Protecting the environment when costs and benefits are privately known

Tracy R. Lewis*

I analyze different approaches for protecting the environment when stakeholders are privately informed about the costs and benefits of pollution reduction. The presence of asymmetric information calls for some important departures from the textbook prescriptions of marketable permits and emission taxes for controlling pollution. For instance, it may no longer be optimal to equate the social marginal benefits to the marginal cost of cleanup in determining appropriate abatement levels. I conclude this review with some suggestions for future research in this area.

1. Introduction

■ Environmental economists have recently made great strides in helping to place incentive-based policies for pollution abatement into practice. The implementation of the SO_2 marketable permit market, provided for under the Clean Air Act Amendments, is a prominent example of this progress. Yet some economists are still impatient with policy makers who persist in employing command and control rather than incentive policy to solve environmental problems. Perhaps this is because the solution to pollution problems seems so obvious, and so treatable using the simple pricing principles that underlie most transactions in our market economy. The classical economic argument for correcting environmental problems, found in most economics textbooks on the environment, proceeds as follows.[1] The cause of excessive pollution and environmental degradation is a market failure whereby property rights for environmental commodities are ill defined and individuals do not bear the full social costs of their

* University of Florida; lewistr@dale.cba.ufl.edu.

[1] For example, see Baumol and Oates (1988) and Tietenberg (1992). In contrast to incentive approaches for abatement, there are command-and-control strategies that include the setting of technology and uniform performance standards.

decisions. Three simple approaches exist to overcome market failure and the attendant inefficiencies it produces: (i) assign property rights to individuals and allow them to be traded in competitive permit markets, (ii) tax pollution to reflect social marginal cost, and (iii) assign liability for damages, and let parties bargain to mutual benefit to eliminate excessive pollution.

Numerous authors have argued vigorously in favor of adopting either the market or charges approach to solving pollution problems.[2] The reluctance of policy makers to employ economic incentives for reducing emissions has been rationalized in several ways. First, there is a belief among many environmental economists that policy makers need to be further educated as to the virtues of incentive-based policies before such policies are likely to be adopted on a large scale.[3] A related school of thought maintains that many regulators come from a legal or engineering/science background that influences their policy leanings toward process-oriented, detailed environmental controls and standards.[4] In addition, some regulators have an antimarket mentality, i.e., that it is immoral to distribute and sell rights to pollute the environment. A third view, derived from the public choice school of thought, maintains that much environmental policy is a rational response of regulators to special interests that attempt to tilt environmental policy in their favor. And although the use of economic incentives may maximize total surplus, it may not be the preferred policy of special interests.

In this survey I establish a framework based on recent developments in the economics of incentive regulation and agency to evaluate different prescriptions for dealing with environmental problems. I argue that the market failure associated with environmental externalities cannot be completely overcome with the simple application of permit markets and changes. One reason for this is that any move away from the current regulatory regime toward a market- or tax-based system will benefit some parties and harm others.[5] Parties that are harmed can employ whatever legal standing or political power they possess to oppose the policy. Thus, political realities require that the harmed parties be compensated to some degree to ensure their approval of and participation in the new process. However, the actual costs incurred by the harmed parties as well as the benefits derived by others is private knowledge. The existence of this private information may hamper attempts to redistribute income from parties that benefit to those that are harmed to such an extent that decentralized incentives may no longer be sufficient, much less implementable. I review this argument in Section 2 of the survey.

In Section 3, I survey recent developments in the incentive regulation literature to suggest strategies for dealing with environmental regulation when the affected parties are privately informed about the costs and benefits that they incur. The application of incentive regulation to environmental protection is particularly appropriate because the regulator is often quite uninformed about the private benefits citizens enjoy from improved environmental conditions and the costs producers and consumers bear to reduce pollution. In my review of incentive regulation I find that in most instances the pure forms of marketable permits or emission charges are insufficient regulatory instruments

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[2] Approach (iii), the Coasian bargaining solution, is generally perceived to be ineffective and impractical, as explained in Farrell (1987).

[3] For example, see early studies by Ruff (1970) and more recent work by Hahn and Stavins (1991) and Stavins (1989, 1992) to educate policy makers on the virtues of incentive-based environmental regulation. The Project 88 program in Environmental and Natural Resources is perhaps the most comprehensive and ambitious attempt to convince environmental policy makers of the virtues of market-based approaches.

[4] See Kelman (1983) and Hahn and Stavins (1991) for an elaboration of this view.

[5] For instance, if marketable emission permits are established, producers in environmentally sensitive regions may be displaced while firms in environmentally robust areas may prosper. See Hahn and Noll (1983). Another implication of this, as pointed out by Hahn and Stavins (1991), is that market-based approaches are likely to be implemented in newly regulated situations where there are no existing constituencies to resist a movement away from the status quo.

for dealing with asymmetrically informed agents. Yet in some instances, straightforward alterations to these incentive devices are all that is needed to make them effective regulatory instruments. Some readers may view these regulatory instruments that have been adapted to account for asymmetrically informed agents as simple and natural hybrids of classic market- and tax-based instruments. Nonetheless, I show that incentive regulation calls for some important departures from the use of these classic instruments.

In Section 4 I summarize my main findings, identify some key unresolved issues, and suggest some directions for future research in environmental regulation.

My primary purpose in presenting this survey is to acquaint environmental economists with recent developments in the theory of incentive regulation. I believe that the insights gleaned from incentives theory can be usefully applied to issues of environmental regulation, and my goal in this survey is to demonstrate some of these applications as well as to identify areas for further research. To accomplish this goal I have deliberately limited the scope of this survey to the narrow but important perspective of analyzing how the distribution of information affects the feasibility and optimality of different environmental policies.[6] Even within this narrow area, my treatment of subjects is not comprehensive. For instance, I touch only briefly on issues of monitoring and compliance. Further, I have only managed to list some but not all of the important contributions to the particular literature on environmental regulation that I review here. Nonetheless, I hope that this selective look at the incentive and environmental regulation literature will provide the reader with useful insights about the feasibility and desirability of implementing incentive policies for environmental protection.

2. Decentralized control with private informed agents

■   In this section I analyze how decentralized policies of (i) trading pollution rights, (ii) pricing emissions, and (iii) Coasian bargaining work when users of the environment are privately informed. With each of these policies one attempts to internalize environmental costs by making the user of environmental resources the residual claimant of all the social costs and benefits of his activity. Although this gives users the correct incentives for making production and emission-reduction decisions, it may cause distributional and political constraints to be violated, thus preventing the implementation of these policies.

Imagine there is a group of domestic firms that supply an export product that sells at a fixed world price. Firms, which are indexed by θ, differ according to how profitable they are.[7] θ is uniformly distributed over $[\underline{\theta}, \overline{\theta}]$. Let $\pi(\theta)$ represent the profits of firm type θ. Assume that π is increasing in θ and that there exists a minimum-type firm $\tilde{\theta} \in (\underline{\theta}, \overline{\theta})$ that generates zero profits.[8] The regulator has beliefs about the distribution of firm types in the economy but does not know the profitability of any particular firm.

Figure 1 illustrates a situation in which each firm emits pollutants that impose an external cost on domestic consumers of $w > 0$. The domestic value of firm θ's production is captured entirely in profits, $\pi(\theta)$. The net social surplus generated by production is $\pi(\theta) - w$. The optimal size for the industry occurs at a critical type $\hat{\theta}$, where $\pi(\hat{\theta}) - w = 0$ and net surplus is exhausted.[9]

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[6] The reader is referred to the excellent recent survey by Cropper and Oates (1992) for a comprehensive review of developments in environmental economics.

[7] Access to different quality inputs explains differences in profits among competing firms.

[8] For simplicity I assume that $\pi'(\theta) = 1$.

[9] This also serves to identify the optimal amount of pollution, since there is a one-for-one correspondence between pollution and the number of firms in the industry.

FIGURE 1

$\pi(\theta)$

$\pi(\theta)$

W

$\pi(\theta) - W$

A

B

$\underline{\theta}$ $\tilde{\theta}$ $\hat{\theta}(W)$ $\bar{\theta}$ θ
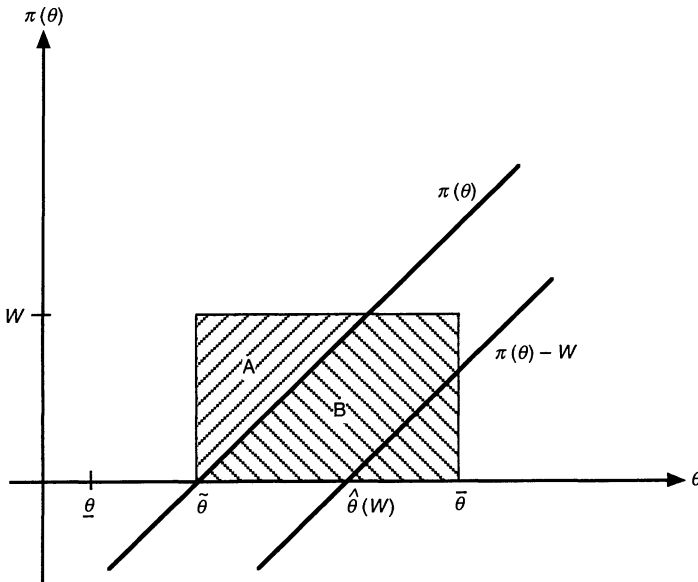
In a free-entry equilibrium, absent regulation, all firms with $\pi(\theta) \cdot \geq 0$ will produce. There will be excessive entry and too much pollution from a social viewpoint. How can this best be rectified? The answer to this depends on the distribution of legal rights and political power among producers and consumers. To illustrate, suppose producers have no legal right to emit pollutants. The government can then reduce the number of firms and the corresponding amount of pollution to optimal levels by levying an emissions tax, τ, equal to, w, the social cost of pollution. The effect of the tax is to reduce profits for industry firms by w, which induces the correct number of firms to exit the market, as indicated in Figure 1.

