Environmental Regulation, Asymmetric Information, and Moral Hazard

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INTRODUCTION

Environmental economics is inherently a study of measurement problems. In a world of perfect information, both the problems and the solutions are straight forward: identify the relevant externality and administer the appropriate policy. In this situation the choice of policy is superfluous; taxes, standards, or marketable permits all possess the same efficiency properties. Only when we move out of the world of perfect information, does the choice of policy become an important issue. Once the assumptions regarding perfect information are relaxed, the choice of policy tool becomes critical.

A great deal of research in environmental economics has been directed at the issue of imperfect information. The areas are wide and varied. Much work has centered on the problem of determining the optimal levels of pollution and the potential distortions

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caused when these levels are not known with certainty. Recently, a great deal of work has been focused on the issues surrounding the enforcement of environmental regulation in the presence of imperfect, or costly, information[1].

This paper addresses the issue of enforcement of environmental policies when measurement of firm behavior is costly. In the paper a model of environmental regulation is developed which focuses on the firm's incentive to cheat on its required levels of abatement. Environmental regulation is modelled as principle-agent problem where the private objectives of the agent (the firm) may differ from the objectives of the principle (society, via the regulator) The approach here follows closely to that found in much of the vertical restraint and property rights literature.

Property rights are created to internalize externalities[2]. Institutions that define and enforce property rights are continuously created and extended as long as the benefit of internalizing the externality is greater than the costs. Whenever property rights of a resource are imperfectly delineated or costly to enforce, some of the value of the resource remains in the public domain. Whenever value is left in the public domain, individuals will have an incentive to alter their behavior in an attempt to capture any economic rents. When ownership is non-exclusive, capture behavior by individuals will often lead to the dissipation of the economic benefit of the resource left in public domain[3]. Environmental policies and laws are attempts by governments to inter-

[1] see, for example: Deewees, D. 1983. "Instrument Choice in Environmental Policy", Economic Inquiry 21, 53-71.; Harfort, J. 1978. "Firm Behavior Under Imperfectly Enforceable Pollution Standards and Taxes', Journal of Environmental Economics and Management 5, 26-43.; Harfort, J. 1987. "Self-reporting of Pollution and the Firm's Behavior under Imperfectly Enforceable Regulations", Journal of Environmental Economics and Management 14, 293-303.; Segerson, K. and Tietenberg, T. 1992. "The Structure of Penalties in Environmental Enforcement: An Economic Analysis", Journal of Environmental Economics and Management , 23, 179-200.

[2] Demsetz, H. (1967) "Toward a Theory of Property rights", American Economic Review , no. 2: 347-59

[3] Barzel, Y. Economic Analysis of Property Rights Cambridge University Press (1989) Chapters

nalize the negative externalities of pollution. The need for government intervention arises when the costs to private individuals of internalizing environmental externalities are prohibitive. However, costly measurement and enforcement of environmental regulation creates the potential for opportunistic behavior. Furthermore, imperfect specification of the policy will produce opportunities for individuals to exploit any unconstrained margins[4].

Barzel (1976) demonstrated that whenever a tax policy failed to fully specify all the attributes of the good being taxed, firms will change the mix of attributes by substituting away from the taxed attributes to the untaxed attributes. This allows firms and consumers to capture back some of the deadweight loss caused by the tax. However, this process is not costless as rents become dissipated due to the non-exclusive rights to potential gains. Barzel's result arises whenever certain attributes of a good in question are costly to measure. Costly measurement often leads to the use of proxies to infer information about the attribute in question[5].

This paper presents a model of environmental regulation in the presence of measurement costs and asymmetric information. Environmental regulation can be viewed as a form of agency problem where the polluting firms may have better information about the true level of their abatement activities than the regulator. If certain aspects of environmental quality are costly to measure, regulators may resort to proxies to in-

2 and 3

[4]For example: The OPEC crisis of the 1970s led to gas rationing and price controls in the United States. However, the policy failed to perfectly define the rationed good. Thus the quality of gasoline immediately started to drop as firms attempted to capture value that had been placed in the public domain.(Barzel, Y. Economic Analysis of Property Rights, chapter 2. Cambridge University Press (1989))

[5]Barzel uses the example of apples, where the attribute in question is the taste of the apple. Since the taste cannot be determined by visual inspection, individuals use appearance to infer information about the taste. Thus producers of apples began dyeing and waxing apples to influence the consumers

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fer information about environmental quality. This may allow firms to circumvent the regulatory constraints by maximizing along those margins that are costly to measure. This problem is especially acute when a single firm produces multiple pollutants[6].

