I.S.S.N: 1885-6888

ECONOMIC ANALYSIS
WORKING PAPER SERIES

A Note on the Complementarity of Uniform Emission Standards and Monitoring Strategies

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Working Paper 6/2009

UNIVERSIDAD AUTONOMA DE MADRID

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A note on the complementarity of uniform emission standards and monitoring strategies*

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4 June 2009

Abstract

Despite the well-known static cost-inefficiency of uniform emission standards to control pollution, governments continue to use them in a variety of settings. In this paper, we show that inspection agencies can sometimes use their informational advantage to design monitoring strategies that complement uniform emission standards in restoring efficiency.

Keywords: pollution standards, monitoring, non-compliance.

JEL codes: K42, L51, Q58.

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I. Introduction

Static cost efficiency is a commonly used criterion to analyze the performance of environmental policy instruments. This property is based on cost minimization, and states that marginal pollution abatement costs across firms should be equal. When polluting firms are heterogeneous, it is well-known that regulations based on uniform emission standards do not satisfy the static cost efficiency property. However, differentiated standards have their own disadvantages, which are mainly related to governments' informational requirements or large associated administrative costs (see, among others, Kolstad 2000 and Bohm and Russell 1985).

In practice, uniform emission standards are very commonly used, despite their disadvantages with respect to efficiency considerations. The main rationale for the use of uniform emission standards is the increasing certainty concerning the amount of pollution that will result from regulations (Weitzman 1974). For example, the US Clean Water Act establishes uniform water pollution discharge limits, independent on firms' location. Also, noise regulations are often designed as uniform standards, such as the Belgian noise regulation[1] for music in public and private institutions and companies. Further, the national ambient air quality standards included in the US Clean Air Act are largely identical for the whole country. Moreover, bans on certain substances, such as CFCs or the use of oil-based paints in urban areas in the US, are by definition uniform standards.

Given the extensive use of uniform standards in practice, our objective in this paper is to reconcile their use with cost efficiency considerations. A key issue in our analysis is to

[1] Royal Decree 24 February 1977.

recognize that *effective* pollution levels coincide with *stipulated* standards only when there are sufficient monitoring and sanctioning resources to induce firms to comply with the standards. Therefore, the enforcement strategy acts as a complementary instrument to uniform standards, and we show that, under certain circumstances, it can completely correct for their inefficiency. The results we obtain crucially depend on the stringency of the standard. In one extreme, if the standard is sufficiently lax, the inspection agency is primarily concerned about deterrence, and therefore, the best the agency can do (in the absence of budgetary restrictions) is to induce firms to comply with the standard. If, however, the standard is sufficiently stringent, the inspection agency's actions are primarily driven by concerns about firms' abatement costs. In this case, we find that the best the agency can do is to design a uniform inspection strategy which induces non-compliance, and marginal abatement costs across firms will be equalized.

Our results are especially relevant because, generally, static cost efficiency considerations of environmental policy instruments have ignored monitoring issues (see, among others, Kolstad 2000, Bohm and Russell 1985 and Cropper and Oates 1992). Downing and Watson (1974) are the first to present a theoretical model of environmental policy enforcement, and Harford (1978) focuses on firms' behavior with respect to imperfectly enforceable emission standards and taxes, but none of them studies efficiency issues related to the link of standards and monitoring strategies. In fact, most of the previous theoretical literature on optimal monitoring considers a setting with homogenous firms or even a single firm; see, for example, Polinsky and Shavell (1979, 1992), Cohen (1987), Garoupa (2001) or Arguedas (2008). Some consider heterogeneous firms, but none of them discusses the link between uniform emission standards and their monitoring strategy in achieving efficiency; see, for example, Rousseau and Proost (2005) and Garvie and Keeler (1994). The only exception we are aware of is Jones and Scotchmer (1990), who investigate the reduction in the inefficiencies associated with uniform standards through the exercise of power over the agency's enforcement budget. They show that requiring the agency to partially self-finance from its noncompliance penalties mitigates the inefficient distribution of compliance among inspected classes of firms when cost information is imperfect. However, a crucial difference between Jones and Scotchmer (1990) and our work is that in theirs, the objective of the inspection agency is deterrence, independently on firms' compliance costs, and they study how inefficiencies associated with compliance with uniform standards can be mitigated through the appropriate choice of the agency's enforcement budget. By contrast, in our work, the agency is concerned not only about deterrence but also on firms' abatement costs, and it can mitigate the inefficiencies of uniform standards through the appropriate choice of the monitoring strategy.