Unfortunately, this is unlikely to work if firms have legal standing and political power to oppose the tax. Although the gains from reducing pollution (marked by area A + B in Figure 1) exceed the firms' losses (marked by area B in Figure 1), the affected producers have strong incentives to oppose the tax.[10] In contrast, members of the public have little individual incentive to counter the firms' opposition because their stake in the outcome is small.[11]

To analyze this possibility, let $P(L)$ represent the probability that a particular policy, such as a pollution tax, can be implemented when the policy imposes aggregate losses on producers of L. Assume that $P'(L) < 0$ and $P''(L) < 0$, implying that the probability of a policy's being implemented decreases with the size of the firms' losses at an increasing rate. Presumably, firms will campaign and lobby to defeat the policy more vigorously the greater the losses they stand to suffer. For simplicity let us assume that industry incurs no cost in opposing the policy. (Including such costs in the analysis would serve only to reinforce the results I obtain below.) Further, imagine that the

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[10] Area A + B represents the reduction in pollution costs plus the revenue collected from the tax. Area B represents the tax paid by firms remaining in business plus the forgone profits of firms exiting the industry.

[11] Reduced pollution improves environmental quality, which will likely provide small individual benefits to a large group of citizens. Individual citizens will capture insufficient benefits to lobby vigorously for the tax, and instead will prefer other citizens to lobby on their behalf. See Olson (1965), Stigler (1971), and Peltzman (1976) for further elaboration of the factors determining political power among different interest groups.

government has limited resources, denoted by $\bar{R}$, for compensating firms harmed by the tax. These resources consist of taxes collected from beneficiaries of the pollution reduction as well as other revenue sources in the economy. It is important to note that the ability of the government to tax the beneficiaries of the pollution reduction is limited because benefits are widespread and the benefits enjoyed by individual citizens are private knowledge.[12]

Now consider a more general tax-subsidy scheme that taxes polluting firms at a rate τ and subsidizes firms at the rate of s that voluntarily refrain from producing in the industry. Under this approach all firms $\theta \geq \hat{\theta}(s + \tau)$ will produce, where $\hat{\theta}(s + \tau)$ is defined by $\pi(\hat{\theta}(s + \tau)) = s + \tau$.[13] The government operates under a budget constraint requiring that the difference between the subsidies paid to firms not to pollute and the taxes collected from polluting firms not exceed $\bar{R}$, the resources available for underwriting the program. Under a binding budget constraint this implies that

$$\bar{R} = F(\hat{\theta}(s + \tau))s - (1 - F(\hat{\theta}(s + \tau)))\tau, \tag{1}$$

where $F(\ )$ is the distribution function for θ. The net loss to firms from the implementation of the policy, $L(s + \tau)$, is given by

$$L(S + \tau) = (1 - F(\hat{\theta}(s + \tau)))\tau + \int_{\theta \in (\tilde{\theta}, \hat{\theta})} \pi(\theta) \, dF(\theta) - F(\hat{\theta}(s + \tau))s. \tag{2}$$

It consists of total taxes collected plus the net loss in profits from firms that are induced to exit the industry minus the subsidies paid to firms to exit the industry. Notice that for simplicity I assume that the net losses aggregated across all firms determine incentives for firms to oppose the policy. A more general analysis might allow the distribution of gains and losses across firms to determine the probability of policy implementation.[14] Using (1) we can rewrite (2) as

$$L(s + \tau) = \int_{\theta \in (\tilde{\theta}, \hat{\theta})} \pi(\theta) \, dF(\theta) - \bar{R}. \tag{3}$$

The government's objective is to pick s and τ to maximize the expected gain from the policy, $G(s, \tau)$, which is given by

$$G(s, \tau) = p(L) \int_{\theta \in (\hat{\theta}, \bar{\theta})} [\pi(\theta) - w] \, dF(\theta) + (1 - p(L)) \int_{\theta \in (\tilde{\theta}, \bar{\theta})} [\pi(\theta) - w] \, dF(\theta). \tag{4}$$

Differentiating (4) with respect to s and τ and simplifying, I obtain the following conditions for the optimal pollution taxes and subsidies:

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[12] Notice that if the government could capture the gains from pollution reduction from the citizens who benefit, it could fully compensate producers for their losses, thus ensuring that the policy would not be opposed.

[13] This assumes that $\hat{\theta} \in (\underline{\theta}, \bar{\theta})$. Notice that $s + \tau$ measures the opportunity cost of production for a firm.

[14] Further, I assume that all firms that do not produce, including those that would not have produced in the absence of a subsidy, receive s'. This arises whenever the government is unable to observe each firm's profit possibilities directly.

$$\tau + s = w\left[P(L)\bigg/\left(P(L) + P'(L)\int_{\theta\in(\tilde{\theta},\hat{\theta})}(\pi(\theta) - w)\,dF(\theta)\right)\right] < w. \qquad (5)$$

According to (5), the adjustment toward the socially efficient elimination of pollution is incomplete. To see this, note that the incentives for firms to exit the industry are reflected by the sum of subsidy plus tax payments, $\tau + s$. Under first-best conditions, these payments would equal w, the marginal social cost of pollution. But when firms may oppose the tax-subsidy policy, (5) indicates that these incentive payments are discounted by the expected marginal reduction in net gains due to a decrease in the probability of implementation that arises as firms' losses increase.

Notice that the optimal tax-subsidy scheme depends on $\bar{R}$, the funds available to the government for funding the program. It is easy to show that

$$dP(L)/d\bar{R} > 0 \qquad (6)$$

and

$$d(\tau + s)/d\bar{R} > 0. \qquad (7)$$

Conditions (6) and (7) reflect the value to the policy maker of having additional funds available to finance the tax-subsidy program for reducing pollution. Condition (6) indicates that additional funds allow for a reduction in industry losses, which reduces the chances that the program will be opposed by the firms. According to condition (7), the adjustment toward a more complete reduction in pollution is also facilitated by increased government funding.

To summarize, it is generally not possible to achieve the socially efficient reduction in pollution using standard tax and subsidy instruments. This arises when citizens are privately informed about the benefits they derive from the policy. In such cases the government has limited ability to redistribute these gains to compensate firms for losses incurred under the policy. But political realities require that these losses be small to dissuade firms from opposing the policy. Consequently, the second-best policy involves two distortions: a partial reduction in pollution, in order to limit the firms' losses, and a possibility that the tax-subsidy scheme may fail to be implemented. It follows that the severity of these distortions will depend on the resources the government has to compensate firms, as well as on the political power firms can exercise to oppose the policy.[15]

It is important to realize that the inability to achieve efficiency in the presence of private information is not peculiar to the tax-subsidy scheme I have proposed. Suppose a free-entry equilibrium initially exists, and consider a marketable permit policy in which the government attempts to limit production to the socially efficient number of firms.[16] It distributes the efficient number of production licenses to consumers and producers somehow and allows agents to buy and sell licenses to determine who produces.[17] Presumably, under competitive conditions firms with the highest profits will bid the most for the licenses and end up producing. Notice that firm types $\theta < \hat{\theta}(w)$ will ultimately be excluded from the market. But political realities require that these types be allocated permits initially, which they can sell as compensation for their losses

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[15] A similar point is made in Klibanoff and Morduch (1995) and in Lewis et al. (1989).

[16] Notice that the government has sufficient information on the distribution of firm types to determine this number.

[17] This example is similar to the revenue-neutral auction proposed by Hahn and Noll (1982).

to ensure their cooperation and participation in the market. Since the firms are privately informed about their type, however, there is no practical way to identify which firms should receive the permits.[18]

Similar implementation problems arise in the Coasian bargaining solution, even with small numbers.[19] To see this, imagine that a single consumer and a single producer gather to bargain over the reduction of pollution as envisioned by Coase. As is well known, if the requirements for the Coase theorem are satisfied (the existence of rational well-informed agents who can bargain costlessly), then it follows as a tautology that the efficient outcome will be reached. However, suppose the producer is privately informed about his profits from production, as given by $\pi(\theta)$, and that the consumer only knows the distribution for θ. Suppose that the firm is vested with the right to produce and that the consumer offers a bribe of w to the firm to cease production. This arrangement causes the firm to fully internalize the cost imposed on consumers and would therefore be efficient. But notice that consumers will not find it optimal to implement this form of bribery. Instead consumers will choose a bribe B to

$$\max_{B} \ (w - B)(F(\hat{\theta}(B)) - F(\tilde{\theta}))/(1 - F(\tilde{\theta})), \tag{8}$$

where the quantity $(w - B)$ represents the net gain if the firm is induced to exit the market and the quantity $(F(\hat{\theta}(B)) - F(\tilde{\theta}))/(1 - F(\tilde{\theta}))$ represents the probability that the firm will exit.[20] The optimal bribe satisfies

$$B = w - [F(\hat{\theta}) - F(\tilde{\theta})]/f(\hat{\theta}) < w. \tag{9}$$

According to (9), consumers offer a bribe that is less than the cost of pollution. This is because the consumer is a monopsonist who shades her bid to induce exit by the polluting firm in the hopes of capturing some of the surplus from the transaction.

Suppose instead that consumers have the right to an unpolluted environment. They can prevent firms from producing and therefore must be compensated for allowing firms to enter. In that case, an efficient solution in which the firm must bribe the consumer to produce by paying w will be implemented. Only firms with profits exceeding w will pay the bribe and continue producing.[21] Thus, as in our earlier discussion of tax schemes, here one sees the importance of the initial assignment of property rights and the form of bargaining allowed under the Coasian solution. Note, however, that generally it will not be possible to achieve efficient solutions for any distribution of property rights when both producers and consumers are privately informed.[22]

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[18] Alternatively, the government could distribute permits to all firms currently in the market, agreeing to buy back enough permits to reduce the market to its efficient size. Notice that this scheme is equivalent to a program in which the government pays exiting firms a subsidy equal to w.

[19] There is a large literature that analyzes allocations reached under Coasian bargaining. Some of the more insightful articles in this literature that deal with asymmetrically informed agents include Cooter (1982) and Farrell (1987).