THE BASIC FRAMEWORK

In this section we present a model of the optimal choice of output and abatement under both a standard and a pollution tax. It is assumed that measurement and enforcement are initially costless. In the next section the assumption of perfect, or costless, measurement will be relaxed.

We first consider an imperfectly competitive firm which faces a downward sloping demand curve for its output, q and the corresponding revenue function $R(q)$. It is assumed that consumer demand for the product and demand for environmental quality are independent. Therefore, the firm's choice of abatement does not impact on demand conditions, but appears only as a cost to the firm. Each firm has the following cost function,

$$c = c(q, a) \tag{1}$$

where q is output and a is any abatement that the firm may carry out. If $a = 0$ then the cost function is the traditional $c = c(q)$. The firm's cost function is assumed

[6] An example of this is found in the British Columbia Pulp and Paper Industry, where a wide variety of anti-pollution policies have been introduced. The results have been that while one form of pollution is reduced, there has been an offsetting increase in other types of pollutants. This substitution effect can be attributed to the fact that the policies target the method of pulp production rather than the pollutants diectly. Source: British Columbia Ministry of the Environment

to be separable and additive in both arguments and have the following properties[7],

$$c_q > 0 \quad c_a > 0$$

The Pollution Problem

Pollution is assumed to be an increasing function of output and a decreasing function of abatement[8]. Let z denote units of pollution where

$$z = z(q, a) \tag{2}$$

and

$$z_q > 0, z_a < 0$$

Therefore, to reduce the level of pollution, the firm can reduce the level of output, increase the level of abatement, or do a combination of both.

Social Policy problem

The role of a benevolent social planner, through the use of any available policy tools, is to maximize social welfare taking into account all costs, including any non market priced costs, such as pollution. However, this requires a knowledge of a social welfare function or, at least, a complete knowledge of the relevant marginal benefit and marginal cost curves. This requires a great deal of information to be in the hands

[7] Calculus notation:

$$c_q = \partial c / \partial q;$$
$$c_{qq} = \frac{\partial^2 c}{(\partial q)^2}$$
$$C_{qa} = \frac{\partial^2 c}{\partial q \partial a}$$

etc...

[8] Abatement in this case represents all aspects of pollution reduction within the control of the firm

of the social planner. Typically, a more manageable approach is to minimize the total costs of attaining an exogenously determined policy goal.

Typically, a regulator imposes a set of constraints on individual firms who, in turn, maximize private profits subject to these constraints. In the case of pollution, a standard, z^*, is set by the regulator. Then the relevant agent's private optimization problem then becomes

$$MAX_{q,a} \quad \pi(q,a) = R(q) - c(q,a) \tag{3}$$

subject to

$$z(q,a) \leq z^*$$

It is assumed that the regulator can determine the true z^* and that both the government and the individual firms understand the nature of the "pollution production function", $z(q,a)$. Letting λ denote the lagrange multiplier on the pollution constraint, the resulting first order conditions are

$$R'(q) - c_q - \lambda z_q = MR(q) - MC(q) - \lambda z_q = 0 \tag{4}$$

$$c_a + \lambda z_a = 0 \tag{5}$$

$$z^* - z(q,a) = 0 \tag{6}$$

Which implicitly defines the optimal q and a as a function of z^*. If we re-arrange the first two equations and eliminate λ, we get the following expression

$$MR(q) = c_q + c_a(-z_q/z_a) = c_q + c_a(MRTS(q,a)) \tag{7}$$

This equation can be interpreted as the firm setting marginal revenue equal to the marginal cost of production plus the social opportunity cost of an additional unit of output[9]. In this case the social cost has been completely internalized. The firm will trade off output against abatement at the margin. This will produce the socially optimal mix of abatement and output at the lowest cost, while still meeting the pollution standard.