Our findings depend on two key features, namely, the consideration of a hierarchical government and the incorporation of an inspection agency's concerns about firms' abatement costs into the objective function. With respect to the former, we assume that the government delegates the responsibility of law enforcement to an inspection agency. This assumption is consistent with empirical evidence, and also supported in a variety of theoretical papers, including Jones and Scotchmer (1990), Chander and Wilde (1992), Bose (1995) and Saha and Poole (2000).

The second assumption refers to the fact that inspection agencies are concerned about balancing costs and benefits when deciding on monitoring. That is, inspection agencies do not act as strict enforcers, but they at least partially consider firms' abatement costs in their objective function. The choice of the objective function of the inspection agency has already been subject of debate.[2] For example, Harford and Harrington (1991) and Stranlund (2007) assume that part of the costs that the agency takes into account consist of the compliance cost burden on the regulated industry. This approach is consistent with our work, that is, the enforcer acts as a cost minimizer in order to attain a specific compliance goal. However, there exist other alternative assumptions for the agency's objective function. For example, Garvie and Keeler (1994) and Hansen et al. (2006) assume that the enforcer minimizes non-compliance subject to a budget constraint; Schmutzler and Goulder (1997) and Franckx (2002) consider that the agency acts as a social welfare maximizer; Jones and Scotchmer (1990) assume environmental harm minimization, or equivalently, environmental benefit maximization; and, finally, Helland (1998) suppose that agencies seek to maximize their net political support (for instance, the US EPA may fear criticism because of an enforcement action's impact on the local economy). Furthermore, empirical studies that estimate the US EPA's objective function from its enforcement actions have generated mixed results. Deily and Gray (1991) and Dion et al. (1998), for instance, reject the social welfare maximization model, while Gray and Deily (1996) find evidence in support of environmental harm minimization. As Heyes and Kapur (2009) conclude, there is considerable uncertainty about the agencies' objectives in practice, since objective functions are usually not published and, if they are, the stated objective will often be too vague to interpret meaningfully (e.g. the EPA's mission statement reads 'To protect human health and the environment'). Overall, evidence seems to point to the conclusion that environmental inspection agencies are mainly concerned with deterrence and only on secondary level with the compliance cost burden placed on the regulated industry. As Firestone (2002) states, *'it may be more reasonable to view them'* (i.e.

[2] For example, Cohen (2000), Firestone (2002, 2003) and Heyes and Kapur (2009) provide extensive summaries of the different arguments and assumptions made in various studies.

EPA enforcement employees) *'as violation-minimizing policemen whose primary goal is general deterrence rather than social welfare maximization'*.

The remainder of the paper is organized as follows. In section 2 we present the model. In section 3, we derive the results. In section 4, we discuss some policy implications. We conclude in section 5. All the proofs are in the Appendix.

II. Model

We consider an industry composed of N firms that emit a hazardous pollutant. The emission level of firm *i* is denoted as $e_i \le e_i^o$, where e_i^o is the emission level without regulation in place. The overall industry level of emissions is $E = \sum_{i \in N} e_i$ and these emissions cause environmental damages equal to $D(E)$ with $D'(E) > 0$ and $D''(E) \ge 0$.

Each firm can reduce its emissions at a cost depending on the emission level e_i and the parameter θ_i, which defines the firms' type. The abatement costs of a firm of type θ_i are represented by the function $c(\theta_i, e_i)$, which has the usual specification: $c_e(\theta_i, e_i) < 0$ for all $e_i < e_i^0$, $c_e(\theta_i, e_i^0) = 0$, $c_{ee}(\theta_i, e_i) > 0$ for all $e_i \le e_i^0$ and $c_{eee}(\theta_i, e_i)$ sufficiently small.