[20] To calculate this probability, note that the firm must be operating originally, otherwise there would be no pollution. This implies that the firm's type, θ, must exceed $\tilde{\theta}$. Conditional on this, the probability that the firm will be induced to exit when offered B is given by $(F(\hat{\theta}(B)) - F(\tilde{\theta}))/(1 - F(\tilde{\theta}))$.

[21] This also arises in market-based regulation. In this instance, if producers must pay a constant fee of W to operate, then the first-best solution can be reached in which the optimal number of firms enter the industry and the consumers are exactly compensated for the increase in external pollution costs they bear.

[22] See Lehrer and Neeman (1996), Myerson and Satterthwaite (1983), Makowski and Mezzetti (1993), and Neeman (1996).

In theory, reliance on the common law tort system would appear to be an attractive supplement or replacement for Coasian bargaining. By assigning liability to polluters to provide compensation for individuals harmed by the pollution, a mechanism for internalizing the damages from pollution is thus provided. However, as Menell (1991) explains, the usefulness of the tort system to solve environmental problems is limited because it is extremely difficult to prove liability in any particular case. This is because the harm resulting from pollutants, which may be manifested in the form of a disease or reduced health, may be attributable to a number of different factors besides the pollution. And even if a link between a pollutant and a disease could be established, it would be difficult in many cases to establish which individual firm's pollution was responsible for the harm. Although statistical evidence may establish a link between pollution and the harm it causes on average, this evidence is not admissible for establishing liability for harm in particular cases.[23] Thus the courts' insistence in evaluating each case on its merits undercuts their ability to provide polluters with the right incentives to exercise care.

The foregoing examples illustrate the importance of distributional, informational, and political constraints in determining which departures from the status quo policy are feasible.[24] They also suggest that there are advantages and disadvantages of regulating privately informed agents by decentralized incentive procedures. The advantage is that the regulator can delegate production and emission-control decisions to better-informed agents. The disadvantage is that it is more difficult to identify and compensate agents who are harmed by departures from the status quo. This limits the set of feasible policies the regulator can implement. I shall now review methods that have been suggested for implementing environmental policy when agents are privately informed.

3. Regulating privately informed polluters

■ How does one control emissions when polluters are privately informed about the costs of achieving specified standards? The insight of early analysis of this question by Kwerel (1977), Dasgupta, Hammond, and Maskin (1980), and Spulber (1988) is that each polluter should be a residual claimant of all the costs and benefits associated with its actions. This endows polluters with the correct incentives to reduce emissions.[25] However, one must satisfy distributional constraints to implement new policies. Privately informed polluters can command information rents by claiming that the imposition of a new policy may force them out of business unless they are compensated for their loss.[26] These claims are impossible to verify, but they must be respected if one does not intend to drive manufacturers from the market. Occasionally these information rents may exceed the extra surplus generated by a more efficient policy. In that instance it will not be possible to implement the policy. Examples of such implementation problems were provided in the previous section.

The incentive regulation literature (as exemplified by Laffont and Tirole (1993a) and the references cited therein) suggests ways to reduce information rents. A review of this work reveals that optimal mechanisms for reducing rents typically require some sacrifice in the productive efficiency of pollution-control policy. Further, the degree of

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[23] Aside from this, the court system is poorly designed to evaluate scientific evidence. See Huber (1987) and Menell (1991) for a discussion of problems with legal analysis of evidence and award of damages.

[24] See Dewatripont and Roland (1992) and Lewis et al. (1989) for further analysis of what regulatory reforms are feasible when agents are privately informed and possess political power.

[25] This is the insight of the Clarke (1971) and the Groves (1973) mechanism for provision of public goods. It carries over to other instances in which agents are privately informed about either the costs or the benefits of some action.

[26] In some instances it will be desirable to induce some businesses to exit the industry and relocate in another region where emissions are not as harmful to the environment.

intervention by regulators rises as a result of the need to limit information rents of privately informed polluters. In this section I examine how these two factors are manifested in different instances of environmental control.

To be concrete and to follow a good portion of the incentives literature, I employ a model of electric utility regulation to analyze pollution-control programs. The example of an electric utility is particularly pertinent, since electricity generation is a major source of air pollution in the United States. In addition, regulators have a clear mandate to control both the prices the utility charges and the pollution it emits. The reader should recognize, however, that my analysis of regulated utilities is presented for pedagogical purposes to illustrate concepts. Clearly this industry is not universally descriptive of other markets where environmental problems also loom large. Further, my analysis is primarily normative. I do not attempt to capture all the distinguishing features of environmental regulation, nor do I try to predict what type of regulation will actually arise in particular markets.[27]

□ **Observable emissions.**[28] I begin by analyzing the simplest static case, where the regulator is relatively well informed about the operating conditions of the utility and can monitor emissions. I then proceed to complicate the analysis in stages with more realistic assumptions. Suppose there is a regulated public utility that produces electricity and pollutants as a byproduct. For now, imagine that there is a single regulatory agency overseeing both the pricing of electricity and the protection of the environment. Later I consider how these activities might be separately regulated.

For simplicity, assume that consumers are identical. They value electricity service, q, and emissions, e, according to the utility function $U(q, e)$. U is increasing in q and decreasing in e.

The utility's cost of producing electric service, q, while limiting emissions to a level, e, is denoted by the function $C(q, e, x, \beta)$. Costs are increasing in q and decreasing in e. The variable x represents specific inputs, including emission-control equipment, that the utility employs. β is a random variable affecting the costs of service and pollution abatement. For example, β may measure the ease with which the utility substitutes fuels or installs scrubbers to reduce emissions. Costs are decreasing in β.

I assume that the regulator is unable to observe costs. At first blush this may seem to be an overly restrictive assumption, in view of the fact that the regulator can presumably ask the firm to verify its costs and to submit records of its cost expenditures. As is well known, however, utilities can and often do engage in cost padding and creative bookkeeping to inflate their accounting costs for regulatory purposes. To capture the idea that regulators have difficulty measuring the true costs of a utility, I adopt the simple but strong assumption that costs are unobservable to the regulator. In adopting this approach I note that my central results carry over to environments where some portion of costs can be monitored by the regulator.[29]

I further assume that the regulator is unable to observe the efficiency of the utility as characterized by β. However, the regulator is able to monitor q, e, and x. I assume that β is distributed by the cumulative distribution function $F(\beta)$ with density $f(\beta) > 0$ for $\beta \in \{\underline{\beta}, \overline{\beta}]$ and that the regulator knows the distribution of β. The variable

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[27] It is interesting to note, for instance, that a tradable permit system for SO_2 and NO_x has been implemented for electricity generation.

[28] See Laffont (1993) for an analysis similar to the model presented here.

[29] Another approach adopted by Laffont and Tirole (1993b) and by Laffont (1993) assumes that the regulator can observe accounting costs but cannot measure how much effort the firm devotes to reducing these measured costs. In such a framework, the characteristics of optimal incentive regulation are virtually the same as the policies derived for my model.

x represents specific inputs, including emission-control equipment, that the utility employs. Under decentralized regulation the utility would choose x to minimize costs. However, I shall show how it is helpful for the regulator to control x to limit the utility's information rent.

The regulator oversees the utility by offering a menu of contracts $\{T(\beta), q(\beta), e(\beta), x(\beta)\}$ for $\beta \in [\underline{\beta}, \overline{\beta}]$. The contract specifies a transfer to the utility of T, an output level q, a required level of emissions e, and specified inputs x to be provided, which are all conditioned on the utility's report of its production parameter, β. Myerson (1979) and others have demonstrated that it is without loss of generality that one can design an "incentive compatible" menu to induce the utility to truthfully report β.[30]

The regulator must transfer enough to ensure that the utility breaks even. Notice that firms with higher β's command greater profits because of their private information about β. The reason is that a β-type firm can always accept the contract intended for the $\beta - \Delta$ firm and earn the same transfer payment, $T(\beta - \Delta)$, but incur a smaller cost. The difference in costs given by

$$R = C(q(\beta - \Delta), e(\beta - \Delta), \beta - \Delta, x(\beta - \Delta))$$
$$- C(q(\beta - \Delta), e(\beta - \Delta), \beta, x(\beta - \Delta))$$

is a rent that a β-type firm earns because it is privately informed about his type.[31] If we divide both sides of the equation above by Δ and allow Δ to go to zero we can see that the rate at which information rents increase with β is given by

$$R'(\beta) = -C_\beta(q(\beta), e(\beta), \beta, x(\beta)) > 0.[32]$$

Often the regulator will want to reduce these information rents. This arises when there is a need to make regulation self-financing, as I assumed in my previous examples. It also occurs when the regulator desires to minimize transfers because of the premium associated with raising public funds.[33,34]

As a useful benchmark, consider the full-information case where the regulator can observe costs and knows the firm's type, β. Assume the regulator wishes to maximize the sum of producer and consumer surplus from electricity service net of the environmental costs associated with the service. In that instance, the regulator would instruct the firm to produce where marginal cost equals price and to reduce emissions to the level where the marginal cost and benefits of emission reduction are equated.[35] Also,

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[30] See Baron (1989) for a good exposition of this result.

[31] Notice that this rent calculation provides a method for quantifying the transactions costs associated with implementing certain environmental policies. Discussions of transactions costs associated with environmental regulation like that appearing in Stavins (1993) could be made more rigorous and compelling if the transactions costs were explicitly derived.

[32] I adopt the conventional notation that derivatives are denoted by variables with primes and subscripted variables denote partial derivatives.

[33] Raising public funds through taxation involves a deadweight efficiency loss. Consequently, it costs more than a dollar to transfer a dollar of public funds to the utility. Every dollar saved in utility transfers can be used to reduce the distortionary impacts of taxation generated elsewhere in the economy. See Bovenberg and Goulder (1993) and the references cited therein.

[34] In the United States and elsewhere, utilities are compensated directly by payments from consumers. My model admits this interpretation as well. In this case, the regulator will still desire to limit the utility's information rents. Excess payments from consumers to the utility reduce funds that the government can collect from consumers for running public programs and reducing government deficits.

