Prizes and Patents: Using Market Signals to Provide Incentives for Innovations

V. V. Chari, Mikhail Golosov, and Aleh Tsyvinski*

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Abstract

Innovative activities have public good characteristics in the sense that the cost of producing, say, the first unit of a new good is high compared to the cost of producing subsequent units. Moreover, knowledge of how to produce subsequent units is often widely known once the innovation has occurred and is, therefore, non-rivalrous. The main question addressed in this paper is whether mechanisms can be found which exploit market information to provide appropriate incentives for innovation. We consider environments in which agents other than innovator receive the signals about the quality of innovation. For example, information from innovators, competitors, and the marketplace can be used to reward the innovator. If such mechanisms are used, the innovator has strong incentives to manipulate market signals. We show that if an innovator cannot manipulate market signals, then the efficient levels of innovation can be uniquely implemented without deadweight losses—for example, by using appropriately designed prizes. We show that patents are necessary if the innovator can manipulate market signals. For an intermediate case of costly signal manipulation, both patents and prizes may be optimal.

1 Introduction

Prosperity and economic growth depend fundamentally on innovation, that is, on the production of new ideas, goods, techniques, and processes. In the endogenous growth literature (See, for example, Aghion and Howitt 1992, Grossman and Helpman 1991, Helpman 1993, Romer 1990) knowledge advance and innovations are the key drivers of economic growth. A widely shared belief is that competitive markets, on their own, will produce an inadequate supply of innovation. One argument that supports this belief is that many types of innovation have public good characteristics. The cost of producing an idea or the first unit of a good is large. The cost of replicating an idea or producing copies of an innovation is small, especially compared to the cost of innovating. In the absence of intellectual property rights, competitors will produce duplicates and sell them at essentially marginal cost. The producer of the first unit of the good will then be unable to recoup the costs of innovation and will rationally choose not to innovate.

An extensive literature on innovation has discussed the efficiency of various mechanisms intended to increase the level of innovation above that produced by the competitive markets.[1] The central question in the theory of intellectual property rights is to determine the best mechanism that weighs the social benefits of innovation against the costs of distortions imposed by the mechanism. One frequently used mechanism is the patent system, which grants property rights to innovators for some period of time and prevents competitors from copying the innovation. Granting monopoly rights of this form induces innovation by allowing inventors to recoup the costs of an innovation. However, patents impose the usual deadweight costs of monopoly on the society. The classic analysis of patents (see, for example, Nordhaus

*Chari: University of Minnesota and Federal Reserve Bank of Minneapolis; Golosov: Yale and New Economic School; Tsyvinski: Yale and New Economic School. We are grateful to the Associate Editor and three anonymous referees for the suggestions. The authors thank the National Science Foundation for support. Golosov and Tsyvinski thank Einaudi Institute for Economics and Finance for hospitality. We thank Daron Acemoglu, Larry Jones, Matt Mitchell, and Nicolas Werquin for useful comments.

[1] See Scotchmer (2004) for a comprehensive treatment.

1969) weighs the costs of monopoly distortions against the benefits of encouraging innovation. Patents are central to growth theory as the mechanism generating innovation but at a cost of associated monopoly distortions (e.g., Romer, 1990, Grossman and Helpman, 1991, Aghion and Howitt, 1992, O'Donoghue and Zweimuller, 2004). It is not surprising that the issue of how to design patents plays an important role in endogenous growth theory (see, for example, an entire chapter devoted to this issue in the textbook by Aghion and Howitt 1998).

An alternative mechanism is to award prizes.[2] Prizes reward innovators while making the fruits of the innovation public. Competitive markets then produce an efficient number of units of the good or exploit the idea associated with the innovation as efficiently as possibly. This mechanism has the advantage that it avoids the monopoly distortions associated with patents. The disadvantage of this mechanism is that it requires the entity awarding prizes to have a great deal of information about the social value of the innovation. This social value is often not directly available to the prize giver. Thus, an important question is, how can the prize giver use information from competitors in the industry or, more generally, from the market to elicit the social value of the innovation?

This question is particularly interesting in the context of the theory of innovation because those who argue that innovation has public good characteristics explicitly assume that copies of innovated goods can be produced at little more than production costs. In other words, once the good is invented, competitors in the marketplace have a great deal of information on how to produce the good in question. The social value of the good depends crucially on the number of units of the good that will be sold in the competitive marketplace. Any theory of patents as a form of intellectual property must ask why mechanisms cannot be devised which exploit information that will become available in the marketplace after the good has been innovated.

In this paper, we ask whether market signals can be used to reward innovation appropriately while avoiding the deadweight costs of monopoly. We answer this question by setting up a general mechanism design framework. In this framework, a planner can use information from innovators, competitors, and the marketplace to reward the innovator. We begin by considering a benchmark environment in which the planner cannot use market signals. We show that the optimal mechanism is to use patents of uniform length across innovations of differing social value and not to use prizes at all.

We then allow the planner to use market signals to reward innovators and assume that the innovator cannot manipulate market signals. As is conventional in the patent literature and the endogenous growth literature, we assume that other producers immediately learn the value of an innovation once it has been made. We show that the optimal mechanism uses prizes and completely avoids the distorting costs of monopoly. We also show how to construct a mechanism that yields the socially efficient outcome as a unique equilibrium. In terms of implementation, such mechanisms may take a variety of forms. For example, a mechanism that makes the prize for the innovation a function of total sales in competitive markets can implement socially efficient levels of innovation. Other mechanisms allow competitors to supply information about the value and profitability of an innovation.

We then analyze environments where the innovator can manipulate market signals. To set the stage, we assume that the innovator can manipulate market signals costlessly. To make such manipulation concrete, we allow the innovator to bribe other producers who have observed the quality of the innovation. We show that prizes are completely ineffective. The optimal mechanism uses only patents. Indeed the optimal mechanism is exactly the same as the benchmark one in which the planner simply cannot use market signals. Costless manipulation, in this sense, makes market signals valueless.

These results are stark: If manipulation is not possible (or very costly), prizes alone are optimal and if manipulation is costless, patents alone are optimal. This starkness leads us to consider an environment in which manipulating market signals is costly but not prohibitively so. We obtain a more nuanced result that the optimal mechanism uses a mix of prizes and patents.

One concrete way of manipulating market signals, in situations in which the planner rewards the innovator based on the number of units sold, is in the form of hidden buybacks. That is, prizes which depend on sales can be manipulated by the innovator secretly purchasing the good so as to make it seem that the market size is larger than it is. We show that, if the costs of these buybacks are small relative

[2] The classic analysis by Wright (1983) discusses patents and research prizes. See also Hopenhayn, Llobet, and Mitchell (2006) for a modern mechanism design treatment of prizes, patents, and buyouts.

to the costs of the innovation, any mechanism that induces innovation must necessarily induce patents.

Our main contribution is to show that the desirability of the patents as a mechanism to induce innovation relies crucially on the ability of the innovator to manipulate signals. If such manipulation is relatively easy, patents are necessary. If manipulation is costly, patents are harmful. In terms of applications and designing mechanisms in practice, our paper implies that we should be cautious about adopting proposed new mechanisms. Such mechanisms require consideration of how to make them manipulation proof. Such manipulation could occur through bribes, buybacks, and, in the context of auction-like mechanisms, the use of accomplices as bidders.

