

## Incentives, prizes, and innovation

Heidi Williams<sup>1</sup>

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### 1. Introduction

Concerns have long been raised that competitive markets may not provide the socially optimal level of incentives for innovation (Arrow 1962, Nelson 1959). Given the key role of innovation in promoting economic growth, both academics and policy makers have thus focused attention on how best to design public policies to promote innovation. Intellectual property rights (IPR), such as patents and copyrights, are perhaps the most frequently used policy levers. In this paper, I discuss the value of prize mechanisms as an additional policy lever for encouraging innovation. Although in principle prizes can overcome important distortions that may arise under IPR, in practice prizes face a variety of challenges that must be carefully addressed in order for them to successfully spur research and development (R&D) into socially desirable technologies that will benefit consumers. I focus attention on recent empirical evidence that can begin to inform policy, and highlight areas where additional theoretical work, empirical analyses, and policy experimentation would be particularly useful.

### 2. Evaluating the social value of prize mechanisms: A framework

How can we evaluate the social value of prizes? Almost all prizes aim to provide incentives for innovation. However, some prize structures also aim to encourage access to technologies conditional on their development (*e.g.* through encouraging marginal cost pricing rather than monopoly pricing), and this feature is also relevant in assessing the social value of prizes.

In order to integrate these and other factors into a general framework for evaluating the social value of prizes, I begin by briefly discussing the main conceptual differences between IPR and prize mechanisms. In addition to clarifying a series of welfare-relevant metrics on which prizes can be evaluated, this discussion aims to preview an argument I will return to below. Namely, because prizes are primarily used as a supplement to IPR such as the patent system, a natural role for prizes is in targeting technologies where the R&D incentives generated by the patent system are not a good match with the social value of the technology (due to, for example, market failures).

#### 2.1. Design aspects of IPR systems

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<sup>1</sup> MIT and NBER; [heidw@mit.edu](mailto:heidw@mit.edu). Financial support from NIA grant number T32-AG000186 to the NBER is gratefully acknowledged.

Research and development (R&D) investments generate knowledge that is inherently non-rival. Moreover, in many contexts imitators can easily copy a new technology once it is developed – in which case the knowledge generated by R&D is also non-excludable. If imitators enter, competition may drive price down to marginal cost. In a static sense, marginal cost pricing is efficient because goods will be used if their social value exceeds the cost of production. However, in a dynamic sense marginal cost pricing can reduce incentives for R&D below the socially optimal level: if firms anticipate facing marginal cost pricing after they sink fixed R&D expenditures, they will be deterred from ever making the R&D investments necessary to develop new technologies in the first place.

This type of model motivates IPR policies such as the patent system. IPR is designed to create incentives for R&D by granting inventors exclusive rights to their innovations for a fixed period of time. In this way, IPR provides R&D incentives—but does so at the cost of monopoly pricing distortions during the life of the patent. That is, monopoly pricing implies that at the margin some goods will not be used even when their social value exceeds the cost of production. Another key aspect of IPR is that firms must disclose their innovation, a point I will return to below.

Most criticisms of IPR tend to focus on the static distortions from monopoly pricing. However, academic criticisms of IPR have also focused on a second potential distortion: namely, that IPR may discourage cumulative innovation. By “cumulative,” here I mean cases where a given product is the result of several steps of invention and research. In such markets, IPR on a given technology may affect the incentives for R&D on subsequent innovations building on that technology. To give a concrete example, in previous research (Williams 2010) I examined the question of how intellectual property rights on sequenced human genes affected subsequent R&D using the sequenced genes in scientific research and product development (such as the development of gene-based medical diagnostic tests). Although the effects of IPR on subsequent innovation are ambiguous from a theoretical perspective, recent empirical evidence consistently suggests that on net IPR discourages subsequent innovation (Murray *et al.* 2009, Murray and Stern 2007, Williams 2010).

From a public policy perspective, the question of interest is how best to balance the goals of providing incentives for the development of new technologies, while minimizing the *ex post* distortions caused by both monopoly pricing and the discouragement of cumulative innovation. Hence, these three metrics give a natural framework for evaluating the social value of prizes.