[35] To be strictly correct, this formulation requires that the marginal costs of production and emission reduction are appropriately weighted to reflect the cost of meeting the budget constraint or paying the utility with public funds.

the utility would choose inputs x to minimize its costs. The regulator would set transfers to just compensate the utility for its costs of production and emission reduction.

Now suppose the regulator cannot observe the utility's type, β, or its costs. In this instance, the regulator selects an incentive-compatible menu of contracts $\{T(\beta), q(\beta), e(\beta), x(\beta),\}$ to maximize total surplus. In addition, the regulator must ensure that utility profits are nonnegative. One can show (see the Appendix) that this exercise is equivalent to solving the following regulator's problem (RP):

$$\max_{\{q(\beta), e(\beta), x(\beta)\}} \int [U(q(\beta), e(\beta)) - \lambda C(q(\beta), e(\beta), x(\beta), \beta)]$$
$$- (\lambda - 1)[1 - F(\beta)]/f(\beta)](-C_\beta) \, dF(\beta)$$

for all $\beta \in [\underline{\beta}, \overline{\beta}]$.

The first square-bracketed expression in RP is the surplus from electricity consumption and production net of environmental costs. Notice that costs are weighted by $\lambda > 1$, which reflects the costs of meeting a financing constraint. Alternatively, one may interpret λ to be the distortionary costs of raising public funds to pay the utility. The second expression is type β's contribution to expected information rents. It is interpreted as follows. More efficient firms may imitate less efficient types and earn rents at the rate $-C_\beta$. The rent accrued by a β-type firm also accrues to the $1 - F(\beta)$ higher types, as they can always imitate a β-type firm. This expression is normalized by $f(\beta)$, the probability that a β type is actually encountered.

The first-order conditions for maximization of RP include

$$-U_e = -\lambda C_e - (\lambda - 1)[1 - F(\beta)]/f(\beta)(-C_{\beta e}), \qquad (10)$$

$$U_q = \lambda C_q + (\lambda - 1)[1 - F(\beta)]/f(\beta)(-C_{\beta q}), \qquad (11)$$

and

$$\lambda C_x = -(\lambda - 1)[1 - F(\beta)]/f(\beta)(-C_{\beta x}). \qquad (12)$$

First consider the regulator's choice of emissions level, e. The regulator induces the firm to set emissions such that the marginal benefit from emission reduction $(-U_e)$ equals the *modified* marginal costs of emission reduction. Marginal costs are modified to account for the effect of emission reduction on information rents as captured by the second term on the right-hand side of (10). To see the implications of this, suppose $-C_{\beta e} < 0$ so that the marginal cost of reducing emissions, $-C_e$, is smaller for more efficient firms. Then, according to (10), the regulator induces the firm to reduce emissions by an inefficiently small amount, since $-U_e > -\lambda C_e$. This distortion causes a reduction in information rents, as the cost advantage in reducing emissions enjoyed by the more efficient firms is diminished.

The regulator may similarly distort the utility's output choice to limit information rents. Suppose that $C_{\beta q} < 0$ so that marginal production costs are decreasing with higher-β types or more efficient firms. Equation (11) indicates that to limit information rents it will be necessary to induce the utility to reduce production below its surplus-maximizing level to reduce the rate of rent accrual, $-C_\beta$.

Notice that under decentralized regulation, the utility would be allowed to choose the cost-minimizing set of inputs to minimize the costs of meeting a specific emissions standard. But according to (12), the regulator will want to control the firm's choice of inputs, and possibly to distort it from the cost-minimizing level. For instance, if

$-C_{\beta x} < 0$ so that rents decrease with higher input use, then the regulator will induce the utility to employ an excessive amount of inputs in order to limit information rents.

Some interesting conclusions emerge from this analysis that call for modifications in the usual pollution-tax type of policies commonly advocated by environmental economists. First, one finds in the absence of financing constraints (where $\lambda = 1$) that the usual efficiency conditions obtain. But when financing is constrained, certain sacrifices in productive efficiency are required to reduce information rents. Traditional efficiency conditions are replaced by a modified rule that requires the marginal benefits from some activity to be equated to marginal costs that are modified to account for the marginal impact of the activity on information rents.

Second, containing information rents requires greater regulatory intervention in specifying the mix of inputs to be employed by the utility. For instance, it is not possible to use uniform emission taxes to achieve the desired outcome characterized in (10)–(12). In theory, though, it may be possible to employ decentralized means to support this information-constrained solution by a set of transfers, input and output prices, and emission taxes. According to this procedure, the utility first selects a vector of transfers, price, and taxes from a specified menu. Next the utility determines its profit-maximizing levels of inputs, outputs, and emissions given its personalized prices and taxes. Under certain conditions, this procedure can induce the utility to choose the second-best allocation characterized in (10)–(12). Unfortunately, though, stringent monotonicity and curvature conditions are required for the implementation of this scheme.[36] And even if the procedure is implementable, it requires the regulator to design a different set of prices and taxes for each conceivable type of utility, $\beta \in [\underline{\beta}, \overline{\beta}]$.

Third, notice that to reduce information rents, the regulator will restrict the mix of inputs employed by the utility to limit emissions. However, this is not to imply that the choice of abatement inputs is dictated to the firm as in command-and-control regulation. Rather, the latitude afforded the firm to choose a strategy for controlling pollution is restricted as compared to decentralized regulation, where the firm is free to choose abatement strategies.

Fourth, reducing output and abatement are alternative ways to limit information rents. This suggests that the conflict between supplying cheap electricity service and maintaining environmental quality is exacerbated by the need to limit information rents. For instance, if the regulator wishes to increase output and reduce the price of service to the utility's customers, it will need to induce less abatement from the utility in order to limit the utility's information rents.[37]

Finally, the analysis makes clear that departures from efficiency in reducing pollution arise because of financing constraints (when $\lambda > 1$) and the private information about costs that utilities are endowed with. One might expect that the productive inefficiencies generated to limit information rents would be reduced over time as the regulator learns more about the utility by observing its performance. This possibility is explored in the subsection below on multiperiod regulation.

□ **Unobservable emissions.** In some instances it may be impossible or too costly for the regulator to effectively monitor the firm's emission.[38] Yet one may control emissions

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[36] Laffont and Tirole (1986) and Laffont (1993b) suggest that appropriately chosen taxes and subsidies can be used to implement information-constrained allocations when agents are privately informed. See Rogerson (1986) for a discussion of conditions necessary for the implantation of decentralized allocations when agents are privately informed.

[37] See Laffont (1994) for a discussion of the regulatory tradeoffs between cost minimization and safety care.

[38] With the passage of the Clean Air Act amendments, accurate monitoring of electric utility emissions has become much more prevalent. Nonetheless, monitoring emissions is a major expense of most environmental regulatory programs, and for some industries and in some applications, accurate monitoring of pollution is not feasible.

by controlling output. To analyze this possibility I assume that $e(q)$ represents maximum emissions resulting from production q. In the absence of direct emission controls the firm emits $e(q)$ to minimize its cost of production. The cost for a firm, $C(q, \beta)$ depends only on the level of production, q, and on its type, β.[39]

Now production is the single instrument the regulator controls to influence both the level of output and the level of emissions simultaneously.[40] Proceeding as before, one can show that the level of production that solves the regulator's problem for this case satisfies the condition

$$U_q - \lambda C_q - U_e e'(q) = (\lambda - 1)[1 - F(\beta)]/f(\beta)(-C_{\beta q}). \tag{13}$$

The left-hand side of (13) represents the net marginal surplus from production, including the marginal cost of emissions. Generally it will be desirable to curtail production so that price exceeds the marginal cost of production in order to account for the environmental costs associated with greater output. The right-hand side of (13) measures the marginal impact on information rents from an increase in production. If $-C_{\beta q} > 0$, then increases in production increase information rents. To reduce rents, then, it will be desirable to further reduce output. Thus, (13) indicates that it may be desirable to curtail production both to reduce environmental damage and to limit information rents.

◻   **Monitoring outputs versus inputs that produce pollution.** The previous analyses emphasize the usefulness of regulating output and emission levels to minimize information rents. But monitoring is costly, and regulators may only be able to monitor the amount of emissions or the amount of output the firm produces, but not both. Which quantity should they monitor and regulate? Lewis and Sappington (1995)[41] analyze a situation where the firm can reduce emissions only by cutting output. Firms differ in their capacity to limit emissions by reducing output. Firms wish to overstate the reduction in output necessary to achieve a given level of emission to receive more favorable treatment from the regulator. Lewis and Sappington find that it is preferable to regulate output rather than emissions when the marginal loss in output from reducing emissions is decreasing in the level of production. By regulating output, the firm's ability to overstate the cost (in terms of forgone production) of reducing emissions can be limited more effectively than regulating emissions. This is surprising, since it may seem preferable to control pollution closest to its source, rather than by controlling output.

◻   **Stochastic emissions.** Here I amend the previous model by assuming that the utility's emissions may be monitored but that the level of emissions is stochastic. For instance, pollution control devices may break down unexpectedly, and this may also cause the waste emitted by the utility to randomly fluctuate.

Following Baron (1985a) I model this case by assuming that emissions are distributed by the function $G(e \mid q, x, \beta)$ with density $g(e \mid q, x, \beta) > 0$ for $e \in [\underline{e}, \bar{e}]$. The variable x is the abatement equipment (e.g., the number of scrubbers) that the regulator requires the utility to install. The firm is privately informed about its productivity parameter, β, which affects both its cost of service, $C(q, x, \beta)$ and the level of emissions.

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[39] Here I am ignoring inputs, x, by assuming they are technologically fixed. In practice, $e(q)$ could be reduced by the proper choice of abatement inputs.

[40] Lewis and Sappington (1992) analyze an analogous situation in which a regulator chooses the price of electricity as a single instrument to influence both the level of output and the amount of conservation services offered by the utility.