We can substitute the optimal values of q and a into the profit function and take the total differential with respect to q and a. If we set the total differential equal to zero and re-arrange we get

$$\frac{dq}{da} = \frac{c_a}{MR - c_q} > 0 \tag{8}$$

Equation 8 is the slope of the firm's iso-profit curves. From the first order conditions we know that the denominator is positive around the optimal q and a. Therefore the slope of the iso-profit curves is positive at the optimum. However, given the assumption of diminishing returns in the production of q ($c_{qq} > 0$), the isoprofit curves are backward bending. Differentiating again we get

$$\frac{d^2q}{da^2} = \frac{\frac{c_{aa}}{(MR - c_q) + c_a c_{qa}}}{(MR - c_q)^2} \tag{9}$$

This expression will be positive unless there are economies of scope associated with the joint abatement-production technologies (i.e. $c_{qa} < 0$). The results are illustrated in figure one.

In figure one both the isoprofit curves of the firm and the optimal pollution level are illustrated in output-abatement space. Profits are increasing as we move towards

[9] The expression $c_a(-z_q/z_a) = c_a(MTRTS_{q,a})$ is the opportunity cost of additional unit of output in the presense of the pollution constraint, z^* {Note *MRTS* denotes *marginal rate of technical substitution*}.

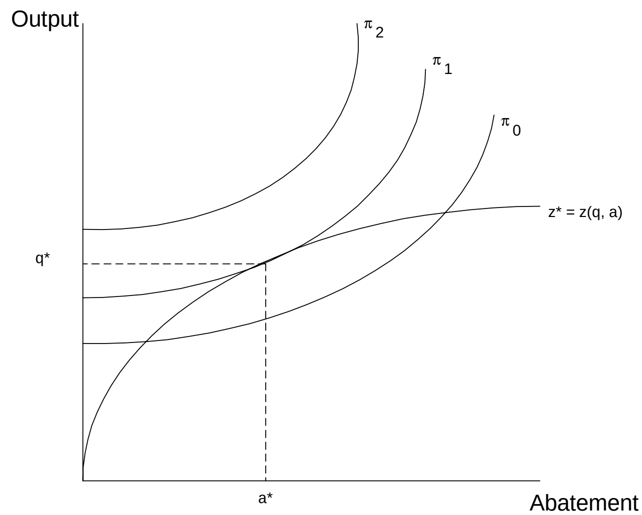

Fig 1: Optimal Pollution/Abatement Mix

FIG. 1.

the upper left of the diagram. The z^* boundary is drawn as an increasing, concave function, which implies diminishing returns to abatement[10]. The firm will choose q and a such that it can reach the highest iso-profit curve without violating the pollution constraint

Optimal Pollution Tax

Now, instead of the standard, z^*, we impose a per-unit tax on z denoted by t. The individual firm's objective function now becomes:

$$Max \quad \pi(q,a) = R(q) - c(q,a) - tz(q,a) \tag{10}$$

differentiating with respect to q and a gives us the following first order conditions:

[10] This seems to be a reasonable assumption for many situations. However, this analysis does not preclude other possible configurations, including discontinuities which may arise if discrete changes in abatement technology are required beyond critical levels of a and/or q.

$$MR - c_q - tz_q = 0 \tag{11}$$

$$c_a + tz_a = 0 \tag{12}$$

In comparing the first order conditions under the pollution tax with the first order conditions under the standard derived earlier, we can see that the optimal tax rate, t^*, is obtained by setting $t = \lambda^*$. Since λ^* is the shadow price of an additional unit of pollution if the standard is binding, then setting $t = \lambda^*$ incorporates the true cost of an additional unit of pollution.

Since the tax, if set at the correct level, produces the same level of q and a as the standard, then how do the two policies compare? From the efficiency perspective, the two policies are identical. However, on distributional grounds they are quite different. Since the firm will choose the efficient mix of q and a under either program, then costs and revenues will be the same except for the tax revenue (t^*z^*) paid by the firm. It is obvious, then, that firms would prefer standards to taxes in this simple framework.