## 2.2. Design aspects of prize mechanisms

Broadly stated, prize mechanisms tend to focus on spurring innovation as their primary goal; in the case of prizes for demonstration projects (as opposed to prizes aiming to spur the development of products directly useable by consumers) spurring innovation may indeed be the *only* goal. Here, a

question naturally arises: why isn't the patent system already providing sufficient incentives for the development of the technology of interest? In some cases, a disconnect between the incentives provided by the patent system and the social value of the technology will arise because of some type of market failure. In thinking about where prizes can be most usefully targeted, it is important to keep this idea in mind. That is, because prizes are used as a supplement to the patent system, a key role for prizes is in encouraging the development of technologies that—because of market failures—may be under-incentivized by the patent system.

There are two additional ways in which prizes can generate social value, even when applied to technologies that may be appropriately incentivized by the patent system—namely, prizes can be designed so as to overcome both of the distortions that can arise under IPR systems. First, prizes can reward innovators in a lump-sum fashion that allows marginal cost pricing, thus avoiding the static efficiency losses from monopoly pricing. Second, prizes can be awarded in a way that places the rewarded innovation in the public domain, thus avoiding the discouragement of cumulative innovation.

To fix ideas, it is worth briefly detailing three examples of prize mechanisms:

- (1) Prizes. In 2007, the U.S. Department of Energy established the Bright Light Tomorrow Prize (L Prize) competition, designed to spur the development of ultra-efficient solid-state lighting products to replace the common light bulb. Such prizes have been the primary focus of recent policy interest in prizes (*e.g.* Kalil 2006).
- (2) Advance Market Commitments (AMCs). AMCs are similar to prizes, but distribute rewards through a price subsidy system that explicitly aims to provide close-to-marginal-cost access to the technology for consumers in both the short- and long-run.
- (3) Patent buyouts. Kremer (1998) discusses how the government of France, in 1839, bought out the patent for Daguerreotype photography and placed the technique in the public domain. He notes that after the patent was bought out, Daguerreotype photography was subject to myriad technical improvements – likely because the patent buyout eliminated the costly reverse engineering that had previously been necessary to do subsequent research on improvements to the photography method.

The L prize illustrates an example of how prizes can aim to incentivize innovation. AMCs provide an example, which we will discuss in more detail in Section 3, of how prizes can be designed so as to avoid monopoly pricing distortions. Finally, the Daguerreotype patent buyout provides an example of how prizes can be designed so as to avoid distortions to cumulative innovation.

Avoiding the monopoly pricing and cumulative innovation distortions that may arise under IPR would clearly be attractive in theory, yet in practice prizes face a variety of challenges that complicate their implementation. Perhaps the most important challenge facing prize mechanisms is the question of

how to set the level of the reward. Despite its shortcomings, one benefit of the patent system is that it naturally overcomes this challenge, in that the patent system creates at least a rough link between the reward an inventor receives and the value consumers place on the innovation. Under the patent system, if a firm develops a “better” product that is more desirable to consumers, the firm will be able to charge a higher price for that product – thus giving firms incentives to invest in product quality improvements that might be difficult for a social planner to observe. In the case of prizes, an important challenge is to design a prize mechanism so as to replicate this (desirable) feature of the patent system.

An important part of this question of how to set rewards under a prize mechanism is defining what event should trigger the payment of rewards. In previous work, Kremer and I (2010) discuss various reward triggers. First, prizes can be awarded based on *ex ante* technical specifications, such the Wolfskehl Prize rewarding the first person to prove Fermat’s Last Theorem. Second, prizes can be awarded based on metrics of *ex post* use, such as the allocation of subsidies per person immunized under the AMC proposal discussed in Section 3. Finally, *ex post* discretion – such as is given to the committee that awards the Nobel Peace Prize – can be allocated in various ways. In that article, Kremer and I argue that essentially any mechanism for rewarding innovation involves some degree of *ex post* discretion, but that mechanisms vary in how much *ex post* discretion is allowed and to whom *ex post* discretion is allocated. Both the patent system and prizes rewarded based on metrics of *ex post* use leave *ex post* discretion relatively more in the hands of consumers instead of in the hands of a committee, which may be desirable as a way of avoiding potential problems such as firms viewing the preferences of a committee as time-inconsistent.