For simplicity, we assume that the industry is characterized by two types of firms: high-cost firms (θ_H) and low-cost firms (θ_L). The number of high-cost (low-cost) firms is N_H (N_L), such that $N_H + N_L = N$. A high-cost firm has higher total and marginal abatement costs for each level of emissions than a low-cost firm. Thus, $c(\theta_H, e_i) > c(\theta_L, e_i)$ and $c_e(\theta_H, e_i) < c_e(\theta_L, e_i)$. Also, we assume $c_{ee}(\theta_H, e_i) \leq c_{ee}(\theta_L, e_i)$.

In order to protect environmental quality, the regulator (or the government) has imposed a uniform emission limit or standard $\overline{e}$ on the firms in the industry. The stringency of the standard and the associated fine in case a firm is discovered exceeding the standard are determined by law. For simplicity, the fine F is assumed to be linear:[3]

$$F = f \max\{0; e_i - \overline{e}\}, \quad f > 0.$$

We assume that there exists an inspection agency that has a budget $B > 0$ to spend on monitoring. We assume that the cost *per* inspection is $m > 0$ and that monitoring is perfectly accurate. We denote by p_i the probability that a firm of type i is inspected by the agency, such that $0 \leq p_i \leq 1$. After the standard $\overline{e}$ and the fine f are made public knowledge, the agency announces an inspection probability p_i for each firm type $i \in \{H, L\}$. Then, each firm reacts to the regulatory policy by selecting the pollution level.[4]

The objective of each (risk-neutral) firm is to choose the pollution level that minimizes the sum of abatement costs and expected fines. Therefore, for a given regulatory policy $\{\overline{e}, f, p_i\}$, a firm of type i solves the following problem:

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[3] In practice, a linear specification of fines is often encountered for civil fines, since this structure is easy to understand by firms, citizens and administrations. For example, the EPA's Clean Air Act Stationary Source Civil Penalty Policy (1991) describes the civil fines for violating air pollution standards as *"$5000 for each 30% or fraction of 30% increment above the standard"*.

[4] Our model is consistent with the fact that agencies responsible for law enforcement (inspection agencies) are better informed about the regulated firms than agents responsible for law design (the government). Therefore, it is conceivable that the latter sets uniform standards while the former uses differentiated inspection strategies.

$$\min_{e_i}\left[c\left(\theta_i, e_i\right)+p_i f \max\left\{0, e_i-\bar{e}\right\}\right]. \tag{1}$$

On the other hand, the objective of the inspection agency is to choose inspection probabilities that maximize compliance with the regulation in place, balanced by concerns about the level of the associated firms' abatement costs.[5] As in Keeler (1995), we introduce the parameter $\psi \in [0,1]$ to reflect the importance given by the inspection agency to abatement costs as a fraction of that given to environmental damages. If $\psi = 1$, the agency acts as a social costs minimizer. If $\psi = 0$, the agency strictly acts as an enforcer and maximizes deterrence without taking firms' costs into account. If abatement costs matter, but have a lower priority than deterrence, then $0 < \psi < 1$. We treat the parameter ψ as exogenous since it typically depends on a wide variety of factors such as past interactions with firms, political influence and the general viewpoint of the agency. Therefore, the optimization problem of the inspection agency is the following:

$$\begin{aligned} \min_{p_H, p_L} \quad & D\left(N_H e_H + N_L e_L\right) + \psi\left[N_H c\left(\theta_H, e_H\right) + N_L c\left(\theta_L, e_L\right)\right], \\ s.t. \quad & m\left[N_H p_H + N_L p_L\right] \le B, \end{aligned}$$

considering that firms react strategically to the regulatory policy $\{\bar{e}, f, p_i\}$, as explained above.

We solve the problem backwards to find the subgame perfect equilibrium. Therefore, we first study the optimal behavior of the firms, and then we analyze the inspection agency's optimal strategy.