Our results have important implications for the analysis of policy in endogenous growth models. In the models of Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992), innovation occurs in otherwise competitive markets solely because the legal system grants monopoly rights to innovators. Monopoly profits that the innovator receives significantly affect the level of innovation. A typical assumption in this literature is that other producers in the economy drive the price of a good to marginal cost as soon as patents expire. In this sense, the models have at their core the features that animate our model: innovations are costly, and the moment a good is innovated, competitors know how to produce it. The policy exercises often conducted in the endogenous growth literature are to examine the welfare effects of changes in the length or breadth of patents. That is, the literature typically ignores prizes or other mechanisms as devices to encourage innovation. Optimal patent lengths are obtained from the usual tradeoff between monopoly losses and the gains from innovation. Depending on the details of how the model is specified, sometimes optimal patent lengths are infinite (See, for example, Judd 1985) and sometimes optimal patent lengths are finite (See, for example, Futagami and Iwaisako, 2003 and 2007). Endogenous growth models can also imply interesting tradeoffs between patent length and the rate of innovation. Horowitz and Lai (1996) using the quality-ladder model of Grossman and Helpman (1991) show that if the inventor can develop higher quality improvements over time, then the relationship between the rate of innovation and length of a patent will have an "inverted-U" shape. An increase in patent life induces the researcher to develop larger inventions but inventions occur less frequently. For sufficiently long patents, the frequency effect dominates the size effect, and so the rate of innovation declines for increases in patent life.

In the step-by-step innovation models of Aghion, Harris, and Vickers (1997) and Aghion, Harris, Howitt, and Vickers (2001) the technology gap between the firms determines the extent of the monopoly power of the leader. Aghion, Harris, Howitt, and Vickers (2001) conjecture that full patent protection may be suboptimal in this model. If the follower is allowed to use the technology of the industry leader, a large technological gap monopoly distortions may be reduced, and the innovative activity may increase via this composition effect. Acemoglu and Akcegit (2009), however, point out that this conjecture ignores potential incentive and general equilibrium effects. The policy of Intellectual Property Rights (IPR) that provides less protection to technologically more advanced firms creates a trade-off with the composition effect as it reduces R&D via a standard disincentive effect. They introduce and characterize a state-dependent system of IPR and show that, in fact, the optimal policy should provide greater (not less) protection to technologically more advanced leaders.

In terms of the endogenous growth literature our results imply that analyses of optimal policy could benefit by being precise about the underlying environment. In some applications, it may be reasonable to suppose that innovators cannot manipulate market signals. In such environments, our results imply that prizes are the best way of ensuring the optimal amount of innovation. In other applications, such manipulation may be easy and patents may, indeed, be the only way of ensuring optimal innovation. A failure to specify the environment implies that the literature is quite possibly analyzing optimal policy within a very restricted set of policy instruments.

Our analysis has direct practical and policy implications. For example, following work by Kremer (1998) the Advanced Market Commitments (AMC) plan has been set up to provide incentives for Pneumococcal vaccine development with the active participation of a number of governments and non-governmental organizations (see Experts Group Report 2008)[3]. This plan proposes to subsidize, at deeply discounted prices, the vaccine manufacturers who sell vaccines which protect against diseases to developing countries. The mechanism makes the amount of the subsidy a function of the number

[3] Kremer, Levin, and Snyder 2009 discuss in details the thory behind the AMC mechanism and possible variations on it.

of doses of vaccine sold by the pharmaceutical company. The mechanism is intended to allow vaccine manufacturers to recoup the cost of innovation while ensuring that vaccines are sold at the marginal cost of production. Our main result shows that this mechanism is vulnerable to manipulation. Consider, for example, our analysis of costly signal manipulation via hidden buybacks. Vaccine manufacturers have strong incentives to buy, or have accomplices buy, dosages of the vaccine secretly. If such buybacks are easy to implement, the mechanism used by the AMC plan is likely to yield highly inefficient outcomes. If hidden buybacks are privately costly, this mechanism is likely to do well in stimulating innovations while avoiding deadweight losses. This mechanism is also vulnerable to implicit or explicit bribes. For example, vaccine manufacturers are often large pharmaceutical firms producing and selling a variety of products. Such firms can arrange for implicit bribes in the form of discounts for other products (for example, antibiotics) they sell to countries participating in the AMC in return for larger amount of vaccines purchased.

The most closely related paper to ours is Scotchmer (1999). She studies an optimal mechanism design problem with private information about costs and profits of the innovator and shows that, in general, the optimal mechanism uses both prizes and patents. One difference between her setup and ours is that in our model, we allow the innovator not to incur innovation costs and produce a socially valueless good. The most important difference is that we study how optimal mechanisms should be constructed using market signals, while she does not consider the use of such signals. Also closely related is Hopenhayn, Llobet, and Mitchell (2006) who study a mechanism design problem of cumulative innovation. They study the optimal reward policy when the quality of the ideas and their subsequent development effort are private information. The main difference, again, is that they do not allow for the use of market signals as a part of the optimal mechanism which is the focus of our paper.

There is a small literature on how information available on the market can be used in designing rewards for innovation.[4] Kremer (1998) is the most influential recent paper with a detailed prize reward mechanism. As we have argued above, his mechanism is subject to the possibility of manipulation. Guell and Fischbaum (1995) propose a mechanism which uses sales on a test market for a relatively short period of time to obtain an estimate of the social surplus. Once such information is received, the government extrapolates this information to obtain an estimate of the total value of the social surplus if a good were to be sold on the total market. Then the innovator receives a prize with the value equal to the estimated surplus. This proposal is certainly subject to market manipulation. The innovator has strong incentives to increase the demand in the test market. In the most plausible cases, if one assumes that the marginal cost of production is small compared to the value of the innovation, and if one assumes that the monopolist can sell the good at zero price, then this mechanism leads to extremely inefficient outcomes. Shavell and van Ypersele (2001) propose an optional reward system in which they allow an innovator to either stay with the patent or choose a buyout reward. Their mechanism has rewards only if the lowest social payoff is positive. If such an assumption does not hold, patents are optimal. Boldrin and Levine (2001) in recent influential work make entirely different technological assumptions for production of new goods. They argue that non-convexities of the kind considered in this paper are not necessary to account for the observed pattern of production of new goods, and, hence, the patents are unnecessary. To the extent that non-convexities of the kind considered here are important in actual innovations, the analysis of the necessity of patents when markets signals can be manipulated is applicable.

2 Model

Consider an economy in which an innovator has an idea of quality θ. This idea can be transformed into a good of quality θ if a fixed cost of $K > 0$ is incurred. If this cost is not incurred, a good of quality $\theta = 0$ is produced. We assume that the quality of the innovation $\theta \in [0, \bar{\theta}]$ and is distributed according to the cumulative distribution function $F(\theta)$. We assume that $\bar{\theta}$ is finite. The social value of the innovation under competitive markets is given by $S(\theta)$, where $S'(\cdot) > 0$, $S(0) = 0$.

We normalize profits if a good is produced under the competitive markets to be equal to zero. The good can also be produced by a monopoly. Let the monopoly profits be given by $\pi(\theta)$, where $\pi'(\cdot) > 0$,

[4] See Abramowicz (2003) for a review of a variety of proposals.

$\pi(0) = 0$. We assume that monopoly conveys deadweight costs. The social value of the innovation under monopoly, $S^m(\theta)$, is smaller than the social value of the innovation under competitive markets:

$$S(\theta) \geq S^m(\theta) \geq \pi(\theta). \tag{1}$$

We assume $S^{m\prime}(\cdot) > 0$, $S^m(0) = 0$.

One simple setup which generates the payoff functions $S(\cdot)$, $S^m(\cdot)$, $\pi(\cdot)$ is as follows. Suppose that the inverse demand function for the single good produced in the marketplace is given by $p = D(q, \theta)$, where θ is a shift parameter that affects the demand curve. Let $c^m \geq 0$ denote the marginal cost of production. Here the social surplus is given by the area below the demand curve and above the cost curve:

$$S(\theta) = \int_0^{D_\theta^{-1}(c^m)} [D(x,\theta) - c^m]\, dx$$

where D_θ^{-1} is the inverse demand function. The social surplus under monopoly is given by

$$S^m(\theta) = \int_0^{D_\theta^{-1}(p^m)} [D(x,\theta) - c^m)] dx,$$

where p^m is the price chosen by a profit-maximizing monopolist. This simple example easily maps onto the general environment described above and generates the surplus function under the competitive markets $S(\theta)$, the surplus function under the monopoly $S^m(\theta)$, and the function for monopoly profits of the form $\pi(\theta)$.