[41] The Lewis and Sappington (1995) work draws on previous analysis by Maskin and Riley (1985), who study whether it is preferable to monitor inputs versus output in controlling information rents.

Total costs are decreasing in β, as are the marginal costs of supplying electricity and abatement.

The distribution function G has the properties that emissions are stochastically decreasing with greater abatement, $G_x > 0$, and stochastically increasing with output, $G_q < 0$. Further, $G_\beta > 0$ so that emissions are stochastically decreasing as the utility becomes more efficient. I also assume that the distribution of emissions satisfies the monotone likelihood property that g_x/g is decreasing in e.[42]

As in the previous models, I assume the regulator offers the utility a menu of options to select from. Each option designates levels of electricity service and abatement inputs the utility is required to supply and a level of compensation the utility is to receive. In addition, suppose the regulator imposes a uniform emissions tax, $\tau > 0$, on the utility. To assess the impact of the tax, notice that emissions are only affected by q and x. Consequently, the tax serves only to affect the utility's level of profit, which equals the payment received by ratepayers minus the cost of providing service and the pollution taxes it is assessed. The imposition of the tax decreases the utility's expected profits by $-\tau \int eg(e \mid q, x, \beta) \, de$. Differentiating this expression with respect to β shows the impact of the tax on the rate of rents accruing to more efficient firms:

$$d/d\beta \left\{ -\tau \int eg(e \mid q, x, \beta) \, de \right\} = -\tau \int eg\beta(e \mid q, x, \beta) \, de$$

$$= \tau \int eG_\beta(e \mid q, x, \beta) \, de > 0. \qquad (14)$$

One obtains the second expression in (14) by integrating by parts, and the inequality follows from the assumption $G_\beta > 0$. Equation (14) demonstrates that the tax burden is less severe for more efficient firms. Hence they earn greater rents from the imposition of a tax, since they are able to avoid emissions more readily than less efficient firms. Consequently, since the only effect of the tax is to increase information rents it is preferable to set the uniform tax to zero. In that case, one controls emissions directly by specifying the level of abatement or by limiting production as in the model of the section above on unobservable emissions.

Suppose taxes are allowed to vary with the level of emissions. In this case, the change in profit from the imposition of a nonnegative emission tax, $\tau(e)$ (bounded above by $\bar{\tau} > 0$), becomes $-\int \tau(e)eg(e \mid q, x, \beta) \, de$. Differentiating this expression with respect to β reveals how the utility's tax liability is affected by its efficiency:

$$d/d\beta \left\{ \int - \tau(e)eg(e \mid q, x, \beta) \, de \right\} = \int - \tau(e)eg^\beta(e \mid q, x, \beta) \, de. \qquad (15)$$

Reductions in tax liability accruing to more efficient firms constitute a rent that these firms enjoy. Notice from (15) that these rents are minimized by setting $\tau(e) = \bar{\tau}$ whenever $g_\beta < 0$ and zero otherwise. The assumption that g satisfies the monotone likelihood property implies there exists an emissions level $e^*(\beta, q, x)$ such that $g_\beta \; (<, =, >) \; 0$ when $e \; (<, =, >) \; e^*(\beta, q, x)$. Thus the minimization of rents calls for taxing the utility at the maximal rate whenever emissions fall below some critical level and to render a zero tax when emissions are higher. The intuition for this paradoxical result is that one

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[42] Intuitively, the monotone likelihood property implies that an increase in abatement reduces the relative likelihood of observing high emission levels.

can monitor emissions to verify the accuracy of the firm's abatement efficiency. If the firm claims that abatement costs are high, then emissions, which are correlated with abatement costs through β, should also be high so if emissions are unexpectedly low, this suggests that the firm may have lied about its abatement costs to obtain greater compensation from the regulator. In this instance the regulator fines the firm to deter it from misrepresenting abatement costs.

One should interpret these results about emission taxes with some care. The analysis I presented above assumes that the regulator controls waste discharges directly by specifying the abatement equipment employed by the utility and by reducing the level of output q. In instances where these options do not exist, emission taxes may become a preferred option for controlling pollution.[43]

Swierzbinski (1994) extends Baron's (1985a) analysis by assuming that it is costly for the regulator to monitor the firm's emissions. He finds that the regulator only monitors with some frequency to reduce costs. Further, the firm is rewarded whenever monitoring reveals that it is complying with abatement standards. In effect the regulator offers the firm a rebate for complying. Swierzbinski finds that costly monitoring reinforces the tendency to reduce abatement to limit information rents (discussed above). This is because the expenses of monitoring and offering a reward for compliance add to the cost of inducing the firm to limit emissions.

☐ **Multiperiod regulation.** The analysis of environmental regulation to this point has been a static one. How do things change if the utility and the regulator interact with each other repeatedly over time? For instance, suppose regulation extends for two periods (say the present and the future) and that β, the utility's private cost parameter, remains the same over both periods. If, by observing the utility's behavior, the regulator should learn the value of β after period 1, will it use this knowledge to eliminate the information rents of the utility and obtain efficient emissions control in period 2?

Surprisingly, the answer to this question is no. To understand why, first consider this unrealistic but useful benchmark situation in which the regulator is able to commit to a long-term policy. The policy stipulates the precise regulatory terms in both periods without the possibility of renegotiation[44] as analyzed in Laffont and Tirole (1991). Under these conditions it turns out that the regulator can do no better than to offer the optimal static regulation (characterized above) in each period. Roughly, the intuition for this surprising result is that if the regulator were to offer a different contract in period 2 based on the information it has previously learned about the utility, the utility would anticipate this when selecting a first-period contract. Specifically, the utility would require large compensation in the first period for revealing its type, realizing that its information rents would be driven to zero in the following period. In effect it is too costly for the regulator to compensate the utility for revealing its identity in a multiple-period setting. Instead, the regulator offers the same optimal static contract in each period. This guarantees the utility that the regulator will not use knowledge of its type in future periods to ratchet up performance and tax away the utility's information rents.

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[43] Although the regulator may always have the option of specifying abatement equipment, it may be unable to effectively control emissions, if it cannot verify that equipment is properly installed and maintained. Further, the regulator may lack the expertise to know how much emissions will be reduced by employing certain equipment.

[44] This is unrealistic because the composition of regulatory commissions changes regularly. Current commissioners are not able to bind succeeding commissioners to a particular policy over time. Commissions can commit to a limited tenure of regulation, through regulatory lag, or short-term agreements not to revisit a policy unless it is precipitated by the utility.

In more realistic settings the regulator may be unable to commit to long-term regulation.[45] Both parties realize that the regulatory commission will use whatever information is gleaned from the first-period contract choice and performance of the utility to design the second-period regulation. Under these circumstances it may be quite costly to compensate the utility for revealing its type initially. The utility knows that this information will be used to ratchet up performance standards in subsequent periods. To overcome this, the regulator may employ a "pooling" contract in which only a single set of terms is offered to the utility in period 1. A pooling contract allows the utility to conceal information about its type. This guarantees that the regulator cannot subsequently use this information to ratchet up performance standards in future periods.[46]

Most important, these results imply that the inefficiencies caused by a need to limit information rents will not necessarily disappear over time. If possible, the regulator will commit to not reducing information rents over time as it learns more about the utility. If such commitment is not feasible, as is likely, the regulator may refrain from obtaining information about the utility by offering pooling contracts in early periods.

□ **Common agency.** Typically, a utility or a commercial or industrial firm will be regulated by several agencies, with each agency overseeing some portion of the firm's operations. For instance, the state public utilities commission (PUC) may be responsible for regulating the quality and the price of service the utility offers its customers. The state environmental protection office (EPO) may regulate the utility to ensure that it satisfies emission standards. Further, it is not uncommon for both federal and state regulators to oversee the same set of firms. When the agencies cooperate in setting policy, they can achieve the second-best (cooperative) regulation characterized above. However, agencies are typically unable or unwilling to work together in pursuing their separate regulatory goals. In this instance the agencies may compete with each other through the policies that they separately impose on the firm.

Baron (1985b) models the interactions between the firm and two regulatory agencies, the PUC and EPO, as a Stackelberg game. In this game the EPO moves first by establishing an emissions policy, followed by the PUC, which sets a pricing policy for the firm. By moving first, the EPO may act strategically. The EPO realizes that the firm's cost-of-abatement parameter, β, will be revealed by the pricing arrangement adopted by the firm and the PUC. Consequently, the EPO makes its policy contingent on this price regulation, allowing it to "free ride" on the information extracted by the PUC contract. This allows the EPO to impose a higher abatement level, since it need not limit information rents. On the other hand, the PUC bears the entire burden of limiting the firm's information rents. As a consequence, the noncooperative regulation results in an emissions standard that is higher and an output level that is lower than the cooperative second-best levels.

Different results occur when both agencies move simultaneously, as analyzed by Encinosa (1994). In this case the abatement and the output levels are higher than their cooperative second-best levels, although both remain lower than their first-best levels. The intuition for this finding is as follows. Each regulator wishes to limit the utility's information rent. Recall that rents accrue to the utility at the rate of $-C_\beta > 0$ and that

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[45] See Freixas, Guesenerie, and Tirole (1985), Laffont and Tirole (1988, 1991) for a discussion of multiperiod regulation without commitment. Baron and Besanko (1987) and Laffont and Tirole (1990, 1991) also discuss situations in which the regulator is able to commit to long-term regulation but contractual terms may be renegotiated over time.

[46] The disadvantage of pooling is that first-period performance cannot be tailored to the utility's efficiency. Predictably, pooling tends to be optimal when second-period returns are not discounted too heavily. Offering separating first-period contracts is optimal when first-period returns are more important.

$-C_{\beta q} > 0$ and $-C_{\beta e} < 0$. This implies that the EPO wants to increase emissions to lower rents and that the CPU wants to reduce output to lower rents. But if q and e are cost substitutes, $C_{qe} < 0$, as seems reasonable,[47] the rent-reduction strategies undertaken by the independent regulators will conflict. If the EPO reduces the abatement standard, then the PUC will increase output q, since marginal production costs decline. Similarly, if the PUC decreases output, the EPO will reduce emissions, since the cost of abatement falls. As a result, the regulators extract less rent from the firm when acting independently than when they cooperate.