### 2.3. Summing up: A framework for evaluating the social value of prize mechanisms

To summarize the discussion in this section, I take the following three welfare-relevant metrics as a framework for evaluating the social value of prizes:

- (1) Does the mechanism encourage R&D investments on socially valuable technologies? Clearly, a first key issue in evaluating prize mechanisms is whether they successfully incentivize innovation. For example, poorly designed prize mechanisms may reward innovators who create technologies that meet an *ex ante* set of technical specifications but for some reason are not valuable to consumers.
- (2) Does the mechanism impose monopoly pricing distortions? Given the deadweight loss that may arise under monopoly pricing relative to marginal cost pricing, pricing is a second key issue in evaluating prize mechanisms that aim to spur the development of technologies that will be directly used by consumers (as opposed to, for example, demonstration projects).

- (3) Does the mechanism allow *ex post* monopoly control of the technology in a way that may discourage cumulative innovation? Because the available evidence suggests (as discussed in Section 3.3) that IPR may discourage cumulative innovation, a third key issue in developing prize mechanisms is whether they allow the technology to be available in a way that does not distort subsequent R&D.

### **3. Evaluating the social value of prize mechanisms: Empirical evidence**

This section reviews the available evidence on the three analytic issues highlighted in Section 2.3, with a goal of clarifying what has been learned that can inform policy. Section 4 concludes by describing areas where additional analyses may be particularly valuable.

#### 3.1. Incentivizing innovation

Do prizes successfully incentivize innovation? Clearly they need not in all cases: for example, in some cases the reward may be too low to successfully encourage R&D, or firms may not perceive the promise of a future reward to be credible. Given these types of concerns, it is helpful to look at the historical record to ask whether past prizes have been successful in spurring innovation. Prior to two very recent papers, such analyses were limited to a relatively small number of historical case studies. For example, a frequently discussed case study is a 1714 prize offered by the British government for a method of measuring longitude. While detailed analyses of such case studies (as provided by Sobel 1996 for the case of this “Longitude” prize) are invaluable in highlighting potential pitfalls arising with prize mechanisms, such case studies are unable to answer the question of whether prize mechanisms can be systematically used to incentivize innovation. Two recent papers gather new datasets on prizes in order to shed more systematic light on this question: Brunt, Lerner and Nicholas (2008) and Nicholas (2010).

Brunt, Lerner and Nicholas (2008) collect a novel dataset in order to analyze prizes awarded (for “inventiveness”) by the Royal Agricultural Society of England (RASE) between 1839 and 1939. The goal of RASE was to encourage scientists to apply their skills to improving agricultural technologies. Starting in 1839, RASE held annual prize competitions. One year in advance of the competitions, RASE announced which technological areas would be targeted as well as the number and value of prizes to be awarded in each area; judges authorized payment of awards, or withheld them if the criteria for winning were not met, and were also given discretion to award additional *ex post* prizes. These competitions awarded substantial monetary prizes (in excess of £1 million in current prices) as well as prestigious but non-pecuniary medals. Between 1839 and 1939, 15,032 inventions competed for these prizes and a total of 1,986 awards were made.

In order to examine the question of whether these prizes encouraged innovation, the authors assemble data on all applications for (and grants of) British patents from 1839 to 1939, matched to information on competition entrants, prize winners, and prize “schedules” (that is, the pre-announced targeted technological areas as well as the number and value of prizes). Following previous work, they also collect information on whether renewal fees were paid for granted patents as a proxy for the quality of patents (since inventors should be more willing to pay renewal fees for more valuable patents; see, *e.g.* Schankerman and Pakes 1986).