3 Benchmark with full information

In this section, we set up a benchmark example of the environment in which the quality of an idea is known to the planner.

The classic analysis of the optimal patent length problem is the work of Nordhaus (1969). The planner seeks to maximize the discounted value of the social surplus. The only instrument available to the planner is a patent of length $\hat{T}$. The problem of the planner is to determine the length of time $\hat{T}$ that a patent will be valid, which solves the following problem:

$$\max_{\hat{T}} \int \left\{ \int_0^{\hat{T}} e^{-rt} S^m(\theta)\, dt + \int_{\hat{T}}^{\infty} e^{-rt} S(\theta)\, dt \right\} dF(\theta)$$

subject to

$$\int_0^{\hat{T}} e^{-rt} \pi(\theta)\, dt \geq K. \tag{2}$$

In the objective function, the social surplus is equal to $S^m(\theta)$ for the time period between 0 and $\hat{T}$ as the good is produced by the monopoly under the patent granted. Afterward, the social surplus is equal to $S(\theta)$ as the good is produced under the competitive markets. The equation (2) is a participation constraint that guarantees that the innovator granted a patent of length $\hat{T}$ at least breaks even.

Letting $\tau = r \int_0^{\hat{T}} e^{-rt} dt$, this problem reduces to

$$\max_{\tau} r \int [\tau S^m(\theta) + (1-\tau) S(\theta)]\, dF(\theta) \tag{3}$$

subject to

$$\tau \pi(\theta) \geq Kr.$$

Suppose now that prizes are available, and prizes can be a function of the quality of the good. Then the problem of the social planner becomes that of maximizing (3) subject to

$$\tau\pi(\theta) + T(\theta) \geq Kr,$$

where $T(\theta)$ represents the prize. Since a prize is a lump sum transfer financed by lump sum taxes on consumers, it does not affect the social surplus. The solution of the problem with prizes is then to set the patent length $\tau = 0$ and reward innovators with prizes above the critical threshold value where the voluntary participation constraint binds. Thus, if the planner has as much information as the innovator, patents are never optimal. This reasoning leads us to consider the environments in which the planner has less information than private agents. For notational convenience, we set $r = 1$ in what follows.

4 Benchmark with private information

Consider a benchmark model in which the quality of the idea θ is private information to the innovator. The planner cannot observe whether the cost K has been incurred or not, so that the planner cannot observe whether the innovator has produced a good of quality θ or a good of quality 0. The instruments available to the planner are the length of the patent and lump sum prizes or taxes.

We now define a mechanism design problem of the social planner as follows. From the revelation principle we can restrict attention to direct mechanisms which consist of a reported type $\theta \in [0, \bar{\theta}]$ from the innovator to the planner and outcome functions $\delta(\theta)$, $\tau(\theta)$, $T(\theta)$. The function $\delta(\theta) : [0, \bar{\theta}] \to \{0, 1\}$ is an instruction from the planner to the innovator recommending whether or not to incur the fixed cost K. If $\delta(\theta) = 1$, the planner recommends that the innovator incur the fixed cost K and if $\delta(\theta) = 0$, the planner recommends that the innovator not incur the fixed cost. The patent length function is given by $\tau(\theta) : [0, \bar{\theta}] \to [0, 1]$. The prize function is given by $T(\theta) : [0, \bar{\theta}] \to (-\infty, \infty)$.

These outcome functions induce the following payoffs for the innovator. Let $V(\theta, \hat{\theta}, \gamma)$ denote the profits of the innovator who has an idea of quality θ and reports an idea of quality $\hat{\theta}$ to the planner, where $\gamma = 1$ denotes that type $\theta > 0$ good is produced, and $\gamma = 0$ denotes that $\theta = 0$ good is produced. The innovator's payoffs are given by

$$V(\theta, \hat{\theta}, \gamma) = \tau(\hat{\theta})\pi(\gamma\theta) - \gamma K + T(\hat{\theta}).$$

The social surplus for the planner under truth telling and given that the innovator follows the planner's recommendation is given by

$$W = \int \{\delta(\theta) [\tau(\theta) S^m(\theta) + (1 - \tau(\theta)) S(\theta) - K]\} \, dF(\theta). \quad (4)$$

The above equation states that for the period of length $\tau(\theta)$ the good is produced under monopoly so that the planner receives the surplus of $S^m(\theta)$, for the period of $(1 - \tau(\theta))$ the good is produced by the competitive markets and the surplus of $S(\theta)$ is received.

A mechanism is *incentive compatible* if for all $(\theta, \hat{\theta})$ it satisfies

$$V(\theta, \theta, \delta(\theta)) \geq \max_{\hat{\theta}, \gamma} V(\theta, \hat{\theta}, \gamma). \quad (5)$$

In this formulation of the incentive compatibility constraint, note that we require that an innovator of type θ who reports truthfully and follows the recommendation of the planner gets a higher payoff than an innovator who deviates from the recommendation of the planner and chooses $\gamma \neq \delta(\theta)$ or deviates from truthful reporting, or deviates in both ways. For convenience, we say that an innovator is obedient if the innovator follows the planner's recommendation.

A mechanism satisfies *voluntary participation* if

$$V(\theta, \theta, \delta(\theta)) \geq 0. \quad (6)$$

We now formally define an interim-efficient mechanism.

Definition 1 *The mechanism is **interim efficient** if it maximizes social surplus (4) subject to incentive compatibility (5) and voluntary participation (6).*

We then have the following proposition.

Proposition 1 ***(Optimality of uniform patents).*** *The interim-efficient mechanism has a constant patent length $\tau(\theta) = \bar{\tau}$, $\forall\theta$ and prizes $T(\theta)$ that are independent of type θ, $\forall\theta$. The interim-efficient mechanism can be implemented with prizes $T(\theta) = 0$.*

Proof. We begin by establishing a preliminary result that if $\delta(\theta) = 1$, $\tau(\theta) > 0$. Suppose by way of contradiction that for some innovator of type $\theta, \delta(\theta) = 1$ and $\tau(\theta) = 0$. The payoff to this innovator under truth telling and obedience is $-K + T(\theta)$. The payoff to this innovator from truthfully reporting the type and not incurring the cost is $T(\theta)$. Since $K > 0$, such a deviation raises payoffs and we have a contradiction. We have established that if $\delta(\theta) = 1$, $\tau(\theta) > 0$.

We use this result to show that there is some critical threshold θ^* such that $\delta(\theta) = 0$ for $\theta < \theta^*$, and $\delta(\theta) = 1$ for $\theta > \theta^*$. The argument is by contradiction. Suppose that $\theta_1 < \theta_2$, $\delta(\theta_1) = 1$, and $\delta(\theta_2) = 0$. Consider the incentive compatibility constraint for the innovator who has an idea of quality θ_2 and contemplates a deviation to reporting θ_1. Under the supposition that $\delta(\theta_2) = 0$, the payoff of the innovator of truth telling is equal to $T(\theta_2)$. Using the incentive compatibility constraint, we then have the following sequence of inequalities leading to a contradiction:

$$T(\theta_2) \geq \tau(\theta_1)\pi(\theta_2) - K + T(\theta_1) > \tau(\theta_1)\pi(\theta_1) - K + T(\theta_1) \geq T(\theta_2).$$

Here, the first inequality is the incentive compatibility constraint that the payoff of type θ_2 is at least as large as the payoff that type would attain by reporting θ_1 and incurring the cost K. The second inequality follows because $\pi(\theta)$ is strictly increasing and by the preliminary result that $\tau(\theta_1) > 0$. The last inequality is the incentive compatibility constraint that type θ_1 not misreport the type to be θ_2. This contradiction argument establishes the critical threshold result that if $\delta(\theta_1) = 1$, $\delta(\theta_2) = 1$ for all $\theta_2 > \theta_1$. Let θ^* be the smallest value of θ such that $\delta(\theta) = 1$.