☐ **Influence of special interests on regulation.** The foregoing analyses assume that the regulator acts independently and benevolently to serve the best interests of society. This abstracts from the possibility that the regulator may be influenced by special interest groups representing industry, consumers, or perhaps environmentalists. For instance, one of several ways that parties may influence agency personnel is to offer bribes and favors to affect agency policy. Alternatively, groups may persuade elected regulatory commissioners to support favored policies by assisting in their reelection campaigns.[48]

The interest group theory of regulation was introduced by Stigler (1971), Peltzman (1976), and Buchanan and Tullock (1975).[49] This theory attempted to explain how a group's size, the cohesiveness of its members, and the members' personal stake in a policy outcome could determine regulation. Building on this foundation, Laffont and Tirole (1991) and Tirole (1992) have modified the theory of optimal incentive regulation to allow for coercive behavior by special interests. In the Laffont and Tirole analysis, the regulator can be bribed or coerced to make policy that favors a particular group. The body overseeing the regulator (e.g., Congress) establishes the type and degree of decision-making authority the regulator may exercise in setting regulatory policy. Congress would like to give the regulator discretion in setting policy to take advantage of its superior knowledge of the industry. However, giving the regulator authority to make policy encourages special interests to try to influence the agency.

Several interesting results emerge from this analysis. First, it is often (but not always) optimal for the overseer to prevent collusion between the regulator and the firm (or other special interests). Although it may not arise in equilibrium, the possibility of collusion does affect the form of permissible regulation. This suggests that even though bribery is not widely observed, the possibility of its occurring does affect regulation.

Second, to combat collusion, the degree of authority delegated to the agency and the incentives for the firm to reduce pollution are restricted. This may be one reason why regulators are sometimes forced by law to offer firms limited options for reducing pollution. It may also explain the preference for direct controls that afford the firm little latitude in meeting pollution targets. For instance, a legislative body that is interested in maintaining employment in its district may wish to restrict pollution-reducing measures to include only those that minimize the displacement of industry.

☐ **Auction markets for pollution permits.** In Section 2 I argued that distributional constraints may impede the implementation of tradable permit markets when firms are

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[47] Assuming $-C_{qe} > 0$ is equivalent to assuming that the marginal cost of production increases with the amount of emission reduction that occurs.

[48] See Kalt and Zupan (1984) and Wilson (1980) for further discussion of how interest groups influence environmental policy makers.

[49] According to this theory, regulations may be influenced or even created to serve the purposes of special interests, including industrials and manufacturers as well as environmental protection groups. This is in contrast to the public interest theory, which views regulation as attempting to maximize social surplus.

privately informed about the effects of permit trading on their profits. An interesting alternative to marketable permits is the auctioning of nontraded pollution permits as described in Lewis and Sappington (1995).[50] Imagine there are N firms that emit pollution as a by-product of their productive activity. $R(e_i, \theta_i)$ is the reduced-form expression of firm i's profit as a function of its allowable emissions e_i. The parameter θ_i, which is known privately by the firm, reflects the firm's value of polluting. For instance, one firm may benefit from polluting more because it is more difficult for it to utilize cleaner fuels. Profits are increasing in e_i and θ_i. Firms benefit by increased emissions, as this permits them either to increase production or to reduce expenditures on emission control.

$\tilde{A}$ is the total number of allowable emissions that is determined somehow, perhaps by political considerations. The auction is conducted by asking each firm to reveal its θ_i. Based on the firms' reports, each firm is assigned a number of permits and required to pay the government a tax (or receive a subsidy). The auction is designed to maximize the total surplus generated by the distribution of available permits subject to (i) no firm may be harmed by the implementation of the auction and (ii) budget balancing; the subsidies paid out can not exceed the payments collected. Once the permits are distributed, firms are not allowed to trade allowances thereafter. Below I explain the importance of this feature.

It is instructive, as a benchmark, to describe the optimal allocation of permits when the government is informed about each firm's pollution value, θ_i. In this instance the government distributes allowances to equate the marginal value of emissions $R_e(e_i, \theta_i)$ for all firms $i = 1, \ldots, N$. In the second-best case, where the θ_i's are private knowledge, the government auction permits firms to equate the "adjusted" marginal value of emissions, $m_e(e_i, \theta_i)$ for all firms, $i = 1, \ldots, N$, where $m_e(e_i, \theta_i)$ is given by

$$m(e_i, \theta_i) = R_e(e_i, \theta_i) - \lambda \tilde{R}_{\theta e}(e_i, \theta_i). \tag{16}$$

$m(e_i, \theta_i)$ is the marginal value of emissions for firm i, modified to account for the impact of firm i's accrual of information rents on the budget constraint. This impact is given by $\lambda \tilde{R}_{\theta e}(e_i, \theta_i)$, where $\tilde{R}_{\theta e}$ measures the effect of an increase in emissions on rent accrual and λ is the budget constraint multiplier.[51]

Notice that in the absence of budgetary constraints (so $\lambda = 0$), the second-best allocation coincides with the first-best distribution of permits, where $R_e(e_i, \theta_i)$ is equated for all firms i. In that case the preferred allocations can be implemented by a tradable permit market in which allowances are bought and sold for a common price equal to $R_e(e_i, \theta_i)$. Generally, however, budget constraints will bind, and it will not be possible to achieve the first-best allocation of permits. Further, it will not be possible to use decentralized market mechanisms and uniform prices to obtain the second-best allocation.[52]

Policy analysts generally agree that it is not possible to determine the socially optimal emission level because one cannot know the social benefits of emission reduction. Nonetheless, it is useful to have information on the marginal cost of achieving different levels of environmental quality. It is interesting to note that the marginal cost of tightening the total emissions constraint is equal to $m_e(e, \theta)$ when allowances are auctioned. Intuitively, one might expect that it becomes more costly to achieve a given

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[50] The restriction that permits not be traded distinguishes this allocation mechanism from the well-known marketable permit schemes.

[51] Proceeding as before, it is straightforward to show that higher θ-type firms contribute to rent accrual at the rate of $\tilde{R}_\theta = R_\theta(1 - F(\theta))/f(\theta)$, where $F(\theta)$ is the distribution for θ.

[52] When confronted with uniform prices, firms will purchase emission permits so that the marginal value of emission is equated for different firms. Generally this will violate condition (16).

level of reductions when firms are privately informed. Surprisingly, one finds that marginal costs may fall in the presence of private information. For instance, suppose that $\tilde{R}_{e\theta} > 0$.[53] Then Lewis and Sappington demonstrate that the marginal cost of achieving a given level of emission reduction is smaller when firms are privately informed. The reason is that a reduction in emissions helps to reduce information rents (since the accrual of rents, R_θ, is increasing in emissions, which makes it less costly to achieve a given environmental standard). However, when $R_{e\theta} < 0$ the reduction of emissions increases information rents, which makes it more costly to achieve a given environmental standard when firms are privately informed.

It is important to note that to limit rents it is necessary to keep firms from trading allowances once they have been distributed. The reason is that a firm with high use value for emissions may claim that it has little demand for emission allowances, to minimize its payment to the government. But if trade of permits is allowed after the initial allocation, the firm with a high use for permits can purchase them in the market. Thus, preventing such trading makes it costlier for a high-valued permit user to pretend to be a low-valued user, since it cannot obtain additional permits by trading. This makes it easier to solicit truthful information from the firms. This restriction on trading may be quite costly, however, if firms' demands for certificates change over time.[54] For that reason, it may be advisable to allow trading to occur after the initial distribution of allowances, even if this increases rents, to afford greater flexibility later.

The issue of how to design marketable permit markets that run for several periods is also important. Laffont and Tirole (1993b) argue that the government's plan for allocating permits over time will affect firms' incentives for investing in abatement technology to bypass the market. For instance, a firm that successfully develops an abatement option need not purchase allowances from the market in succeeding periods. The government may wish to discourage this behavior if the sale of pollution allowances is an important source of government revenue. To discourage excess investment in abatement, the government may wish to price discriminate among firms according to their tendency to bypass the market in future periods. This is accomplished by allowing firms to buy different options to purchase emission permits at reduced prices in the future. Thus a firm that has good prospects for acquiring abatement capacity in the future may wish to purchase allowances at future spot prices, but only if their abatement options fail to materialize. However, firms that anticipate the need to purchase allowances in the future may wish to purchase an option allowing them to obtain allowances in future periods at a discounted price. Laffont and Tirole demonstrate that this form of price discrimination, which separates the core users from the marginal users of pollution allowances, affords greater revenues for the government.

4. Summary, unresolved issues, and research directions

■   Most economists agree that supplying agents with incentives to reduce pollution is superior to command-and-control strategies. Incentive regulation allows better-informed agents to decide which of the more cost-effective abatement options to adopt. Yet better-informed agents know more than the policy maker about their capabilities to reduce pollution. Consequently, these agents may command information rents by asking to be compensated for obeying abatement policies that they claim are burdensome. Such claims cannot be entirely ignored. Policies imposing excessive cleanup costs on polluters may be politically infeasible or may drive valued producers from the

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[53] This would arise if larger θ reflects greater demand for the firm's product. Consequently, increased output (which comes from greater emissions) is more valuable when demand is greater.

[54] Changes in technology, or consumer demand, may cause individual firms' demand for emission allowances to vary over time.

marketplace. The art of good incentive regulation, then, is to induce agents to perform at high levels while limiting their information rents.

Section 3 examined the tradeoffs inherent in good incentive regulation. There I demonstrated that important modifications to the textbook prescriptions for effluent fees and market permits are necessary. The research surveyed in this section indicates that in order to reduce the rents accruing to privately informed polluters, (i) the amount of pollution abatement may be distorted below its efficient level; (ii) nonlinear (rather than linear) emission taxes that vary across firms are implemented; (iii) consequently, polluters do not equate their marginal costs of abatement; (iv) in some instances, uniform taxes are optimally set equal to zero, and in other instances a polluter is penalized if it abates too much and is rewarded if it pollutes too much; (v) plausible circumstances exist where it is preferable to control the abatement technology rather than tax emissions; and (vi) the marginal cost of reducing emissions may decrease when polluters are privately informed about abatement costs.

