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A Note on Pollution Regulation With Asymmetric Information

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Summary

The paper addresses the problem of information asymmetry between a regulator and the polluting firms and proposes a very simple mechanism where the regulator is free to choose, without communicating in advance to the firms, between two instruments: an effluent fee or a standard: as a result in a real world setting this uncertainty might induce firms to a truthful revelation. Moreover, under the assumption of linear marginal abatement or marginal social damage functions, in many cases the resulting optimal behaviour might be an under reporting for some firms and an over reporting for others so that the resulting marginal aggregate benefit function might be not so far from the true one and the aggregate pollution level attained by the mechanism not so far from optimal.

Keywords: Effluent Fee, Standards, Asymmetric Information, Truthful Revelation

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Introduction

In the field of pollution regulation the problems stemming from the asymmetry of information between the regulator and the polluting firms have been thoroughly studied. The seminal works by Weitzman (1974) and (1978) focused on the relative performance of price and quantity instruments when benefit or abatement cost functions are imperfectly known and on this line of research another important contribution was Roberts and Spence (1976) proposal of a mixed tax and licences scheme. A different approach was pioneered by Kwerel (1977) who proposed a mechanism to induce truthful revelation of abatement cost function by polluting firms: it encompasses issuing the optimal number of transferable licences and paying a subsidy for licences hold in excess of emissions. Some shortcomings of this scheme were evidenced by Dasgupta Hammond and Maskin (1980) who proposed alternative solutions drawing heavily on the literature on incentive compatible mechanisms for the provision of public goods. In the following decades several works, ingenious and theoretically elegant, addressed the problem in different contexts: among them, to cite only few, Varian (1994), Duggan and Roberts (2002) and Montero (2008). Notwithstanding the relevance of such theoretical results one cannot refrain from noting, with Chavez and Stranlund (2009, p.138) or Montero (2008, p.497), that in the real world none of the most sophisticated mechanisms has never been implemented. Starting from this premise this paper adopts a pragmatic perspective investigating the robustness of the incentive for polluting firms to report a false marginal abatement cost function and presenting a very simple mechanism with interesting properties: the basic idea behind this mechanism is that the regulator is free to choose either an effluent fee or a standard but the polluting firms don't know in advance which instrument will be chosen when they are requested to communicate their marginal benefit function (or marginal abatement cost function). Its theoretical underpinnings are found in the well known Weitzman (1974) result that price and quantity instruments for pollution control achieve opposite outcomes when there is uncertainty about marginal abatement cost functions; another important ingredient is drawn from a paper by Bulckaen (1997) where it is demonstrated that, under an effluent fee, the gain for a polluting firm to hide its true abatement cost function is not unbounded if the firm is committed to behave in accordance to the reported abatement cost function.

1. The Model

This section presents some results which can also be found in Kwerel (1977) or Bulckaen (1997); they are repeated here to ease the reading of the paper. There are N polluting firms with cost functions indicated by:

$$C^i(y^i, x^i, \hat{\theta}^i) \qquad \text{i=1,..,N}$$

where y is output, x pollution, supposed to be verifiable by the regulator, and $\hat{\theta}$ a parameter known only to the firm; they are obviously increasing in y and it is assumed they are decreasing and convex in x. The corresponding marginal abatement cost functions, suppressing the output variable, are indicated by:

$$C_x^i(x^i, \hat{\theta}^i) = \frac{\partial C^i}{\partial x^i} \qquad \text{i=1,..,N}$$

They are negative and increasing:

$$\frac{\partial^2 C^i}{\partial {x^i}^2} = C_{xx}^i(x^i, \hat{\theta}^i) > 0 \qquad \text{i=1,..,N}$$

In contrast with most of the literature it is chosen to deal with the corresponding marginal benefit functions which are the opposite of the marginal abatement cost functions and will be denoted by:

$$B_x^i(x^i, \hat{\theta}^i) = -\frac{\partial C^i}{\partial x^i} \qquad \text{i=1,..,N}$$

They are positive (so it is more intuitive to define over or under reporting) and decreasing, that is:

$$B^i_{xx}(x^i,\hat{\theta}^i) = -\frac{\partial^2 C^i}{\partial {x^i}^2} < 0 \qquad \text{i=1,..,N}$$

The damage function, which is assumed to be common knowledge, is:

$$D(X) \qquad \text{with} \qquad X = \sum_{i=1}^{N} x^i$$

It is increasing and convex for X>0, that is:

$$D_X(X) = \frac{\partial D}{\partial X}(X) > 0 \quad D_{XX}(X) = \frac{\partial^2 D}{\partial X^2}(X) > 0$$

