government. Senators Cornyn and Lieberman, for example, recently introduced a bill that would require open access to all research publications funded by US federal agencies within six months of first publication.[23] However, their proposal offers no compensation to journals which find their exclusivity on such articles limited to six months. In effect, the bill reduces the period of copyright from the current 95 years to six months. In such a case, a broad reward mechanism in which the rewards to a journal were based on the number of citations to articles in that journal would provide a method to compensate the journal for its trouble in identifying good articles and editing them.[24] Obviously, like other methods of paying for journals, this would be a very imperfect mechanism. However, it might be better than simply shortening copyright on scientific journal articles. More generally, it might be preferred to the current system of very high prices for scientific journal subscriptions.

[22] Virgin Earth Challenge guidelines, http://www.virginearth.com/, last accessed February 23, 2007.

[23] Federal Research Public Access Act of 2006, S. 2695, 109th Congress.

[24] Simple citations would likely not be a good measure of scientific value – but perhaps some composite measure of citations, citations per word, and times accessed might do better. Tsao (1989) proposes a citation-based payment system.

African agriculture

Many agricultural innovations for tropical countries have extremely low rates of appropriability because of dysfunctional patent systems, difficulty of identifying and prosecuting infringers, innovations embodied in seeds, and easy inventing around. This has led, particularly in Africa, to low rates of technical innovation. Will Masters (2005) has proposed a system to use rewards for innovations in African agriculture, with the reward to be based *ex post* on technical field trials and farm surveys on adoption. (However, his proposed mechanism does not include a fixed annual fund, which would make it more susceptible to moral hazard on the part of the prize-granting authority. He also proposes to make the prize a one-time grant.) If it were possible to measure adoption rates and to obtain evidence of yield increases, as Masters indicates, then they could form the basis of a reward mechanism for innovations in African agriculture.

## 9. Conclusions

How should innovation be rewarded? Most likely a range of tools – patents, research grants, targeted and *ex post* prizes – will continue to be used, as each has its particular strengths and weaknesses. This paper has presented a unified model allowing a comparative view of these mechanisms. It has also, using the same modeling framework, presented an analysis of a new mechanism, which I have labeled "optional broad rewards". I have shown that this mechanism has many attractive properties as well as some important limitations in the innovations to which it might constructively be applied. The most important possible uses are likely in pharmaceutical markets – especially for neglected diseases – and carbon emissions markets.

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