Considering incentive regulation in the context of environmental protection suggests some areas for future research that are particularly pertinent for environmental policy. One of these areas pertains to developing strategies for information acquisition. An important issue is how policy makers can obtain better information about the costs and benefits from environmental regulation, particularly when interested parties may wish to distort information they relay to the regulator to influence policy. Another important area for future research concerns the organization of environmental policy making. How regulatory authority should be divided between different agencies, and the autonomy agencies should be allowed in setting policy, are key factors affecting environmental protection. Possible approaches for addressing these and other research issues are outlined below.

□ **Design of incentive regulation.** *Feasibility of implementing nonlinear taxation.* A principal finding of my analysis is that firms with different abatement costs are confronted with different marginal pollution prices. Nonlinear taxes contain the information rents of privately informed polluters, as explained in Section 3. The ability of the regulator to price discriminate among polluters depends on its (i) preventing arbitrage or trading among polluters, (ii) monitoring pollution emissions, and (iii) acquiring information on the distribution of costs among polluters.

Future work is needed to assess when these conditions are likely to be satisifed and when favorable opportunities exist for applying nonlinear taxes. Further, one needs to know what alterations in environmental regulation are required when one or more of these conditions are partially satisfied. For instance, what are the consequences of restricting arbitrage or trade of pollution permits to ensure that firms face different pollution prices?[55] Of course, deciding whether to satisfy these conditions is the regulator's choice. It must decide what resources to expend on monitoring abatement and how important is it to have disaggregated information on the cost distribution of polluters. The regulator must also design methods to acquire this information over time without disrupting current performance incentives, as discussed in Section 3.

The regulator may want to experiment by offering just a few different emission schedules rather than a schedule designed for each type of polluter. It may also try offering relatively simple linear regulatory schemes.[56]

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[55] Wilson (1993) provides an excellent discussion of practical implementation issues associated with nonlinear pricing.

[56] See Schmalensee (1989) and Gasmi, Ivaldi, and Laffont (1991) for analysis of relatively simple regulatory schemes.

Robustness of incentive regulation to uncertainty. The analysis in Section 3 assumes that although the policy maker does not know the firm's exact abatement cost, it is informed about the distribution of costs and the firm's other structural parameters. In reality, policy makers are unlikely to have all this information when pollution-control strategies are formulated. This brings into question the robustness of policies prescribed in Section 3 to uncertainty about the marginal benefits of abatement, the firm's product demand, the cost of raising public funds, and the distribution of abatement costs.

Work on this important question might benefit by adopting Weitzman's (1974) approach in his classic analysis of prices versus quantities. Weitzman demonstrated conditions under which either prices or quantities would be the preferred instrument for directing an organization or economy facing uncertainty about either the costs or benefits of some activity. Numerous environmental economists have applied this analysis to study the use of emission taxes versus pollution quotas under uncertainty.[57] One might apply Weitzman's model to study the robustness of incentive regulation to parameter uncertainty as follows: One would assume that when regulation is determined, the regulator and the firm share the same imprecise information about some aspect of the firm's operation, such as product demand. At the same time, however, the firm is privately informed about its cost of abatement. The policy maker solicits the firm for this information to determine the regulation. After the regulation has been set, but just before making an output and abatement decision, the firm learns its product demand for that period. Following Weitzman, one would assume it is not possible for adjustment in regulatory policy to accommodate this late-arriving information. Thus, the policy maker would design regulation anticipating how the firm will react once it learns further information that was not available when the regulation was set. With this framework one could examine the impact of parameter uncertainty on optimal incentive regulation, as well as the tradeoff between efficiency and rent extraction.

□ **Mechanisms for gathering information.** Because the primary focus of this survey is on the impact of private information on optimal emissions-control policy, I believe an important future area of research is to examine policies for information collection. In particular, these are policies to assist the regulator in either monitoring the behavior of firms, determining the firm's capability for preventing harm to the environment, or determining the benefits of preserving environmental quality.

Monitoring firms to prevent environmental accidents. If firms could be held completely liable for any environmental damage they cause, it would be unnecessary to monitor them, since they would automatically internalize the costs of their actions when deciding what to do. However, limited liability provisions of the law and bankruptcy protection keep polluters from fully internalizing the potential costs they cause. These provisions also require society to finance part of the loss from environmental disasters with tax dollars, which are costly to collect.

One approach to solve this problem recently adopted in the United States under the Comprehensive Environmental Response and Compensation and Liability Act (CERCLA) is to make banks, and other creditors that finance the firm's operation, at least partially liable for the environmental damage generated by the firm. This requires creditors with deep pockets to bear some of the costs of environmental accidents. There are several interesting areas of research to address in analyzing this policy. Is the cost of risk bearing less for the lender than for society at large? Should minimum equity requirements for the firm be imposed in addition to or instead of lender liability?[58]

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[57] See Adar and Griffin (1976), Fishelson (1976), Roberts and Spence (1976), and, more recently, Stavins (1993).

[58] Boyer and Laffont (1994) and Pitchford (1994) provide an initial analysis of some of these issues.

Most important from the viewpoint of this survey is that given that banks specialize in overseeing loans, perhaps they can efficiently monitor the firm to ensure it takes proper care to avoid environmental damage.[59]

Another possibility is to extend liability for one firm's environmental mishap to other firms in the same industry. For instance, all companies that ship oil might be required to support an industry fund to be used to compensate the victims of accidental oil spills. This would encourage shippers to monitor each other's behavior in avoiding accidental spills. Such an arrangement would be effective provided that firms in the same industry are well positioned to observe and monitor each other's behavior in preventing environmental accidents. This type of peer-group monitoring has been successful in credit markets and rotating savings arrangements.[60]

Information gleaned from interested parties. It is important to understand how politicians and environmental policy makers, who initially are relatively uninformed about the costs and benefits of a given environmental decision, may gather information. Often, policy makers must rely on other interested parties who are better informed to supply information. McCubbins, Noll, and Weingast (1987, 1989) and others have developed a political science theory of agency whereby politicians design procedures for delegating environmental policy decisions to regulators and interest groups, which are better endowed and informed to investigate different policy options. Although the political overseer may not know which is the preferred policy in each case, he can design procedures to increase the chances that his preferred policy is eventually chosen. This is done by assigning the burden of proof and stipulating procedural requirements to favor particular outcomes.

With some important exceptions, much of the work in this area is largely descriptive.[61] One potentially useful approach for modelling the regulatory process is to consider regulation as a game of disclosure or persuasion.[62] In the game, respondents present evidence to the regulator (e.g., EPA) to support their request to introduce a possibly toxic chemical into the marketplace. Other stakeholders, including the respondent's competitors and consumers, may also disclose information to the regulator about the chemical. Relying on the information presented by the stakeholders, the regulator then decides whether or not to permit the chemical to be marketed. The regulator's decision balances the cost of making a type-one error (banning a valuable product from the market) against the cost of making a type-two error (permitting a harmful substance to be consumed).

The equilibrium to this game may be analyzed to study how the political overseer tilts the outcome of the regulatory process his way. Possible instruments available to the overseer include assignment of the burden of proof, allocation of resources to the regulatory agency, and the ability of congressional oversight committees to review, appeal, and overturn regulatory decisions. More generally, these "rules of the game" determine the costs and the payoffs to different parties from participating in the regulatory process. In effect, one can choose administrative procedures to optimally select parties for participation based on their preferences and their ability to collect and disseminate information.

Monitoring environmental compliance. In Section 3 I briefly discussed some of the ways that pollution may be controlled when one cannot readily observe emissions and monitoring is costly. Most analyses of emissions control assume that the regulator can

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[59] See Holmström and Tirole (1994) for a discussion of the role of banks as monitors of firm activity.

[60] See Banerjee, Besley, and Guinnane (1994), Besley, Coate, and Loury (1993), Stiglitz (1990), and Varian (1990) for a discussion of such arrangements.

[61] For instance, see Austen-Smith and Wright (1992) and Gilligan and Krehbiel (1987).

[62] See Lewis and Poitevin (1994), Lippman and Seppi (1993), and Milgrom and Roberts (1986).

commit to a monitoring strategy whereby it checks the firm's performance with some probability. In equilibrium the threat of monitoring induces the firm to select the desired level of abatement. But as several researchers have remarked, there is no incentive for the regulator to monitor given the firm is complying.[63] How then does the regulator commit to monitoring? Or, phrased another way, "Who monitors the monitor?" One approach to resolving this issue, analyzed in Lewis and Sappington (1995), is to recognize that regulatory agencies are frequently rewarded based on their success at identifying noncomplying parties.[64] Therefore, agencies are more likely to monitor firms if the regulations are designed so that in equilibrium, firms are out of compliance some fraction of the time. But since it is costly for agencies to exert enforcement effort, compliance standards should be set to minimize the costs of enforcement effort for any desired level of abatement activity. In addition, insuring that the regulator carries out its announced policy also relates to issues of how one can keep bureaucrats from being captured by industry interests, which I reviewed briefly in Section 3.

Eliciting information about benefits from environmental preservation. Often, policy makers wish to elicit information from individuals about their willingness to pay for a program to reduce pollution or to provide or preserve an environmental amenity. Public decisions to proceed with the program may be based on the response of these individuals to contingent valuation questionnaires or surveys.[65] In evaluating these responses, one wonders whether the respondents have an incentive to understate or overstate their preferences for the program in order to influence policy decisions. More generally, does the contingent valuation method somehow bias the respondents' answers, and if such biases exist, can they be predicted or corrected so that the surveys are still valuable to the decision maker?