Marketable Permits

Since λ^*, which is a function of z^*, is the shadow price of the pollution constraint, it is the firm's demand curve for units z. Therefore, $\lambda^*(z^*)$ is the firm's demand curve for marketable permits. If the market for permits is competitive, then the equilibrium price will equal t^*.

MEASUREMENT AND ENFORCEMENT ISSUES

Now we will relax the assumptions of perfect measurement and costless enforcement. Problems in measurement may involve measuring output (q), abatement (a), or emissions (z). If the relationship between output, abatement and emissions is understood, then knowledge of the levels of any two will allow for the third to be inferred. However, if only one of the three variables can be accurately measured, then room for marginal distortions may arise, as firms will attempt to maximize along those margins that can not be measured.

If emissions are the only variable that can be costlessly measured, then a standard or a tax on z will produce correct behavior. It is not necessary that the government knows the level of q and a, since a policy targeting emissions forces firms to address the variable in question directly.

Problems arise when emissions are costly to measure relative to other variables and proxies are used to infer pollution levels and to obtain policy objectives. The two obvious proxies are abatement levels and output levels. A policy that targets only abatement or output will leave an additional margin unconstrained, along which firms will maximize.

Consider first a policy of imposing only abatement standards. This policy is illustrated in figure two. Point E is the socially optimal q^*, a^*, and z^*. Suppose an abatement standard is set equal to a^*. The ultimate goal of the policy is to attain a pollution level equal to z^*. However, if the choice of output by the firm is unconstrained, the firm can increase profits by expanding output and moving to point F. At point F the firm is able to move to a higher iso-profit curve while still maintaining the abatement standard. However, at point F, the firm is producing output level that

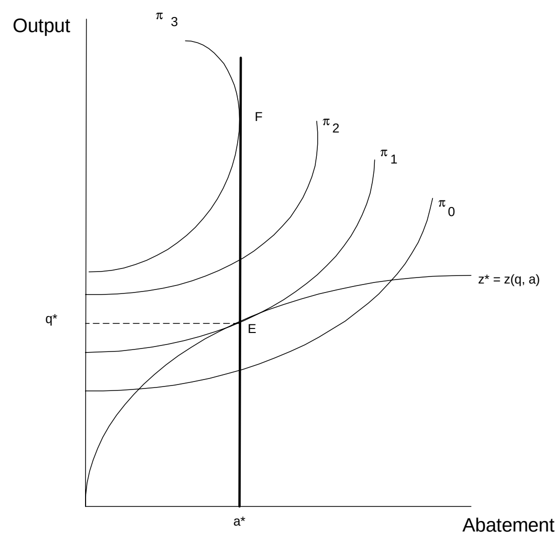

Fig 2: Abatement Standard Only

FIG. 2.

is too large for the level of abatement and is therefore producing a level of pollution that is greater than the socially desired level.

If restrictions are imposed only on output due to prohibitive costs of measuring abatement or emissions, then two possible equilibria arise. These are illustrated in figures $3a$ and $3b$. If costs are monotonically increasing in abatement a corner solution will arise. Assuming that an output restriction equal to q^* has been imposed upon the firm, then the private equilibrium will occur at point G in figure 3a. If q_0 is the level of output the firm would choose when none of the pollution externality is internalized, then the result in figure $3a$ is also analogous to a per-unit tax on output.

Figure $3b$ illustrates the other possible equilibrium; that of an interior solution. In this case the marginal cost of abatement is not strictly monotonic. Therefore, in equilibrium, the firm will engage in some positive level of abatement even though the

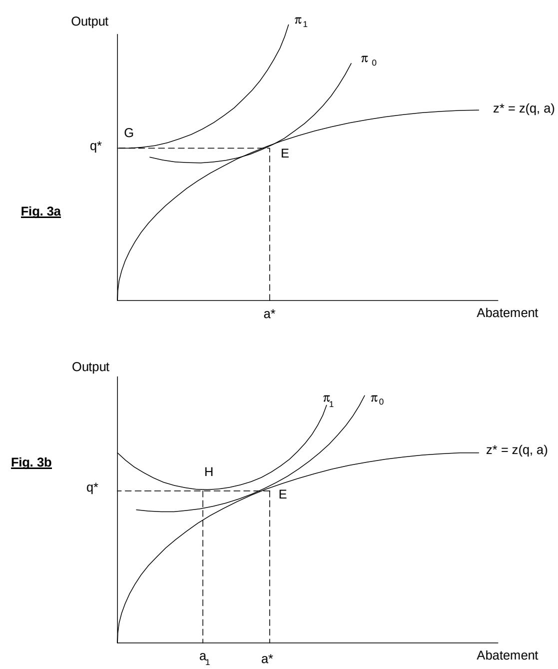
Output
π1
π0
z* = z(q, a)
G
q*
E
Fig. 3a
a*
Abatement
Output
π1
π0
z* = z(q, a)
Fig. 3b
H
q*
E
a1
a*
Abatement