Using this data, the authors present a number of empirical results. First, they find that the RASE contests attracted large numbers of entrants. This is true for both pecuniary and non-pecuniary prizes, with the largest entry effects arising from the non-pecuniary RASE gold medal. Second, they find that prizes are associated with “real” changes in contemporaneous patenting activity in the technological areas targeted by the RASE contests. This result suggests that RASE prizes were spurring not only the entry of technologies into RASE contests, but actually spurring the development of new technologies (as measured by patents) that would not otherwise have been developed. Importantly, the induced innovation seems to be composed of “high quality” inventions as measured by the renewal fee metric described above. Within the sample of “high quality” patents as defined by this measure, the authors find that a doubling in monetary prize value is associated with a 4 percent increase in contemporaneous patents, and that an additional medal is associated with a 20 to 21 percent increase in contemporaneous patents.

In a second recent paper, Nicholas (2010) examines a similar research question in the context of Japan’s Meiji era – during which patents were introduced in Japan (in 1885) and a large number of mostly non-pecuniary prizes were awarded (by 1911, 1.2 million prizes were awarded at 8,503 competitions). Using a methodology similar in spirit to that in Brunt, Lerner, and Nicholas (2010), he finds evidence that prizes increased patent outcomes on the order of 30 percent.

To summarize, both studies suggest prize awards – including non-pecuniary prize awards – can encourage not only entry into prize contests, but also “real” innovation, as proxied by patenting activity. While the results of these studies clearly do not imply that prizes will successfully spur innovation in all cases, they are suggestive that the types of prizes that have been implemented in the past can be successful on this metric.

### 3.2. Avoiding monopoly pricing distortions

In some cases—such as a prize seeking to encourage a demonstration project—the only goal of the prize mechanism will be to encourage innovation. However, in other cases the prize will aim to spur the development of a technology that will actually be used directly by consumers. In such cases,

evaluating the social value of the prize requires taking into account how the rewarded technology will be priced.

In the case of patents, inventors are allowed monopoly power for a fixed time period (namely, the life of the patent). In the case of prizes, the prize mechanism can be designed so as to avoid the deadweight loss that can arise with such monopoly pricing. I here briefly review one specific proposal—the Advance Market Commitment (AMC) proposal—in order to clarify how prize mechanisms can be designed so as to minimize or eliminate monopoly pricing distortions.

The application of AMCs has largely focused on encouraging R&D on vaccines for diseases concentrated in poor countries (see, *e.g.* Kremer and Glennerster 2004). An AMC is a legal contract detailing a guaranteed top-up price that will be paid by sponsors (say, \$15 per treatment) for a pre-defined maximum number of vaccine purchases, conditional on (1) the vaccine fulfilling a given set of technical specifications, and (2) poor countries expressing demand for the product (paying, or other purchasers paying on their behalf, a more affordable price of say \$1 per treatment). The key idea is that the subsidized price provides a financial return for the vaccine developer, but in exchange the developers must agree to a cap on the long-run price charged for the product (or agree to license the technology to other manufacturers). Hence, price subsidies layered on top of the existing patent system achieve close-to-marginal-cost pricing in the short-run, and the agreement for developers to provide the technology at an affordable price (or license the technology to other manufacturers) achieves close-to-marginal-cost pricing in the longer-term.

To summarize, while prize mechanisms frequently focus almost exclusively on providing incentives for innovation, in cases where prizes aim to spur the development of products useable by consumers, it is important to focus attention on pricing—since pricing will be a key determinant of consumers' access to technologies conditional on their development. Price subsidies (such as those used in the AMC mechanism) are one mechanism for increasing access to technologies within the context of the current patent system.

### 3.3. Encouraging cumulative innovation

As discussed in Section 2, a key aspect of the patent system is the requirement that firms must disclose their invention, which in principal disseminates the scientific knowledge underlying the patented technology. However, a question remains of whether the patenting of a given technology nonetheless discourages cumulative innovation, in the sense of subsequent innovation building on the initial (patented) technology. Although the effects of IPR on subsequent innovation are ambiguous from a theoretical perspective, recent empirical evidence consistently suggests that on net IPR discourages subsequent innovation (Murray *et al.* 2009, Murray and Stern 2007, Williams 2010). This empirical

evidence raises the idea that one useful context for prize mechanisms may be to reward innovations where IPR may be expected to substantively distort cumulative innovation.