The regulator has the objective to maximize social net benefit and asks each firm to communicate its benefit function (which can be different from the true function) indicated by:

$$B^i(x^i,\theta^i) \qquad \text{i=1,..,N}$$

Aggregate maximum benefit function is the solution to the following program:

MAX $\sum_i B^i(x^i,\theta^i)$ s.t. $\sum_i x^i = X$

and the resulting function will be indicated by:

$$B(X,\boldsymbol{\theta}) \qquad \boldsymbol{\theta} = (\theta^1,..,\theta^N)$$

Its derivatives are:

$$B_X = B^i_x > 0$$
$$B_{XX} < 0$$
$$B_{X\theta^i} = B^i_{x\theta}$$

where

$$B^i_{x\theta} = \frac{\partial B^i_x}{\partial \theta} > 0 \qquad \text{i=1,..,N}$$

is the effect on marginal benefit function of a reported parameter θ^i different from $\hat{\theta}^i$. Maximum social net benefit is:

MAX $B(X,\boldsymbol{\theta}) - D(X)$

Optimal pollution level $X(\boldsymbol{\theta})$ is given by the first order condition:

$$D_X(X) = B_X(X,\boldsymbol{\theta}) \qquad (1)$$

To achieve this and the corresponding optimal pollution levels by each firm, the regulator can set an effluent fee or a standard according to the following conditions:

$$t(X(\boldsymbol{\theta})) = D_X(X(\boldsymbol{\theta})) = B_X(X(\boldsymbol{\theta}), \boldsymbol{\theta}) \tag{2}$$

$$D_X(X(\boldsymbol{\theta})) = B_x^i(x^i, \theta^i) = B_X(X(\boldsymbol{\theta}), \boldsymbol{\theta}) \tag{3}$$

By the implicit function theorem we get from (1):

$$\frac{dX}{d\theta^i} = \frac{B_{x\theta}^i}{D_{XX} - B_{XX}} > 0 \qquad \text{i=1,..,N} \tag{4}$$

From (2), using (1) we get:

$$\frac{dt}{d\theta^i} = D_{XX}\frac{dX}{d\theta^i} = D_{XX}\frac{B_{x\theta}^i}{D_{XX} - B_{XX}} \qquad \text{i=1,..,N} \tag{5}$$

If the regulator sets an effluent fee, by differentiating with respect to θ^i the equilibrium condition at individual firm level $t(\boldsymbol{\theta}) = B_x^i(x(\boldsymbol{\theta}), \theta^i)$, it is obtained:

$$\frac{dt}{d\theta^i} = B_{xx}^i \frac{dx^i}{d\theta^i} + B_{x\theta}^i \qquad \text{i=1,..,N}$$

hence, by substitution of (5):

$$\frac{dx^i}{d\theta^i} = \frac{1}{B_{xx}^i}\left(\frac{dt}{d\theta^i} - B_{x\theta^i}^i\right) = \frac{B_{XX}}{B_{xx}^i}\frac{B_{x\theta}^i}{D_{XX} - B_{XX}} > 0 \qquad \text{i=1,..,N} \tag{6}$$

Reported parameter θ^i is determined by optimizing behaviour of polluting firms. If the regulator sets a standard it requires:

$$\text{MAX } B^i(x^i(\boldsymbol{\theta}), \hat{\theta}^i) \qquad \text{i=1,..,N}$$

with first order condition:

$$B_x^i(\hat{\theta}^i)\frac{dx^i}{d\theta^i} = 0 \qquad \text{i=1,..,N} \tag{7}$$

Given (6), condition (7) requires $B_x^i(\hat{\theta}) = 0$ implying an over reporting of the true benefit function in order to let the regulator choose current (unregulated) pollution level, indicated by x_0. If the regulator sets an effluent fee the objective is:

$$\text{MAX } B^i(x^i(\boldsymbol{\theta}), \hat{\theta}^i) - t(\boldsymbol{\theta})x^i(\boldsymbol{\theta}) \qquad \text{i=1,..,N}$$

and the resulting first order condition for θ^i is:

$$\left(B_x^i(\hat{\theta}^i)\frac{dx^i}{d\theta^i} - \frac{dt}{d\theta^i}x^i - t\frac{dx^i}{d\theta^i}\right) = 0 \qquad \text{i=1,..,N} \tag{8}$$