Next we show that the incentive compatibility constraint implies that for the set of the innovated goods, the patent length is nondecreasing in the quality of the good θ. Adding and subtracting $\tau\left(\hat{\theta}\right)\pi\left(\hat{\theta}\right)$ to the incentive compatibility constraint (5), we have that for any θ, $\hat{\theta} \geq \theta^*$,

$$V(\theta,\theta,\delta(\theta)) \geq V\left(\hat{\theta},\hat{\theta},\delta\left(\hat{\theta}\right)\right) + \tau\left(\hat{\theta}\right)\left(\pi(\theta) - \pi\left(\hat{\theta}\right)\right). \tag{7}$$

A similar argument implies that:

$$V\left(\hat{\theta},\hat{\theta},\delta\left(\hat{\theta}\right)\right) \geq V(\theta,\theta,\delta(\theta)) + \tau(\theta)\left(\pi\left(\hat{\theta}\right) - \pi(\theta)\right). \tag{8}$$

Adding (7) and (8) and rearranging we obtain

$$\tau(\theta)\left(\pi(\theta) - \pi\left(\hat{\theta}\right)\right) \geq \tau\left(\hat{\theta}\right)\left(\pi(\theta) - \pi\left(\hat{\theta}\right)\right). \tag{9}$$

Inequality (9) and the assumption that $\pi(\theta)$ is increasing immediately implies that if $\theta > \hat{\theta}$, then $\tau(\theta) \geq \tau\left(\hat{\theta}\right)$.

Next, we show that since social surplus is decreasing in the length of the patent, a constant patent length is optimal. To see this result, suppose that for some $\theta > \theta^*$, $\tau(\theta) > \tau(\theta^*)$. Note that under any mechanism that induces innovation by type θ^*, obedience implies that

$$\tau(\theta^*)\pi(\theta^*) + T(\theta^*) - K \geq T(\theta^*)$$

so that $\tau(\theta^*)\pi(\theta^*) - K \geq 0$. Now consider an alternative mechanism that sets $\tau(\theta) = \tau(\theta^*)$ for all $\theta \geq \theta^*$, sets $T(\theta) = T(\theta^*)$ for all θ. Payoffs under this mechanism under truth-telling and obedience are given by $\tau(\theta^*)\pi(\theta) + T(\theta^*) - K$. Since $\tau(\theta^*)\pi(\theta^*) - K \geq 0$, and $\pi(\theta)$ is increasing it follows that

$\tau(\theta^*)\,\pi(\theta) + T(\theta^*) - K \geq T(\theta^*)$ so that the innovator of type θ does not gain by not incurring the cost. Clearly, the innovator's payoffs are unaffected by misreporting some $\hat{\theta} \geq \theta^*$. Misreporting that $\hat{\theta} < \theta^*$, simply yields $T(\theta^*)$ and is not profitable. Thus, the alternative mechanism is incentive compatible. This mechanism yields higher social surplus than the original mechanism because social surplus is decreasing in patent length.

Under our assumption (1) that social surplus is at least as large as monopoly profits, social surplus maximization also implies that $\tau(\theta^*)\,\pi(\theta^*) - K = 0$. To see this result, suppose that $\tau(\theta^*)\,\pi(\theta^*) - K > 0$. Then, from (1)

$$\tau(\theta^*)\,S^m(\theta) + (1 - \tau(\theta^*))S(\theta) - K > 0 \tag{10}$$

for all θ in some neighborhood of θ^*. Consider an alternative mechanism that reduces the threshold level of innovation to θ^{**} where θ^{**} satisfies

$$\tau(\theta^*)\,\pi(\theta^{**}) - K = 0$$

and sets $T(\theta) = 0$ for all θ. Under such a mechanism, it is easy to see that all innovators with $\theta \geq \theta^{**}$ will innovate. From (10), social surplus is positive for all $\theta \in [\theta^{**}, \theta^*]$ so that social surplus is higher under the alternative mechanism.

Next, we show that $T(\theta) = T$, $\forall\theta$. Clearly, incentive compatibility implies that $T(\theta)$ must be constant in the interval $[0, \theta^*)$. Suppose $T(\theta^*) > T(0)$. Then any type in the interval $[0, \theta^*)$ would claim to be type θ^*, not incur the cost and would be better off. Incentive compatibility by these types thus implies that $T(\theta^*) \leq T(0)$. Now consider the incentive constraint that type θ^*must prefer to incur the cost over not incurring it given by

$$\tau(\theta^*)\,\pi(\theta^*) - K + T(\theta^*) \geq T(0).$$

Using the result that $\tau(\theta^*)\,\pi(\theta^*) - K = 0$, we have that $T(\theta^*) \geq T(0)$. It follows that $T(\theta^*) = T(0)$. Incentive compatibility implies that all types above θ^* must receive the same transfers. We have shown that $T(\theta) = T$, $\forall\theta$. *Q.E.D.* ■

Two features of our model play important roles in this proof. The first is that the planner does not observe whether the cost has been incurred. That is, the planner does not observe whether a socially valuable good or a valueless good has been produced. This hidden action aspect of our model is the main difference between our model and that in Scotchmer (1999). This feature implies that an innovator always has an incentive simply to pocket any offered prize and produce a good of no value. Thus, pure prize systems induce no innovation. The second feature is that the planner cannot observe the quality of the innovated good. This feature implies that, as in many incentive problems (See Myerson, 1980), the screening variable, $\tau(\theta)$ must be nondecreasing in type as inequality (9) makes clear. Social welfare maximization then makes it optimal to set the patent length to a constant.

Notice that the interim-efficient mechanism yields the same allocations as the mechanism in Nordhaus (1969) described above. Here, however, we allow for the possibility of prizes in addition to patents. Incentive compatibility and welfare maximization imply that it is optimal not to use prizes or taxes but to use patents only. Hence, the result that only patents are used does not follow by assumption but rather by the need to provide incentives for innovation.

We now formally define a full information efficient mechanism.

Definition 2 *A mechanism is* ***ex post efficient*** *(or full information efficient) if it maximizes the social surplus (4) subject to the voluntary participation constraint (6).*

It is immediate that the ex post efficient mechanism has no deadweight loss. Specifically, the ex post efficient mechanism has the planner recommending the innovator to innovate if $S(\theta) \geq K$. Note that the ex post efficient mechanism can be implemented by a variety of prizes. Specifically, any prize that satisfies $K \leq T(\theta)$ if $\delta(\theta) = 1$ implements the ex post efficient outcomes.

5 Market signals, prizes, and patents without manipulation

Consider a version of the economy in which private agents other than the innovator receive signals about the quality of the good innovated. One can imagine a variety of schemes that elicit the information that other agents — or more generally, the markets — possess. Two specific schemes gained significant recent attention both theoretically and in policymaking circles.

Specifically, suppose that in addition to the innovator, another private agent, called a *competitor*[5], observes the value of the innovated good θ after it was innovated. We refer to this other agent as a competitor because we think it is likely that other firms in the industry are informed about the value of the innovation. The competitor can also be thought of as any agent who has information about the value of the innovation. In this environment, the planner can allow the length of the patent, and the prize/transfers depend on information revealed by the competitor about the quality of the good.

We first show how to implement the ex-post efficient allocation using the signals of the competitor. We then describe a mechanism that can implement such allocation uniquely.

5.1 Implementing ex-post efficient allocation

Let θ denote the (confidential) report made by the innovator to the mechanism designer and $\delta(\theta)$ the recommendation by the mechanism to incur the fixed cost K. Recall that if the cost is not incurred, the innovator produces a good of quality 0. After the innovator produces the good, the competitor must submit a report of the quality of the good. The competitor only observes the quality of the good produced, and, in particular, does not observe the innovator's type or report. Let θ^c denote the report made by the competitor. A mechanism consists of reports made by the innovator and the competitor and outcome functions $\delta(\theta)$, $\tau(\theta, \theta^c)$, $T(\theta, \theta^c)$, $T^c(\theta, \theta^c)$, where $\delta(\theta)$ denotes the recommendation by the mechanism to incur the cost K; $\tau(\theta, \theta^c)$ denotes the length of the patent; $T(\theta, \theta^c)$ denotes the prize to the innovator; and $T^c(\theta, \theta^c)$ denotes transfer to the competitor.