It is worth first reviewing the empirical evidence suggesting that IPR can distort cumulative innovation, at least in some contexts. It is difficult to estimate the effects of intellectual property on subsequent innovation, largely because technologies that are held with IPR in most cases will be inherently different than technologies that are in the public domain. For example, Moser (2007) finds evidence that higher quality innovations are more likely to be patented. Such patterns of selection into IPR complicate simple comparisons of the levels of subsequent R&D on – say – patented and non-patented technologies, since the levels of subsequent R&D may reflect both any effects of IPR on subsequent innovation, and the “selection effect” of which technologies are patented in the first place.

A number of recent papers have attempted to circumvent such selection issues in order to isolate the effect of IPR on subsequent innovation. Murray and Stern (2007) use data on life sciences technologies, and find that patent grants decrease citations to scientific papers on the patented technology, relative to scientific papers on similar non-patented technologies. Murray *et al.* (2009) find that the removal of IPR restrictions on certain types of genetically engineered mice increased citations to scientific papers on affected mice relative to scientific papers on unaffected mice. Murray *et al.* (2009) also find evidence, consistent with the model of Aghion, Dewatripont, and Stein (2008), that IPR reduces the diversity of scientific experimentation. Finally, in previous work (Williams 2010) I found evidence that non-patent contract-law-based IPR on sequenced human genes appears to have discouraged both subsequent scientific research (in terms of gains in knowledge about the functions genes have within the human body) and subsequent product development (in terms of the use of sequenced genes in genetic diagnostic tests that are available to consumers).

To summarize, although the effects of IPR on cumulative innovation are ambiguous from a theoretical perspective, the body of available empirical evidence suggests that IPR substantively hinders both subsequent scientific research and subsequent product development. Across a relatively heterogeneous set of technologies within the life sciences, and examining various forms of IPR, the available empirical evidence suggests that IPR hinders cumulative innovation – with declines on the order of 30 percent. Clearly much more work is needed in order to examine the extent to which these patterns generalize to other markets and other forms of IPR, but the best available evidence suggests that mechanisms that reward innovation in a way that places the technologies in the public domain may have substantial benefits in terms of encouraging cumulative innovation.

#### **4. Areas where new investment may shed light on how best to apply prize mechanisms**

The historical record suggests that prizes can be successful in what is normally their primary goal—namely, spurring innovation. Of course, this need not be true in all contexts: in any given case the reward may be too low to successfully encourage investment, or firms may not perceive the promise of a future reward to be credible. Hence, additional evaluations of how well past and future prize mechanisms successfully spur innovation would be very valuable. Such evaluations require careful construction of a counterfactual—that is, an approximation of what innovation would have been in the absence of implementation of the prize mechanism. The available empirical studies have constructed such counterfactuals by examining historical contexts in which a relatively large number of roughly similar prizes were offered for some but not all of an otherwise similar group of technologies. This suggests that one potentially fruitful method for prospectively evaluating the impact of prizes would be to take advantage of a setting in which there exists a large group of roughly similar desired technologies (for example, characterizing proteins for each of the approximately 28,000 human genes). In such settings, a series of prizes for individual technologies could be rolled out in an order determined via random lottery, and the (random) differences in timing of whether individual technologies received prize incentives earlier versus later could then be used to infer how prize incentives affect innovation. In the absence of such a large scale experiment, careful advance planning—allowing for prospective data collection—will be helpful in evaluating prizes for individual case studies.

In moving beyond this general idea that prizes may spur innovation, I stress three key points. First, because prizes are primarily used as a supplement to IPR such as the patent system, a natural role for prizes is in targeting technologies where the R&D incentives generated by the patent system are not a good match with the social value of the technology (due to, for example, market failures). Second, if prizes aim to spur the development of technologies that will directly be used by consumers (as opposed to, for example, demonstration projects), then it is important to focus attention on pricing issues that can be important determinants of consumers' access to technologies conditional on their development. Third, a valuable role for prize mechanisms may be in rewarding innovations where IPR would be expected to otherwise distort incentives to invest in cumulative innovation.