FIG. 3.

only regulatory constraint is on output. As shown in figure $3b$, the equilibrium will occur at point H, with abatement equal to a_1. In both cases, the level of abatement will be insufficient to meet the desired level of pollution.

REGULATION WITH ASYMMETRIC INFORMATION AND MONITORING COSTS.

Now suppose that the firm is operating under a standard set by regulation. Furthermore, assume that while output is costless to measure, the firm has private information about the true amount of abatement it has invested in. If the regulator has knowledge of the pollution "production function", then the level of abatement can be inferred from the measured level of pollution. Therefore, in order to ensure that the firm is engaging in the correct level of abatement, the regulator will have to monitor the level of emissions. If emissions are costly to measure, then there will be less than perfect monitoring of emissions.

Given the regulation, the firm may have an incentive to cheat on the level of abatement he is to supply. The decision to cheat will be a function of the profits from cheating and the probability of detection by the regulator. The probability of detection will, in turn, depend on the level of monitoring activity that the regulator engages in and the degree by which the firm lowers the level of abatement below the regulated level.

Define ϕ as the frequency of monitoring carried out by the regulator, which is normalized to be between 0 and 1. Furthermore, define Δa as the difference between the required level of abatement (a^*) and the actual level of abatement (a') that is supplied by the firm ($\Delta a = a^* - a'$). Therefore, lower the actual level of abatement relative to the level specified, the greater will be Δa ($\Delta a = 0$ implies no cheating).

The probability of the firm being detected cheating will be a function of both the frequency of monitoring and the degree of cheating by the firm. Let α denote the probability of detection, and can be expressed as follows:

$$\alpha = \alpha(\phi, \Delta a) \tag{13}$$

$$where \quad \partial\alpha/\partial\phi > 0, \quad and \quad \partial\alpha/\partial\Delta a > 0.$$

If the firm is detected cheating on abatement, there is usually a penalty or sanction levied against the firm[11]. Denote the sanction as $S(\Delta a)$, where $dS/d(\Delta a) \geq 0$. Therefore the expected profit from supplying sub par level of service can be expressed as

$$E(\pi) = (1 - \alpha(\phi, \Delta a))\pi(q, \Delta a) + \alpha(\phi, \Delta a)[\pi(q, \Delta a) - S(\Delta a)] \tag{14}$$

$$= \pi(q, \Delta a) - \alpha(\phi, \Delta a)S(\Delta a)$$

where $\pi(q, \Delta a)$ is the firm's profit function.

Differentiating with respect to Δa and setting to zero solves for Δa that maximizes the firm's expected profits from cheating, or

$$\frac{\partial\pi}{\partial(\Delta a)} - \alpha(\phi, \Delta a)\frac{dS}{d(\Delta a)} - S(\Delta a)\frac{\partial\alpha}{\partial(\Delta a)} = 0 \tag{15}$$

Equation (15) will determine the level of Δa that the firm will choose, given that it does decide to cheat on its required level of abatement. The signs of each of the

[11]The form and types of sanctions used by regulating bodies can be wide and varied, including incremental penalties based on the severity of non-compliance. In this section we assume a simple lump-sum penalty set by the regulator. For more detailed treatments of penalties, see Harford (1978), (1987); Segerson and Tietenberg (1992)