[5] See the discussion in the introduction for a motivation of this objective function.

III. Results

First we look at the firms' behavior when they are confronted with a uniform emission standard. Next we derive the optimal inspection strategy for the environmental agency conditional on the stringency of the standard and the monitoring budget.

3.1 Firms' behavior

As explained in the previous section, firms choose their emissions levels so as to minimize expected costs, consisting of abatement costs and expected fines for non-compliance, see (1). The solution of this optimization problem is presented next.

Lemma 1. *Given* $\{\overline{e}, f, p_i\}$*, firm i's optimal emission level,* e_i^**, is given by the conditions:*

$$\begin{aligned} &c_e\left(\theta_i, e_i^*\right) + p_i f \geq 0, \\ &e_i^0 \geq e_i^* \geq \overline{e}, \\ &\left[c_e\left(\theta_i, e_i^*\right) + p_i f\right]\left[e_i^* - \overline{e}\right] = 0. \end{aligned}$$

The intuition of this result is straightforward. Given the policy $\{\overline{e}, f, p_i\}$, the firm can decide to either comply with the standard, or not. The optimal strategy is to comply when the marginal expected penalty for non-compliance is larger than the marginal abatement costs savings of exceeding the standard; that is, when $p_i f \geq -c_e\left(\theta_i, \overline{e}\right)$. In that case, the optimal strategy is $e_i^* = \overline{e}$.[6] However, the optimal strategy is to exceed the standard if the marginal expected penalty is below the marginal abatement cost savings at the standard. In that case, the firm will choose the emission level such that marginal abatement cost savings and

[6] In a static model such as ours, the firm never chooses an emission level strictly below the standard: it just increases abatement costs, but there are no penalty savings.

marginal expected fines are equal. Therefore, $e_i^* > \overline{e}$ and $c_e\left(\theta_i, e_i^*\right) + p_i f = 0$. Note that $e_i^* < e_i^o$ as long as $p_i > 0$.

From lemma 1, we can immediately see that there exists a threshold inspection probability for each firm type, such that compliance is ensured above that threshold. That minimum probability required is:

$$\overline{p}_i = -\frac{c_e\left(\theta_i, \overline{e}\right)}{f} \tag{2}$$

Obviously, $\overline{p}_H > \overline{p}_L$, since $c_e\left(\theta_H, e_i\right) < c_e\left(\theta_L, e_i\right)$ for all e_i.

Thus, $p_i \geq \overline{p}_i$ ensures compliance with the standard, i.e., $e_i^* = \overline{e}$. However, $p_i < \overline{p}_i$ ensures that firms of type i exceed the standard, i.e., $e_i^* > \overline{e}$, where $c_e\left(\theta_i, e_i^*\right) + p_i f = 0$. This expression defines an implicit relationship between the inspection probability and the induced emission level, such that:

$$\frac{\partial e_i}{\partial p_i}\left(\theta_i, e_i\right) = -\frac{f}{c_{ee}\left(\theta_i, e_i\right)} < 0, \tag{3}$$

which represents the effect on emissions of a marginal increase in the inspection probability; the larger the probability, the lower the emission level. Our assumptions, $c_{ee}\left(\theta_H, e_i\right) \leq c_{ee}\left(\theta_L, e_i\right)$ and $c_{eee}\left(\theta_i, e_i\right)$ sufficiently small, ensure that the impact of the inspection frequency on emissions is 'almost' constant, and that high-cost firms react more than low-cost firms to an increase in the probability of inspection (in terms of emission reduction), independently of the emission level. That is:

$$\frac{\partial e_H}{\partial p_H}\left(\theta_H, e_H\right) < \frac{\partial e_L}{\partial p_L}\left(\theta_L, e_L\right). \tag{4}$$