The payoffs to the innovator depend on the reporting strategy of the competitor. Let $\tilde{\theta}$ denote the quality of the good observed by the competitor. This quality is given by θ if the innovator has incurred the cost K and is zero otherwise. We let $\theta^c\left(\tilde{\theta}\right)$ denote the competitor's reporting strategy. The payoffs to the innovator are then given by

$$V(\theta, \hat{\theta}, \gamma; \theta^c\left(\tilde{\theta}\right)) = \tau(\hat{\theta}, \theta^c\left(\tilde{\theta}\right))\pi(\gamma\theta) - \gamma K + T(\hat{\theta}, \theta^c\left(\tilde{\theta}\right)) \tag{11}$$

where $\tilde{\theta} = \theta$ if $\gamma = 1$, and $\tilde{\theta} = 0$ if $\gamma = 0$. In this formulation of the payoff to the innovator, $V(\theta, \hat{\theta}, \gamma; \theta^c\left(\tilde{\theta}\right))$, the arguments are, in order, the true type of the quality of the good θ, the report by the innovator $\hat{\theta}$, the decision of the innovator γ to incur the cost K, and the report of the competitor $\theta^c\left(\tilde{\theta}\right)$. Note that the payoff depends on the reporting strategy of the competitor, $\theta^c\left(\tilde{\theta}\right)$. Since the revelation principle holds, we can restrict attention to truthful reporting strategies. The payoffs to the competitor are given by $T^c\left(\theta, \theta^c\right)$.

The *incentive compatibility constraint* for the innovator is given by

$$V(\theta, \theta, \delta\left(\theta\right); \theta^c(\theta)) \geq \max_{\hat{\theta}, \gamma} V(\theta, \hat{\theta}, \gamma; \theta^c\left(\tilde{\theta}\right)) \tag{12}$$

for all θ where, again, $\tilde{\theta} = \theta$ if $\gamma = 1$ and 0 if $\gamma = 0$ and the voluntary participation constraint is given by

$$V(\theta, \theta, \theta, \delta\left(\theta\right)) \geq 0 \tag{13}$$

for all θ.

This formulation of the incentive compatibility constraint follows from the revelation principle that states that the Bayesian equilibrium of any game can be implemented as a truth-telling equilibrium of a direct mechanism.

The *incentive compatibility constraint* for the competitor requires that the competitor's reporting strategy is to tell the truth for all observed quality levels $\tilde{\theta}$. Given that the innovators follows a truth-telling strategy, the incentive compatibility constraint for the competitor is given by

$$T^c(\theta, \theta) \geq T^c(\theta, \hat{\theta}). \tag{14}$$

[5] This agent does not necessaily have to be a competitor but rather an *observer*.

for all $\theta, \hat{\theta}$ and the competitor's voluntary participation is

$$T^c(\theta, \theta) \geq 0 \tag{15}$$

An interim-efficient mechanism is defined as follows

Definition 3 *The mechanism is* ***interim efficient*** *if it maximizes social surplus (4) subject to incentive compatibility for the innovator, (12), incentive compatibility for the competitor, (14), and the voluntary participation constraints (13), and (15).*

An ex post efficient mechanism is defined as follows.

Definition 4 *A mechanism is* ***ex post efficient*** *(or full information efficient) if it maximizes social surplus (4) subject to the voluntary participation constraints (13) and (15).*

Note that since ex post efficiency assumes that the planner has the same information as the private agents, the ex post efficient outcomes in the environment with and without market signals are identical.

In the following proposition, we show that the patents are never optimal. Indeed, the full information optimum can be achieved solely with prizes.

Proposition 2 ***(Optimality of prizes)*** *In the environment with market signals, the interim-efficient mechanism is ex post efficient.*

Proof. Let the planner's recommendation be to produce the good when the social value is higher than fixed costs: $\delta(\theta) = 1$ if $S(\theta) \geq K$; $\delta(\theta) = 0$ otherwise. Let $T(\theta, \theta) \geq K$ if $\theta = \theta^c$; $T(\theta, \theta^c) = 0$ if $\theta \neq \theta^c$. Let $T^c(\theta, \theta^c) = 0$. In other words, implement the full information outcomes associated with the value of θ only if both agents report that same value of θ. If the agents disagree, then give the innovator a transfer equal to zero. The competitor always receives the same transfer regardless of his report. Then the best response of the competitor is to report the value of the innovated goods truthfully. *Q.E.D.* ■

Note that above we restricted the planner to award the patent only to the innovator. A more general setup would allow the planner to reward the competitor with the patent. This restriction is without loss of generality, since Proposition 2 shows that the planner can achieve the full information outcome.

This proposition is closely related to the result in the auction and mechanism design literatures that if bidders' signals are correlated, the seller can extract all the surplus. (See, for example, Cremer and McLean 1988, McAfee, McMillan and Reny 1989, and McAfee and Reny 1992) The proof of our proposition uses methods similar to that in these literatures to obtain ex post efficiency.

So far, we have assumed that the competitor receives the same signal as the innovator. Suppose now that the competitor receives a noisy, but unbiased, signal s of the quality of the good so that $E(\theta|s) = s$ and that $E(s|\theta) = \theta$. Consider a mechanism which sets the prize to the innovator $T(\theta, s) = s$ if $S(s) \geq K$ and 0 otherwise and sets the transfer to the competitor to 0. Since the innovator is risk-neutral, this mechanism yields the ex post efficient level of innovation as a truth-telling outcome.

The competitor's report also has an immediate market interpretation and a practical application. Consider the simple market setup described above in which the inverse demand for the good is given by $p = D(q, \theta)$ and c is the marginal cost of production. Suppose the market consists of a large number of producers, all of whom can produce the good at marginal cost. The mechanism designer then makes the knowledge of how to produce the good freely available to all producers and asks each producer to report sales of the good. Since the price p equals the marginal cost of production c in a competitive market, aggregate sales q can then be used to uncover the market size parameter θ. Another example of the practical implementation of this mechanism is the patent-buyout mechanism in Kremer (1998).

Note that we have also assumed that the cost of innovating is known to the designer. Our results extend readily to the case in which this cost is drawn from some distribution, say, $G(K)$ and is private information to the innovator. To see this extension, consider a mechanism in which the innovator's prize is given by the social surplus if the innovator's and competitor's reports agree, so that $T(\theta, \theta) = S(\theta)$ and the innovator receives no prize if the reports disagree so that $T(\theta, \theta^c) = 0$ if $\theta \neq \theta^c$. Clearly, truth telling is incentive compatible and the mechanism implements the efficient allocation in the sense that $\delta(\theta) = 1$ if and only if $S(\theta) \geq K$.

5.2 Unique implementation of prize mechanisms

The mechanism that we have discussed uses information from the competitor to reward the innovator. Under our particular mechanism, the competitor is indifferent about what information to report. Truth telling is one of the equilibria of the game. Typically, the game has many other equilibria. A natural question is whether we can design a mechanism which is ex post efficient and has a unique equilibrium. Here, we adapt the mechanism of Moore and Repullo (1988) to our environment. We show that such a mechanism has a unique subgame-perfect equilibrium in which both the innovator and the competitor report the truth.