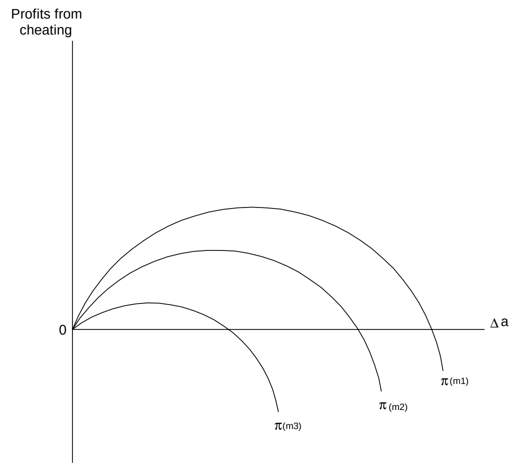

Fig. 4: Profits from cheating on abatement with imperfect monitoring

FIG. 4.

partial derivatives are given below each term in the equation. For any given level of ϕ, the profit function of the firm is at first increasing, then decreasing in Δa. Intuitively this results from the fact that as the level of abatement falls, the profits for the firm initially rises but also so does the likelihood of detection. ϕ serves as a shift parameter in the profit function. Profits as a function of cheating on abatement (Δa) is illustrated in figure 4. As ϕ increases, the expected profits from cheating shifts down. It is possible that, given certain levels of ϕ and S, the expected profit function could be everywhere negative.

It could be suggested that, for a given level of ϕ, that the regulatory board simply increase $S(\Delta a)$ until the expected profits from cheating are negative. This would guarantee compliance to the standard. While in some cases this may hold, there is an upper bound on penalties above which, they no longer become credible. The reason for this is that once the penalty exceeds the firm's ability to pay, the firm will simply default and shut down. If this is the case then the expected profits from cheating on abatement becomes

$$E(\pi) = (1 - \alpha(\phi, \Delta a))\pi(q, \Delta a) \tag{16}$$

Therefore, if $\pi(q^*, a^*)$ is the profit of the firm when no cheating occurs, then the firm will choose to cheat if

$$\pi(q^*, a^*) \leq \pi(q, \Delta a) - \alpha(\phi, \Delta a)S(\Delta a) \tag{17}$$

or

$$\pi(q^*, a^*) \leq (1 - \alpha(\phi, \Delta a))\pi(q, \Delta a) \tag{18}$$

whichever is greater.

This represents the incentive compatibility constraint faced by the regulator.

If the regulator decides to monitor the firm he will incur monitoring costs which are denoted as M. The costs of monitoring will be an increasing function of the frequency or intensity of monitoring. Therefore the costs of verifying compliance are

$$M = M(\phi)(dM/d\phi > 0) \tag{19}$$

Once the regulator has chosen ϕ, the firm will determine Δa from equation (15). Then, based on either (17a) or (17b), the firm will make its decision to cheat. The cheating equilibrium is illustrated in figure 5. The firm reduces abatement from point E by the amount Δa, reaching the higher iso-profit curve at point N. If ϕ is increased, then the firm would decrease Δa (i.e. increase abatement levels) and move to a lower iso-profit curve.

What determines the optimal ϕ? One would expect the regulator to select the sanction (S) and the level of monitoring (ϕ) that minimizes monitoring costs subject to equations (17) and (18). If there is increasing marginal costs to monitoring, it is

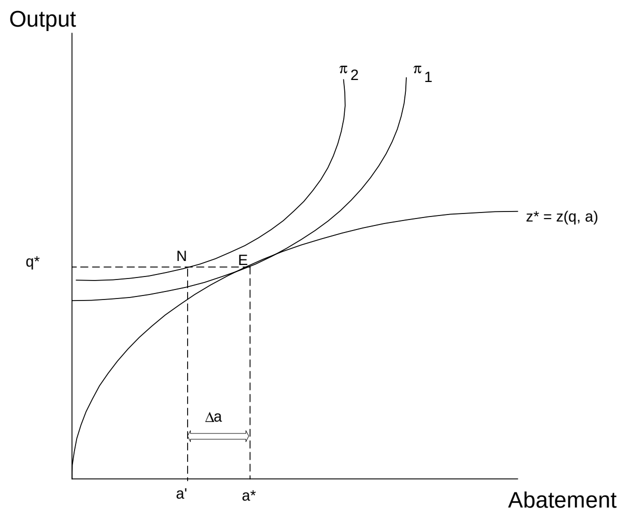

Fig 5: Cheating Equilibrium

FIG. 5.

possible that there will always be some opportunity for the firm to cheat. Figures 6a and 6b illustrates two possible solutions.