Substituting (5) and (6) into (8) we get:

$$\frac{B_{XX}}{B^i_{xx}}\frac{B^i_{x\theta}}{D_{XX}-B_{XX}}\left(B^i_x(\hat{\theta}^i)-\frac{B^i_{xx}}{B_{XX}}D_{XX}x^i-B^i_x(\theta^i)\right)=0 \qquad \text{i=1,..,N}$$

hence:

$$B^i_x(\hat{\theta}^i)-B^i_x(\theta^i)-\frac{B^i_{xx}}{B_{XX}}D_{XX}x^i=0 \qquad \text{i=1,..,N} \qquad (9)$$

These results confirm, as is well known since Kwerel (1977), that polluting firms have, in either case, an incentive to misrepresent their true benefit function. In particular, condition (9) implies that for $\theta=\hat{\theta}$ the marginal benefit from under reporting is strictly positive; nonetheless, as pointed out in Bulckaen (1997), the calculation of the optimal level of reported parameter θ requires the knowledge of the slope (at *X*) of the marginal damage function and the slope (at each x^i) of marginal benefit functions of all other firms thus showing a crucial role played by the information available to each firm.

2. Proposed Mechanism

Given the conclusions of the previous section it is interesting to evaluate the performance of a very simple mechanism which has a particular feature which makes it different from any other mechanism proposed in the literature: the information provided by the firm will be used by the regulator, according to its objective, to determine either an effluent fee per unit of emission or a standard (which can also be interpreted as a number of unmarketable permits) but the firms don't know in advance which instrument will be chosen by the regulator. Assuming as reasonable that each firm assigns an equal probability to each instrument, its expected net benefit, as a function of the reported parameter, is given by:

$$EB^i(\mathbf{\theta})=1/2\left(2B^i(x^i(\mathbf{\theta}),\hat{\theta}^i)-t(\mathbf{\theta})x^i(\mathbf{\theta})\right)$$

and the first order condition for a maximum, after some straightforward substitutions, is:

$$\frac{dEB^i}{d\theta^i}=2B^i_x(\hat{\theta}^i)-B^i_x(\theta^i)-D_{XX}\frac{B^i_{xx}}{B_{XX}}x^i=0 \qquad \text{i=1,..,N} \qquad (10)$$

Calculating (10) for $\theta^i=\hat{\theta}^i$, the condition for under or over reporting is obtained:

$$\theta^i \gtrless \hat{\theta}^i \qquad \text{if} \qquad B^i_x(\hat{\theta}^i)-D_{XX}\frac{B^i_{xx}}{B_{XX}}x^i \gtrless 0 \qquad (11)$$

The reader will notice a resemblance with the well known results of Weitzman (1974): here, for a given marginal benefit function, the incentive to under (over) report is stronger the steeper (flatter) the marginal damage function and the flatter (steeper) the marginal benefit function with respect to the reported aggregate function. A particular feature of the proposed mechanism emerges: the same information that in Bulckaen (1997) are required to compute the optimal level of under reporting are now necessary to determine whether it is optimal to under or over report: the uncertainty about the instrument chosen by the regulator balances the incentive to under report the true benefit function when an effluent fee is selected and the opposite incentive if a standard is chosen.

The above condition (11) can be reformulated in a slightly different manner as follows:

$$\left.\frac{dEB^i(\mathbf{\theta})}{d\theta^i}\right|_{\theta^i=\hat{\theta}}=B^i_x-\frac{D_{XX}}{B_{XX}}\frac{B^i_{xx}x^i}{B^i_x}B^i_x$$

The term D_{XX}/B_{XX} , computed at the optimal level of X, is the relative slope of marginal social damage and aggregate benefit functions and its absolute value is greater equal or less than 1: let's indicate its absolute value by α. Similarly let's indicate by β^i the absolute value of $B^i_{xx}x^i/B^i_x$ which is greater equal or less than 1: The above expression can thus be reformulated as:

$$\left.\frac{dEB^i(\boldsymbol{\theta})}{d\theta^i}\right|_{\theta^i=\hat{\theta}} = B^i_x\left(1-\alpha\beta^i\right) \tag{12}$$