The mechanism has two stages. In Stage 1, the innovator and the competitor make reports to the planner. Denote the report of the innovator by θ_1 and that of the competitor by θ^c. If $\theta_1 = \theta^c$, equals say θ, then implement the ex post efficient outcome associated with the common report θ. If $\theta_1 \neq \theta^c$, then move to Stage 2. In Stage 2, the innovator is given a choice between two alternatives, denoted by A and B. In each alternative, the innovator is granted a patent with the length $\mu_A(\theta_1, \theta^c)$ and $\mu_B(\theta_1, \theta^c)$ and prizes $T_A(\theta_1, \theta^c)$ and $T_B(\theta_1, \theta^c)$ chosen to satisfy for all (θ_1, θ^c)

$$\begin{aligned} & \max\left\{\mu_A(\theta_1, \theta^c)\,\pi(\theta_1) - K + T_A(\theta_1, \theta^c); T_A(\theta_1, \theta^c)\right\} \\ > \; & \max\left\{\mu_B(\theta_1, \theta^c)\,\pi(\theta_1) - K + T_B(\theta_1, \theta^c); T_B(\theta_1, \theta^c)\right\}, \end{aligned} \tag{16}$$

$$\begin{aligned} & \max\left\{\mu_B(\theta_1, \theta^c)\,\pi(\theta^c) - K + T_B(\theta_1, \theta^c); T_B(\theta_1, \theta^c)\right\} \\ > \; & \max\left\{\mu_A(\theta_1, \theta^c)\,\pi(\theta^c) - K + T_A(\theta_1, \theta^c); T_A(\theta_1, \theta^c)\right\}, \end{aligned} \tag{17}$$

$$T(\theta, \theta) - K > \max_{\theta_1}\left\{\mu_B(\theta_1, \theta)\,\pi(\theta) - K + T_B(\theta_1, \theta); T_B(\theta_1, \theta)\right\}. \tag{18}$$

The basic idea behind this mechanism is that in the second stage, the innovator is given an option to rescind on his previous report at a cost. The first inequality ensures that if θ_1 is the true report and θ^c is not, the innovator will choose alternative A. The second inequality ensures that if θ^c is the true report and θ_1 is not, the innovator will choose alternative B. The third inequality ensures that if the competitor tells the truth, the innovator also tells the truth and finds it optimal not to go to Stage 2. Since four choice variables need to satisfy only three inequalities, clearly we can choose these four variables.

Now we turn to the transfers to the competitor. If both agents report the same value of θ in Stage 1, the competitor receives a transfer of zero. If the reports differ, then the competitor pays a tax $-\underline{T}$ if the innovator chooses an alternative A and receives a transfer $\bar{T}$ if the innovator chooses an alternative B.

We claim that this mechanism has a unique equilibrium that is truth telling. Suppose that the equilibrium for some realized value of θ involves these two agents reporting a common value of $\hat{\theta} \neq \theta$. Under this supposed equilibrium, the payoff of the competitor is equal to zero. Now consider a deviation by the competitor to the true report, that is setting $\theta^c = \theta$. Under this deviation, the mechanism requires the players to proceed to Stage 2. Inequality (17) guarantees that in this subgame, the innovator will optimally choose the alternative B. Recall that if the innovator chooses the alternative B, the competitor receives a positive transfer. Thus, such deviation is profitable and the equilibrium cannot have both agents reporting a common value $\hat{\theta} \neq \theta$.

Now suppose that the innovator reports the truth and the competitor lies and reports a value of $\hat{\theta} \neq \theta$. The mechanism requires that the players move to Stage 2. In that stage, inequality (16) guarantees that in Stage 2, the innovator will choose option A. The competitor's payoff is then given by the tax that the competitor must pay. A deviation of the competitor to reporting the truth gives the competitor a zero payoff which dominates misreporting. Thus, we cannot have an equilibrium in which the innovator tells the truth and the competitor lies.

Next suppose that the competitor reports the truth and the innovator lies and reports a value of $\hat{\theta} \neq \theta$. The mechanism requires that the players move to Stage 2. In that stage, inequality (17) guarantees that the innovator will choose option B. The innovator's payoff is then given by the left-hand side of (17) equal to the right-hand side of (18). Consider a deviation from the supposed equilibrium in which the innovator reports the truth. The payoff to this deviation is given by the left-hand side of (18). Thus, this deviation is profitable and the game cannot have an equilibrium in which the competitor reports the truth and the innovator lies.

This argument establishes the following proposition on a unique implementation of the ex post efficient equilibrium.

Proposition 3 *Consider the game in which the innovator and the competitor both receive the same signal about the quality of the good to be innovated. There exists a mechanism which has truth telling by both agents and which implements the ex post efficient outcome.*

6 Market signals with bribes

We now consider an environment in which the innovator can bribe the competitor to misreport the quality of the good. We show that in this environment, the equilibrium outcomes coincide exactly with those in the environment in which no agent other than the innovator observes the quality of the good. This result implies that patents are again optimal as in Proposition 1.

In what follows we again consider environment described in Section 5.1. We begin by describing how the possibility of bribes modifies the constraints that the social planner faces. We do so by considering an arbitrary mechanism which consists of abstract action sets A for the innovator and A^C for the competitor, actions $a \in A$ and $a^c \in A^c$, recommendations by the planner to innovate $\delta(a)$, length of patent granted to the innovator $\tau(a, a^c)$, length of the patent awarded to the competitor $\tau^c(a, a^c)$, and the prizes $T(a, a^c)$ and $T^c(a, a^c)$.

We assume that the players can observe each other's actions. We also assume that they can agree, before the actions are chosen, to pay transfers (bribes) to each other contingent on the actions chosen by the innovator and the competitor. We assume that these bribes are not observable to the mechanism designer and that there are no limits to the size of the bribes. Let $B(a, a^c, \theta)$ and $B^c(a, a^c, \theta)$ denote the payments made by the innovator and the competitor so that

$$B(a, a^c, \theta) + B^c(a, a^c, \theta) = 0. \tag{19}$$

Note that we assume that these bribes can be enforced. The payoffs of the agents are augmented with the bribes. The revelation principle clearly holds in this environment so that any Nash equilibrium of the arbitrary mechanism can be implemented by a direct mechanism. Let $V\left(\theta, \hat{\theta}, \hat{\theta}^c, \gamma\right)$ and $V^c\left(\theta, \hat{\theta}, \hat{\theta}^c, \gamma\right)$ denote the payoffs granted by the direct mechanism to the innovator and the competitor. These payoffs are given by

$$V(\theta, \hat{\theta}, \hat{\theta}^c, \gamma) = \tau(\hat{\theta}, \hat{\theta}^c)\pi(\gamma\theta) - \gamma K + T(\hat{\theta}, \hat{\theta}^c), \tag{20}$$

and the payoffs to the competitor are given by

$$V^c(\theta, \hat{\theta}, \hat{\theta}^c, \gamma) = \tau^c(\hat{\theta}, \hat{\theta}^c)\pi(\gamma\theta) + T^c(\hat{\theta}, \hat{\theta}^c). \tag{21}$$

Note that these payoffs do not include the bribes. When augmented by the bribes, the payoffs are given by $V(\theta, \hat{\theta}, \hat{\theta}^c, \gamma) + B(\theta, \hat{\theta}, \hat{\theta}^c, \gamma)$ to the innovator and $V^c(\theta, \hat{\theta}, \hat{\theta}^c, \gamma) + B^c(\theta, \hat{\theta}, \hat{\theta}^c, \gamma)$. Here, θ denotes the quality of the idea, $\hat{\theta}$ denotes the report by the innovator, and $\hat{\theta}^c$ denotes the report by the competitor.

Lemma 1 *The truth-telling equilibrium of any direct mechanism must satisfy the bribe-proofness condition:*

$$V(\theta, \theta, \theta, \delta(\theta)) + V^c(\theta, \theta, \theta, \delta(\theta)) \geq V\left(\theta, \hat{\theta}, \hat{\theta}^c, \gamma\right) + V^c\left(\theta, \hat{\theta}, \hat{\theta}^c, \gamma\right). \tag{22}$$

for all $\theta, \hat{\theta}, \hat{\theta}^c, \gamma$.