Although very attractive in theory, in practice prizes face a variety of challenges that complicate their implementation. As discussed in Section 2.2, perhaps the most important challenge facing prize mechanisms is the question of how to set the level of the reward. Below, I outline a number of questions surrounding prize mechanisms on which additional theoretical work, empirical evidence, and policy experimentation would be particularly valuable:

- (1) How can competition be encouraged within prize mechanisms? As discussed in Section 2.2, one strength of the patent system is that the rewards firms receive have at least a rough correspondence with the desirability of the technology to consumers. For example, if a given

patented technology is superseded by a new, improved technology developed by a different firm, sales will move from the initial entrant to the second entrant. This desirable feature stands in contrast to “standard” prize structures which award a lump-sum payment to one innovator, thus failing to provide incentives for subsequent improvements. One prize structure aiming to encourage market-like competition is the Advance Market Commitment (AMC) proposal (Section 3.2). Because the AMC pays out prizes as a per-unit subsidy, the available prize funds can be paid out to multiple innovators – that is, if an improved vaccine becomes available that is more desirable to consumers than is the initial entrant vaccine, demand (and the subsidy) will switch to be awarded to the subsequent entrant. Further investigation of this or alternative mechanisms for encouraging competition within prize mechanisms would be useful.

- (2) How can rewards under prize mechanisms be calibrated to be roughly in line with the incremental social benefits of the rewarded innovations, in the absence of a price mechanism? Here, a key issue is to design metrics that are non-manipulable by firms, thus avoiding distortions that could otherwise arise due to pure rent seeking. In the case of prize awards for pharmaceutical products, this could involve the use of comparative effectiveness trials to determine the incremental social value of a new pharmaceutical innovation, relative to the next best available therapy.
- (3) What stages of development are prizes most relevant for? Very little empirical evidence is available on how well prizes do at incentivizing innovation for “early” versus “late” stage technologies. Prizes may have a valuable role to play in encouraging researchers to undertake high-risk research on early stage technologies, such as an HIV vaccine. On the other hand, sometimes the relevant barrier preventing a technology from realizing its full social value is not its initial development but rather overcoming monopoly pricing distortions that would otherwise arise under the patent system. In my view, prizes can likely play different but useful roles in both contexts, but additional empirical investigation of these issues would be useful.
- (4) When are prizes most useful relative to direct funding of R&D? This issue is discussed in more detail in Kremer and Glennerster (2004); I here briefly summarize a few of their key arguments:
  - a. Direct funding of R&D through institutions such as the U.S. National Institutes of Health (NIH) has been very successful in generating innovation. A commonly heard generalization is that direct funding of R&D generates research leads, which private firms then transform into products useable by consumers. This highlights one natural role for prizes, which would be for encouraging the translation of research leads into marketable products in cases where market incentives are not sufficient to encourage entry by private firms.

- b. Kremer and Glennerster also argue that—given the incentives facing academic researchers—direct R&D funding may be better-suited for basic research relative to later stages of applied research (which often involves time consuming but less intellectually rewarding tasks).
  - c. Prizes may also have important advantages relative to direct R&D funding in cases where scientific opinion is divided about the feasibility of a given technology. That is, whereas a project such as building a bridge may naturally fit with direct funding, instances such as the development of a malaria vaccine where there exists substantial disagreement in the scientific community about which technological approaches are most promising may particularly benefit from prize incentives.
- (5) How large of a role can prestigious, non-pecuniary prizes play in encouraging innovation? The empirical, historical studies discussed in Section 3.1 (Brunt, Lerner, and Nicholas 2008; Nicholas 2010) suggest non-pecuniary prizes can stimulate innovation on new, high-quality technologies. Investigation of the extent to which this generalizes and applies to modern contexts would be very useful.
- (6) Which institutional mechanisms are the most effective depositories for encouraging cumulative innovation? A variety of institutional mechanisms—ranging from Biological Resource Centers (Furman and Stern, forthcoming) to the online open-access database used by the Human Genome Project (Williams 2010)—appear to be successful in encouraging cumulative innovation. It would be useful to generate additional evidence on which types of institutions are most effective in encouraging subsequent R&D, and to know the extent to which such institutions could be used in conjunction with the patent system (through more clearly navigating aspects of the patent system such as disclosure requirements and experimental exemptions).

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