3.2 Agency behavior

The inspection agency knows the specific type of each firm, and is thus able to differentiate its monitoring strategy depending on the type. However, monitoring is still necessary to formally document a violation so as to allow prosecution and sanctioning. As explained in the previous section, we assume that achieving compliance (or maximizing deterrence) is a primary goal for an environmental inspection agency and that costs to firms matter only in varying degrees depending on the situation. The agency's optimization problem is the following:

$$\begin{aligned} \min_{p_H, p_L} \quad & D\left(N_H e_H + N_L e_L\right) + \psi\left[N_H c\left(\theta_H, e_H\right) + N_L c\left(\theta_L, e_L\right)\right], \\ s.t. \quad & c_e\left(\theta_i, e_i\right) + p_i f \geq 0;\; e_i \geq \overline{e};\; e_i^o \geq e_i;\; i = H, L, \\ & m\left[N_H p_H + N_L p_L\right] \leq B, \end{aligned} \qquad (5)$$

where the first three constraints represent the firms' best responses, as established in Lemma 1, and the last inequality restriction is the agency's budgetary constraint.

Before presenting the optimal inspection strategy, we define e_i^a as the emission level of firm type *i* preferred by the agency; that is, the one that minimizes the sum of external damages plus the weight of abatement costs, or the one that satisfies the optimality condition $D'\left(N_H e_H^a + N_L e_L^a\right) + \psi c_e\left(\theta_i, e_i^a\right) = 0$. Also, let $E^a = N_H e_H^a + N_L e_L^a$. Note that these preferred emission levels do not depend on existing legislation (i.e. the stringency of the emission standard) or on the agency's available budget. Our assumptions ensure that $e_L^a < e_H^a$. For a graphical illustration, see figure 1.

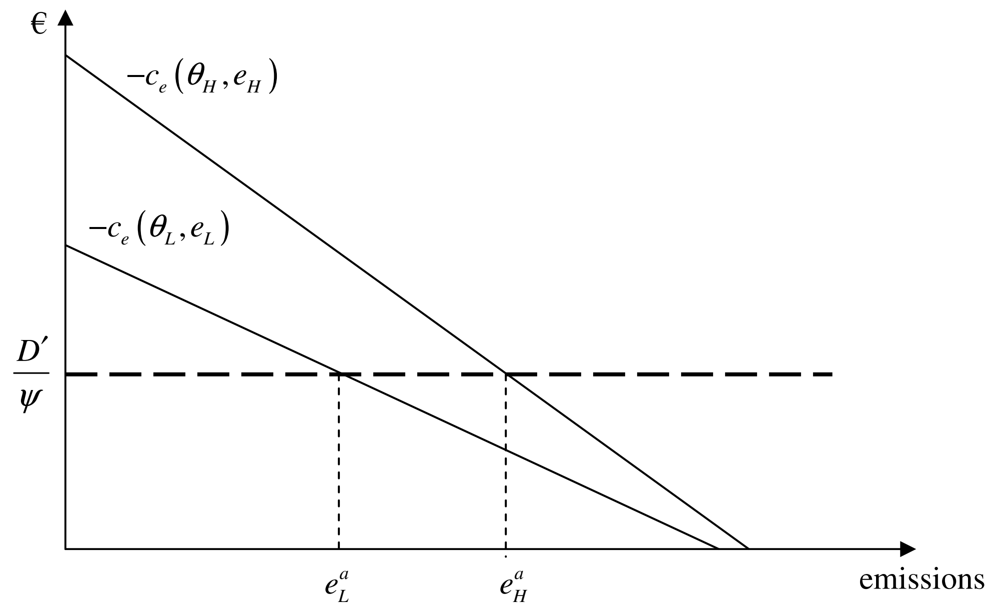

Figure 1: Emission levels preferred by the agency

Also, let p_j^R be the *residual* probability such that $B = m\left[N_j p_j^R + N_i \overline{p}_i\right]$, where $\overline{p}_i$ is the threshold probability which induces type i firms to comply with the standard, see (2).

Now, we are ready to present the characteristics of the inspection agency's optimal policy. It is very important to point out that the stringency of the emission standard crucially influences the agency's monitoring and enforcement options since the agency has no power to control firm behavior for emission levels below $\overline{e}$.