Proof. The proof is by contradiction. Suppose for some θ, $\hat{\theta}$, $\hat{\theta}^c$ and γ truth telling is an equilibrium and the bribe-proofness condition (22) is not satisfied. Suppose that, at the report $\hat{\theta}, \hat{\theta}^c$, the innovator is strictly better off if both misreport so that $V\left(\theta, \hat{\theta}, \hat{\theta}^c, \gamma\right) > V(\theta, \theta, \theta, \delta(\theta))$ and the competitor is strictly worse off so that $V^c\left(\theta, \hat{\theta}, \hat{\theta}^c, \gamma\right) < V^c(\theta, \theta, \theta, \delta(\theta))$. Consider a bribe by the innovator that offers the competitor all the surplus the innovator gains by misreporting, so that the bribe equals $V\left(\theta, \hat{\theta}, \hat{\theta}^c, \gamma\right) -$

$V\left(\theta,\theta,\theta,\delta\left(\theta\right)\right)$. Since, by assumption, (22) does not hold, this bribe makes the competitor's payoffs higher than under truth telling, so that truth telling is not an equilibrium. We have a contradiction. *Q.E.D.* ■

Note that this lemma relies upon the assumption that the bribe payments are not observable to the mechanism designer. Note also that the proof of this lemma fails if the size of bribes is sufficiently limited. To see that the lemma does not hold if bribes are limited, suppose we restrict bribes to be less than some upper bound $\bar{T}$. If $\bar{T}$ is sufficiently small, the innovator will not be able to offer all the surplus gained by misreporting, $V\left(\theta,\hat{\theta},\hat{\theta}^{c},\gamma\right)-V\left(\theta,\theta,\theta,\delta\left(\theta\right)\right)$. Then the innovator will not be able to induce the competitor to misreport. A planner can then always set the transfer to the competitor $T_2\left(\hat{\theta},\hat{\theta}^{c}\right)$ sufficiently greater than $\bar{T}$ if $\hat{\theta}\neq\hat{\theta}^{c}$. With such prizes, the innovator cannot bribe the competitor and the planner can implement the efficient allocation.

We use this lemma to show that the solution to the social planner's problem in this environment with bribes coincides with the solution to that in the environment without market signals.

The *incentive compatibility constraint for the innovator* is given by

$$V(\theta,\theta,\theta,\delta\left(\theta\right))\geq\max_{\hat{\theta},\gamma}V(\theta,\hat{\theta},\theta,\gamma), \tag{23}$$

and the *incentive compatibility constraint for the competitor* is given by

$$V^{c}(\theta,\theta,\theta,\delta\left(\theta\right))\geq\max_{\hat{\theta}^{c}}V^{c}(\theta,\theta,\hat{\theta}^{c},\delta\left(\theta\right)). \tag{24}$$

We denote the sum of the payoffs to the innovator and the competitor by

$$\bar{V}\left(\theta\right)=V\left(\theta,\theta,\theta,\delta\left(\theta\right)\right)+V^{c}\left(\theta,\theta,\theta,\delta\left(\theta\right)\right).$$

The bribe-proofness constraint is now given by

$$\bar{V}\left(\theta\right)\geq\max_{\hat{\theta},\hat{\theta}^{c},\gamma}\left[V(\theta,\hat{\theta},\hat{\theta}^{c},\gamma)+V^{c}(\theta,\hat{\theta},\hat{\theta}^{c},\gamma)\right].$$

The social planner's payoffs in the truth-telling equilibrium are now given by

$$W=\int\left\{\delta(\theta)\left[\bar{\tau}\left(\theta\right)S^{m}(\theta)+\left(1-\bar{\tau}\left(\theta\right)\right)S(\theta)-K\right]\right\}dF\left(\theta\right), \tag{25}$$

where

$$\bar{\tau}\left(\theta\right)=\tau\left(\theta\right)+\tau^{c}\left(\theta\right).$$

The social planner's problem is to maximize (25) subject to (22), (23), (24), and the analog of the voluntary participation. We now state the proposition that characterizes the social planner's problem.

Proposition 4 ***(Optimality of patents with bribes)*** *The solution to the social planner's problem with bribes coincides with that in the environment with no market signals problem. In particular, the solution to the social planner's problem coincides with the outcome described in Proposition 1, in that the interim-efficient mechanism has no prizes $T\left(\theta\right)=0$, $\forall\theta$, and a constant patent length $\bar{\tau}\left(\theta\right)=\bar{\tau}$, $\forall\theta$.*

Proof. Consider a relaxed version of the social planner's problem which does not impose the individual incentive compatibility constraints and which replaces the voluntary participation constraint by two constraints — one that requires that the sum of the payoffs to the innovator and the competitor is non-negative, and the other that the sum of transfers to them is non-positive. This formulation of the problem is identical to the social planner's problem in the environment with no market signals. To see that the formulations are identical, note that, using (20) and (21), (22) can now be written as

$$\bar{V}\left(\theta\right)\geq\max_{\hat{\theta},\hat{\theta}^{c},\gamma}\left[(\tau(\hat{\theta},\hat{\theta}^{c})+\tau^{c}(\hat{\theta},\hat{\theta}^{c}))\pi(\gamma\theta)-\gamma K+T(\hat{\theta},\hat{\theta}^{c})+T^{c}(\hat{\theta},\hat{\theta}^{c})\right].$$

Repeating essentially the same steps as in Proposition 1, it is straightforward to see that the solution to the relaxed problem must have a threshold θ^* below which it is optimal not to innovate, the patent length is nondecreasing in the quality of the good θ. And since social surplus is decreasing in the length of the patent, having a constant patent length is optimal. *Q.E.D.* ■

Note that the proof of this proposition relies crucially on the preceding lemma. We have argued that the lemma fails to hold if bribes are exogenously limited in size. It follows that the proposition relies crucially on the assumption that the bribes can be made sufficiently large.

This proposition provides a very strong, perhaps overly strong, result. It implies that a variety of ways of sustaining innovative activity, such as government subsidies for innovation, subsidies to research and so on are ineffective in stimulating innovation. The observation that, in practice, such mechanisms have been effective suggest that the idea that bribes can be made entirely in secret is too strong an assumption. Nevertheless, it highlights the importance of monitoring side payments in using prize-like mechanisms to provide innovation incentives and highlights the sense in which innovators have incentives to abuse mechanisms which rely on market signals. Below, we discuss other ways in which innovators could distort market signals.

One interpretation of bribes is that they are implicit payments sustained by a form of implicit collusion. An example of such implicit collusion is as follows. Suppose that the economy has two agents and lasts for an infinite number of periods. Agents discount the future at the rate β. With probability 0.5, one of these agents is the innovator and the other is the competitor in each period. Suppose that the planner chooses some mechanism. Fix an equilibrium of this infinitely repeated mechanism. The bribe paid by the innovator to the competitor can now be thought as the difference between the payoffs in this equilibrium and the best equilibrium. Suppose that the payoffs in any equilibrium are bounded above and that the differences in the payoffs in the best and the worst equilibria are given by $\bar{B}$. Then the size of the payoffs is limited and Proposition 4 does not necessarily hold. Indeed, we can show that a mechanism which induces truth telling exists. Specifically, suppose that the planner chooses in each period a mechanism similar to the Moore and Repullo (1998) mechanism described above. Let the planner set the Stage 2 transfers to the competitor at $\bar{T} > \bar{B}$. By the same argument as in the section on the unique implementation in the single period game, it follows that the competitor always tells the truth regardless of the innovator's strategies. Thus, manipulation in the form of implicit collusion alone does not suggest that patents are optimal.

7 Market signals with costly manipulation

We have obtained two rather stark results. If market signals cannot be manipulated (or can only be manipulated at a very high cost), prizes are optimal. If the innovator can manipulate market signals costlessly, say at no cost except for bribes to other participants, patents are optimal. We now turn to intermediate cases in which manipulating market signals is costly but not prohibitively so. We obtain more nuanced results. The optimal mechanism uses both prizes and patents.

In terms of specific examples of costly signal manipulation, one possibility is hidden buybacks which can occur if the planner uses prize like mechanisms which reward the innovator based on total sales. Such prizes can be manipulated by the innovator (or its accomplices such as subsidiaries or related parties) secretly purchasing the good so as to make it seem that the market size is larger than it is. Another example of the costly manipulation may be other costs associated with paying bribes (such as probability of being punished). Alternatively, if one thinks of our environment with bribes as representing collusion, costly manipulation may stem from the limits to such collusive agreements.