Figures 6a and 6b show the marginal costs of monitoring and the expected profits from cheating as a function of the level of monitoring . In 6a, the level of ϕ that drives the returns to cheating to zero is less than 1, therefore there is an interior solution that produces no cheating. This occurs at point A, where the profit from cheating schedule intersects the honest profit line. In 6b, the firm's profit from cheating schedule does not intersect the honest profit line until $\phi = 1$. Therefore, it would require perfect monitoring to deter cheating. If the marginal costs of monitoring are increasing as illustrated in 6b, then it will be prohibitively costly to prevent the firm from engaging in some cheating.

However, 6b suggests an alternative policy option for the regulator. At ϕ_1 the marginal cost of monitoring (GH) equals the expected profit from cheating(EF). Beyond ϕ_1 the marginal cost is greater than the firm's expected profits. Therefore, it would

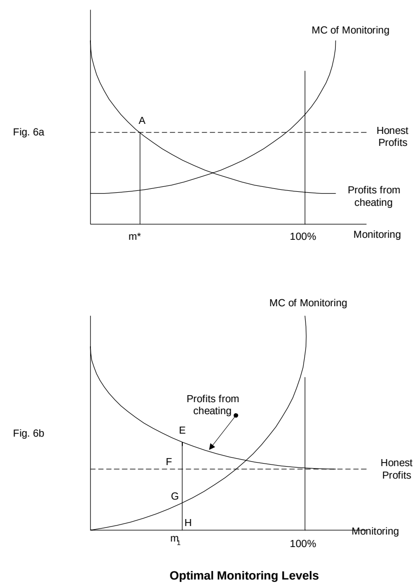

FIG. 6.

be efficient to monitor only to ϕ_1 and to pay the firm an abatement subsidy to ensure honest behavior. A subsidy on abatement will encourage the firm to reveal information about its true level of abatement. If s denotes the subsidy on abatement such that the total subsidy is equal to sa^*, then the regulator's constrained minimization problem could be expressed as follows:

$$MinM(\phi) + sa^* \tag{20}$$

subject to

$$\pi(q^*, a^*) + sa^* \geq \pi(q, \Delta a) - \alpha(\phi, \Delta a)S(\Delta a) \tag{21}$$

or

$$\pi(q^*, a^*) + sa^* \geq (1 - \alpha(\phi, \Delta a))\pi(q, \Delta a) \tag{22}$$

and

$$z(q, a) \leq z^* \tag{23}$$

Therefore, the regulator chooses ϕ and s such that an incentive compatible cost minimum is reached.

Alternatively, a tax on output may have the result of lowering the incentive to cheat on abatement. A tax on output will cause the firm's iso-profit curves in figure 5 to "flatten out". While a tax on output will lower the firm's profits regardless of whether the firm cheats or not, the tax will have the effect of reducing the marginal profits from cheating.

CONCLUSION

This paper presents an alternative framework for analyzing various regulatory policies for pollution. The model addresses the issue of incentive compatibility and asymmetric information within pollution regulation. When enforcement costs are taken into account, the issue of subsidizing firms not to pollute re-opened. However, this is not a subsidy on pollution but a subsidy on abatement investment. The subsidy is a premium paid to firms for revealing information about the true level of abatement, thereby lowering the costs of enforcement.

The model is limited by the fact that this is a static model and the number of firms are exogenous. It does not address issues of market dynamics where firms are allowed to enter and exit. Possible extensions of the model would be to consider marketable permit issues and indivisibilities in the supply of abatement. Indivisibilities in abatement implies that there will be non-convexities in the iso-profit curves. This suggests the possibility of multiple equilibria in meeting the pollution standard.

The model does focus on issue imperfect measurement and the types of distortions that arise when regulatory constraints are only imperfectly enforced. This paper is consistent with the central theme found in the property rights literature; that whenever property rights are imperfectly delineated, behavior will change to capture any rents left in the public domain.

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