Thus the choice to under or over report the true benefit function is determined by the interaction of β^i and α: the former is greater than 1, for any given level of marginal benefit, the greater the corresponding level of x^i and the steeper the marginal benefit function; alternatively, for any given level of x^i, the steeper the marginal benefit function and the lower the level of corresponding marginal benefit. The latter is greater than 1 the steeper the marginal social damage function with respect to the aggregate marginal benefit function.
Further insights emerge under the additional assumption, often found in the literature, of linear marginal benefit functions of the form:

$$B^i_x = b^i_0 - b^i x^i \qquad \text{i=1,..,N}$$

in which case the only parameter to communicate to the regulator is the (constant) slope of such functions given that emissions are observable. The resulting aggregate marginal benefit function, necessary to determine the optimal effluent fee or standard, will be a piecewise linear function: if the optimal level of pollution is strictly positive for each firm the equation of such function is:

$$B_X(X) = \frac{\sum_i \frac{b^i_0}{b^i}}{\sum_i \frac{1}{b^i}} - X\frac{1}{\sum_i \frac{1}{b^i}} \tag{13}$$

Condition (11) now yields:

$$\frac{dEB^i(\boldsymbol{\theta})}{d\theta^i} = B^i_x\left(1-\alpha\frac{b^i-b^i_0}{b^i-B_0}\right) \qquad \text{i=1,..,N} \tag{14}$$

where:

$$B_0 = \frac{\sum_i \frac{b^i_0}{b^i}}{\sum_i \frac{1}{b^i}} \tag{15}$$

Given that α is the same for each firm, expression (14) makes more explicit than (11) that for some firms it might be optimal to over report their true marginal benefit functions while for others the opposite is true. Specifically, if maximum marginal benefit for firm i is below (above) the weighted average (B_0) parameter β^i is less (greater) than one; if, in addition the marginal damage function is flatter (steeper) than the aggregate marginal benefit function, for firm i is unambiguously optimal to over (under) report its true marginal benefit function. Conversely if the conditions for the sign of β^i are the same as before but those for the sign of α are reversed it might be optimal for each firm to over or under report its true marginal benefit function.
Interesting results emerge under the alternative assumption of linear and proportional marginal social damage function. Computing (10) for $\theta^i = \hat{\theta}^i$ yields:

$$\frac{dEB_x^i}{d\theta} = 1 - \frac{x^i}{X}\frac{B_{xx}^i}{B_{XX}} \qquad (16)$$

whose sign depends on the relative weight of firm i in total pollution and in overall curvature of the aggregate benefit function. If a relatively small optimal pollution level and curvature identifies a relatively efficient polluting firm the above expression requires that for a relatively efficient (inefficient) polluting firm it is optimal to over (under) report its marginal benefit function. As a result of such optimal behaviour the resulting overall pollution level might even be not so far from optimal but not the distribution among polluting firms, with a resulting gain for relatively efficient firms at the expense of inefficient ones in terms of abatement costs.

A general conclusion which can be drawn form the results of this section is that, under the proposed mechanism, the decision to under or over report the true marginal benefit function crucially depends on detailed information about the marginal benefit function of all other firms: if such information is not available a prudent choice might be truthful revelation. Moreover in many circumstances it might be true that for some firms it is optimal to over report while for others the opposite is true: in such cases the resulting aggregate marginal benefit function might also be not so far from the true one and consequently also the aggregate pollution level attained by this mechanism.

Summary and Conclusions

The paper addresses the problem of asymmetry of information between a regulator and some polluting firms starting from the recognition that none of the mechanisms proposed in the literature for a truthful revelation of the relevant functions by the polluting firms have been implemented in the real world. It proposes a very simple mechanism with some appealing properties: its main ingredient is the possibility for the regulator to choose, without communicating in advance to the firms, among two instruments: an effluent fee and a standard. This added uncertainty implies that each firm requires detailed information on the marginal benefit (abatement cost) functions of all other firms in order to choose whether it is optimal to under or over report its true function and this information might not be available or might be costly to acquire: as a result in a real world setting this informational gap might induce firms to a truthful revelation. Under the additional assumptions of linearity of marginal benefit or marginal social damage functions it is demonstrated that, in many cases, the resulting optimal behaviour might be under reporting for some firms and over reporting for others so that the resulting marginal aggregate benefit function might be not so far from the true one: consequently aggregate pollution level attained by the mechanism might be not so far from the optimal one but not the distribution of this aggregate among polluting firms: in other words an “almost” optimal aggregate pollution level might be reached with a not cost minimizing distribution among polluting firms; finally, if there is a sufficiently sharp distinction among relatively efficient and inefficient firms the resulting distribution of pollution favours the formers in terms of abatement costs.

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