We begin by describing a fairly abstract environment in which the planner receives the signal s about the quality of the good innovated. Our formal set up is reminiscent of the literature on costly state falsification (see, for example, Lacker and Weinberg (1989) and Maggi and Rodriguez-Clare (1995)). In our model, the innovator can manipulate the signal by incurring **a** cost. Specifically, by incurring a cost $c|s-\theta|$, $c \geq 0$, the innovator can ensure that the planner receives a signal s. Note that if the innovator does not manipulate the signal, then $s = \theta$, so the signal reveals the quality of the good perfectly. With this formulation, the payoffs of an innovator who has an idea of quality θ and chooses to report the idea of quality $\hat{\theta}$ are given by

$$V^m(\theta, \hat{\theta}, \gamma) = \delta(\hat{\theta}) \left[\tau(\hat{\theta})\pi(\gamma\theta) - \gamma K + T(\hat{\theta}) - c|\hat{\theta} - \theta| \right]. \tag{26}$$

Incentive compatibility now becomes

$$V^m(\theta, \theta, \delta(\theta)) \geq \max_{\hat{\theta} \in [0, \bar{\theta}], \gamma} V^m(\theta, \hat{\theta}, \delta\left(\hat{\theta}\right)). \tag{27}$$

The social planner's payoff and the voluntary participation constraint are unchanged. The social planner now maximizes the social surplus subject to the incentive compatibility constraint (27) and voluntary participation (6).

Let $S(\theta^*) = K$ denote the threshold value of the quality of the good such that if $\theta \geq \theta^*$, the full information efficient mechanism requires that the good be innovated, $\delta(\theta) = 1$. If $\theta \leq \theta^*$, then the good is not innovated, $\delta(\theta) = 0$. We then have the following proposition. We show that if the manipulation costs are sufficiently high, patents are not optimal. If the manipulation costs are sufficiently low, the patents are used in any efficient mechanism. We asume that $\bar{\theta}$ is sufficiently high that a mechanism which uses patents alone has innovation for some sufficiently high values of θ.

Proposition 5 *If $c \geq \frac{K}{\theta^*}$, then the solution to the social planner's problem can be implemented with prizes alone. If $c < \frac{K}{\bar{\theta}}$, then the solution to the social planner's problem necessarily requires using patents.*

Proof. First, suppose that $c \geq \frac{K}{\theta^*}$. Consider the following mechanism that sets $T(\theta) = K$ if $\theta \geq \theta^*$; $T(\theta) = 0$, otherwise; $\delta(\theta) = 1$ if and only if $\theta \geq \theta^*$. We will show that this mechanism is incentive compatible. Consider a reporting problem of an innovator with the quality of idea $\theta < \theta^*$. Truth telling yields a payoff of zero for this innovator. Suppose that this innovator deviates, claims that the quality of his idea is $\hat{\theta} \geq \theta^*$ and produces a good of quality θ. The payoff from such deviation is given by

$$V^m\left(\theta, \hat{\theta}, 1\right) = -K + K - c|\hat{\theta} - \theta| = -c|\hat{\theta} - \theta| < 0.$$

Thus, this deviation is not incentive compatible.

Suppose next that the innovator deviates and claims that the quality of the idea $\hat{\theta} \geq \theta^*$ and does not incur the cost K, thereby producing a good of quality 0. The payoff from such a deviation is given by

$$V^m\left(\theta, \hat{\theta}, 0\right) = K - c|\hat{\theta} - 0| \leq K - c\theta^* \leq 0.$$

Thus, this deviation is not incentive compatible either.

Next suppose that $c < \frac{K}{\bar{\theta}}$. The proof is by contradiction. Since a mechanism which only uses patents is feasible and has innovation for some values of θ, the welfare-maximizing mechanism also has innovation for some value of θ. Suppose that for some value of θ, the mechanism specifies $\delta(\theta) = 1$ and some prize $T(\theta)$. Voluntary participation implies that

$$T(\theta) \geq K.$$

Consider the incentive compatibility constraint for the innovator who has an idea of quality 0 and contemplates deviation to this value of θ. Incentive compatibility requires

$$0 \geq T(\theta) - c(\theta - 0) \geq K - c\theta \geq K - c\bar{\theta}.$$

Since $K - c\bar{\theta} > 0$, we have a contradiction. This mechanism is not incentive compatible. *Q.E.D.* ■

7.1 A simple example

We now consider a simple example which demonstrates that as the cost of manipulating the signal rises, the length of the patent falls. Moreover, we analytically characterize the length of the patent and the size of the prize and show that they can co-exist in contrast to the more stark results of the previous sections. To do so, we suppose that the quality of the ideas takes three values: $0 < \theta_1 < \theta_2$. Suppose that $S(\theta_1) < K$ and $S(\theta_2) > S^m(\theta_2) > K$, and that $c < \frac{K}{\theta_2}$. From Proposition 5 we know that the mechanism must feature patents. Since $S(\theta_1) < K$, it is optimal to have no innovation if the quality of the idea is θ_1. The interesting incentive compatibility constraint is the one that ensures that an innovator of quality θ_1 does not misreport the quality of the idea and manipulate the signal. This constraint is given by

$$0 \geq \tau(\theta_2)\pi(\theta_1) - K + T(\theta_2) - c(\theta_2 - \theta_1). \tag{28}$$

The incentive compatibility constraint that the innovator of type $\theta = 0$ does not misreport the quality of the idea and manipulate the signal is given by

$$0 \geq T(\theta_2) - c(\theta_2 - 0). \tag{29}$$

Note that this incentive compatibility constraint is also the incentive compatibility constraint for the innovator with the idea θ_1 who chooses not to incur the cost and to misreport the signal.

The voluntary participation constraint for type θ_2 is given by

$$\tau(\theta_2)\pi(\theta_2) + T(\theta_2) \geq K. \tag{30}$$

The voluntary participation constraints for type 0 and type θ_1 imply that

$$T(0) = T(\theta_1) \geq 0. \tag{31}$$

The social surplus is given by

$$\tau(\theta_2) S^m(\theta_2) + (1 - \tau(\theta_2)) S(\theta_2) - K.$$

Clearly, social surplus is maximized by making $\tau(\theta_2)$ as small as possible subject to the incentive compatibility and the voluntary participation constraints. Since reducing $\tau(\theta_2)$ relaxes (28), it follows that the voluntary participation constraint (30) must be binding so that

$$\tau(\theta_2)\pi(\theta_2) + T(\theta_2) = K. \tag{32}$$

Substituting for $T(\theta_2)$ from (32) into (28), we have

$$0 \geq \tau(\theta_2)\pi(\theta_1) - \tau(\theta_2)\pi(\theta_2) - c(\theta_2 - \theta_1).$$

Since the right side of this inequality is strictly negative, it follows that (28) is not binding at the optimum. Thus, (29) and (30) must be binding so that $T(\theta_2) = c\theta_2$. From these constraints we have

$$\tau(\theta_2) = \frac{K - c\theta_2}{\pi(\theta_2)}. \tag{33}$$

We have shown that the length of the patent $\tau(\theta_2)$ is strictly decreasing in the manipulation cost c. Note that the optimal mechanism uses both prizes and patents.

8 Conclusion

We have formulated the problem of providing incentives for innovation as a mechanism design problem. We show that if innovators cannot manipulate market signals, patents are wasteful. If they can manipulate market signals easily, patents are necessary. If such manipulation is costly but not prohibitively so, the optimal mechanism uses a mix of patents and prizes.

We think of our analysis as being applicable to a large class of environments in which firms and individuals incur up-front costs to undertake innovations which can then be copied relatively easily by many others. We can interpret the quality dimension as reflecting the probability that a given firm will develop a successful idea. Under this interpretation, firms can always choose not to incur the up-front cost and claim that they were unlucky. Important extensions to consider in future work are to allow for competition in the race to develop new ideas and to allow for analyses of optimal patent breadth.

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