A promising approach to analyzing elicitation methods is to recognize the formal similarity between contingent valuation and mechanism design. Mechanism design, which forms the theoretical foundation for Section 3 of this survey, also attempts to implement regulatory and allocative decisions based on the private information reported by individual agents to a policy maker. However, there are important differences between contingent valuation and mechanism design. Under mechanism design, the policy maker is committed to implementing a particular decision based on the information reported to him. In contrast, under contingent valuation, the policy maker is not committed to a particular course of action. Consequently, the respondents are left to form their own expectations about how decisions will be affected by the information they report.

Recent articles by Werner (1994) and Werner and Groves (1993) analyze how individuals are likely to respond in surveys when reasonable constraints on how the government will react to the survey information are imposed. For instance, respondents may reasonably believe that the government is constrained to tax all agents with similar characteristics, such as income, the same amount to support the program. Further, agents who are not surveyed are likely to be assessed amounts consistent with those who are surveyed. Under these constraints, Werner and Groves show that agents will have an

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[63] For instance, see Swierzbinski (1994) in the context of pollution monitoring and Melumad and Mookherjee (1989) in the context of income tax audits.

[64] The IRS compliance division is instructed to allocate auditing resources to raise revenues from fines levied against taxpayers who are out of compliance. More generally, bureaucrats are rewarded with promotions and pay raises depending on their performance in enforcing standards and regulations.

[65] See Mitchell and Carson (1989) for a standard treatment of this methodology and Hausman (1993) for a critical review.

incentive to underreport their willingness to pay for a public project, but not dramatically so.[66]

Carson, Groves, and Machina (1994) plan to extend this line of inquiry further by systematically evaluating the properties of different elicitation methods with regard to (i) the information conveyed to the respondent, (ii) the way in which the respondent may reply, and (iii) the respondents' beliefs about how the information will be utilized. Establishing a link between the survey methodology and the corresponding responses should allow policy makers to better interpret estimates from different valuation approaches.

□ **Explaining environmental regulatory authority.** To this point in this survey I have analyzed environmental policy, taking as given the regulatory environment in which firms and policy makers operate. But this raises important questions about how regulatory responsibility is assigned and how much discretion regulators are afforded to implement policies and in turn how much discretion firms are given to meet pollution standards. An important area for future research is in understanding the political and economic factors that shape the environmental regulation.

Degree of delegation in setting environmental policy. With regard to understanding the degree of discretion afforded to regulators and firms in meeting environmental goals, it is helpful to think of factors that would limit their discretion. Holmström (1984) and Armstrong (1994) attempt to make precise the factors that influence the latitude given to regulators and firms to choose preferred emission-control options. They analyze a simple case where a policy maker chooses which decisions to delegate to a subordinate (a regulator, for instance) and the range of policy alternatives the subordinate has to choose from. The policy maker and subordinate differ according to their preferences for various policies and the information they possess about policy effectiveness. There are no payments between the policy maker and the subordinate. Under these conditions, Holmström and Armstrong find policy makers more likely to dictate pollution-control strategies and less likely to delegate these decisions to regulatory agencies; moreover, the less informed the agency is about available policy options and implications, the more subject it is to influence by special interests, and the greater the discrepancy between the agency's and the policy maker's preferences. The last two predictions are consistent with the reduced latitude Congress gave the EPA in overseeing the Superfund program during the Reagan Administration.

Another approach to studying delegation of decision making appears in Boyer and Laffont (1994). They consider the design of a constitution determining how much latitude is afforded future governments to set environmental policy. The designer realizes that future governments will be ruled at various times by two different political majorities, one that cares primarily about the profits of industrial producers and one that gives greater weight to protecting the environment. Giving latitude to ruling parties to make environmental policy is advantageous because the party will be relatively well informed about current conditions at the time it makes a decision. However, giving parties significant decision-making power enables them to follow their narrow interests, which do not represent the preferences of society. Boyer and Laffont demonstrate that the latitude afforded ruling parties under the constitution will be greater the more variance there is over time in economic conditions, and the greater the majority of the ruling party when it is in power. They argue that when economic conditions vary, it is more important for the ruling party to be able to shape environmental policy to current

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[66] These findings are consistent with much of the literature, such as Cummings, Brookshire, and Schultze (1986) and Carson, Flores, and Martin (1996), which does not find that contingent valuation surveys produce drastically biased reports of willingness to pay.

conditions. Further, a ruling party that controls a large majority of voters is less likely to adopt policies that are not in the public interest.

Jurisdiction of regulatory control. I remarked earlier in the discussion of common agency in Section 3 that in the United States and Europe, a firm's activities are usually regulated separately by several independent agencies. Since there is an obvious loss of cooperation and coordination between independent agencies, this brings into question the virtues of decentralized regulation.

The advantages of separation of power in government and in regulatory affairs have long been recognized by political theorists.[67] A central advantage of decentralizing political and regulatory authority is that it allows for a safeguard against nonbenevolent and opportunistic behavior of political and regulatory overseers. A fertile area for future research would be to formalize this idea in models of agency and regulation. Such analysis may permit us to rationalize current regulatory structures as well as predict which regulatory and political organizations work best in different environments.

Some work has already begun along these lines. Laffont and Martimort (1994) analyze the ability of special interests to capture regulatory agencies when multiple independent agencies oversee specific activities of the firms. For instance, a public services commission may regulate the pricing of electric service. Whereas the environmental protection office oversees the utility's abatement activites. Laffont and Martimort demonstrate that this division of regulatory responsibility reduces the information each agency obtains and thus limits their ability and discretion to provide favors for special interests. This reduces each agency's value of capture for special interests.

Another analysis by Martimort (1994) examines the advantages of decentralized regulation in a dynamic model where regulators may behave opportunistically by ratcheting up a firm's performance standards over time. As discussed in Section 3, the ratcheting up of emissions standards may be counterproductive if it induces firms to underperform in earlier periods. Martimort finds that one way to overcome this is to decentralize regulation. If the regulators act independently, pursuing different goals, they cannot collude on raising the firm's standards of performance in subsequent periods. This reduces the threat that a firm that performs at a high level initially will subsequently be penalized by confronting higher standards later on.

5. Conclusion

■ I conclude this review by acknowledging the tremendous positive influence that environmental economists have had on shaping the way we think about treating environmental externalities. Through their writings, teachings, and briefings, environmental economists have exposed policy makers to the virtues of the "polluter pays" principle whereby polluters are forced to account for the external social costs they generate when making personal production and consumption decisions. Establishing markets for the trade of pollution permits or the levying of pollution taxes are the main procedures recommended by environmental economists for implementing the polluter pays principle. The primary advantage of these procedures over command-and-control regulation is that decisions to reduce pollution are delegated to the individuals who are best informed about their options.

Although market and tax-based policies are efficient, they may not be sufficient instruments for redistributing benefits. The surplus generated from a new policy needs to be redistributed among the affected parties to ensure that each favors the policy.

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[67] See McCubbins, Noll, and Weingast (1987), Moe (1984), and Wilson (1980) for recent discussions of the implications of the decentralization of oversight power in regulation.

This is a key insight of incentives theory, and it is the most important message of this survey for environmental economists to grasp. Incentives theory attempts to identify efficiency-enhancing policies that can also be implemented. And, as with market and tax-based policies, incentive regulation relies on self-interested privately informed individuals to select their best option for reducing pollution. Despite the similarity in approach, incentive regulation differs from market and tax-based procedures in one important way. Market and tax policies offer uniform financial incentives for the reduction of pollution. With incentive regulation, firm-specific financial incentives are offered as a way to redistribute benefits and to reduce information rents commanded by the more efficient firms.

In writing this survey I have adopted a normative view of policy, asking what optimal regulations can be implemented given distributional, informational, and political constraints. One virtue of this approach is that it attempts to instill some positive elements into the analysis by asking which policies are feasible given realistic political and distributional constraints. I see the next progression in this work as being a positive analysis asking which kind of environmental policies will be implemented under the same informational and distributional constraints when special interests try to intervene to affect policy.

Appendix

■ The profit for a firm of type β that selects a regulatory option intended for type β' is given by

$$\pi(\beta'/\beta) = T(\beta') - C(q(\beta'), e(\beta'), x(\beta'), \beta). \tag{A1}$$

Incentive compatibility requires that $\pi(\beta)\beta\pi(\beta/\beta)\cdot\pi(\beta'/\beta)$ for all β, β'. Differentiating (A1) with respect to β, and recognizing that firms will choose their most preferred option from the menu, $\{T(\beta), q(\beta), e(\beta), x(\beta),\}$, incentive compatibility requires that (assuming $\{T(\beta), q(\beta), e(\beta), x(\beta),\}$ is differentiable)

$$\pi'(\beta) = -C_\beta(q(\beta), e(\beta), \beta, x(\beta)) > 0. \tag{A2}$$

Further, since all types must earn nonnegative profits, and since profits are increasing in β, it follows that minimization of rents and incentive compatibility requires that $\pi(\underline{\beta}) = 0$ and

$$\pi(\beta) = \int -C_\beta(q(\tilde{\beta}), e(\tilde{\beta}), x(\tilde{\beta}), \tilde{\beta}) \, dF(\beta). \tag{A3}$$

The regulator maximizes the expected sum of producer and consumer surplus, assuming that consumers pay the utility directly with transfers. The expression for expected total surplus is

$$V = \int \{U(q(\beta), e(\beta)) - \lambda T(\beta) + T(\beta) - C(q(\beta), e(\beta), \beta, x(\beta))\}dF(\beta), \tag{A4}$$

where $\lambda > 1$ is the cost of raising public funds. Substituting for $T(\beta)$ from (A1), employing (A3), and integrating by parts, one can rewrite (A4) as

$$V = \int \{U(q(\beta), e(\beta)) - \lambda C(q(\beta), e(\beta), \beta, x(\beta)) + (\lambda - 1)C_\beta(q(\beta), e(\beta), \beta, x(\beta))(1 - F(\beta)/f(\beta)\} \, dF(\beta), \tag{A4a}$$

which corresponds with the expression in RP in the text.

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