Proposition 1. *The optimal inspection strategy* $\left(p_H^*, p_L^*\right)$ *is the following:*

i) *If* $\overline{e} < e_L^a$ *(stringent standard), then:*

a. *If* $mN\dfrac{D'\left(E^a\right)}{\psi f} \leq B$, *then* $p_H^* = p_L^* = \dfrac{D'\left(E^a\right)}{\psi f}$.

b. *Else,* $\left(p_H^*, p_L^*\right)$ *such that* $\left[D'(E)-\psi p_H^* f\right]\frac{\partial e_H}{\partial p_H}=\left[D'(E)-\psi p_L^* f\right]\frac{\partial e_L}{\partial p_L}$,

where $c_e\left(\theta_i, e_i\right)+p_i^* f=0$ and $B=m\left[N_H p_H^*+N_L p_L^*\right]$.

ii) *If* $e_L^a \leq \overline{e} < e_H^a$ *(moderate standard), then:*

a. *If* $m\left[N_H \frac{D'(\tilde{E})}{\psi f}+N_L \overline{p}_L\right] \leq B$, *where* $\tilde{E}=N_H \tilde{e}_H+N_L \overline{e}$ *and* $\tilde{e}_H$ *such that* $D'\left(N_H \tilde{e}_H+N_L \overline{e}\right)+\psi c_e\left(\theta_H, \tilde{e}_H\right)=0$, *then* $p_H^*=\frac{D'(\tilde{E})}{\psi f}$, $p_L^*=\overline{p}_L$.

b. *Else:*

i. *If* $\left[D'(E)-\psi p_H^R f\right]\frac{\partial e_H}{\partial p_H} \geq \left[D'(E)-\psi \overline{p}_L f\right]\frac{\partial e_L}{\partial p_L}$, *then* $p_H^*=p_H^R$, $p_L^*=\overline{p}_L$, *such that* $B=m\left[N_H p_H^R+N_L \overline{p}_L\right]$.

ii. *Else,* $\left(p_H^*, p_L^*\right)$ *such that* $\left[D'(E)-\psi p_H^* f\right]\frac{\partial e_H}{\partial p_H}=\left[D'(E)-\psi p_L^* f\right]\frac{\partial e_L}{\partial p_L}$,

where $c_e\left(\theta_i, e_i\right)+p_i^* f=0$ *and* $B=m\left[N_H p_H^*+N_L p_L^*\right]$.

iii) *If* $e_H^a \leq \overline{e}$ *(lax standard), then:*

a. *If* $m\left[N_H \overline{p}_H+N_L \overline{p}_L\right] \leq B$, *then* $p_H^*=\overline{p}_H$, $p_L^*=\overline{p}_L$.

b. *Else:*

i. *If* $\left[D'(E)-\psi p_j^R f\right]\frac{\partial e_j}{\partial p_j} \geq \left[D'(E)-\psi \overline{p}_i f\right]\frac{\partial e_i}{\partial p_i}$, *then* $p_j^*=p_j^R$, $p_i^*=\overline{p}_i$, *such that* $B=m\left[N_j p_j^R+N_i \overline{p}_i\right]$; $i, j=H, L, i \neq j$.

ii. *Else,* $\left(p_H^*, p_L^*\right)$ *such that* $\left[D'(E)-\psi p_H^* f\right]\frac{\partial e_H}{\partial p_H}=\left[D'(E)-\psi p_L^* f\right]\frac{\partial e_L}{\partial p_L}$,

where $c_e\left(\theta_i, e_i\right)+p_i^* f=0$ *and* $B=m\left[N_H p_H^*+N_L p_L^*\right]$.

Assume first that the standard is sufficiently stringent (case i). If there are enough monitoring resources (case i.a), the agency can implement its most preferred outcome $\left(e_H^a, e_L^a\right)$ by setting a uniform inspection strategy across firm types. Therefore, cost-efficiency can be achieved with a uniform standard, if it is complemented with an appropriate uniform monitoring strategy. Note that this strategy implies that both types of firms exceed the standard $\overline{e}$. If, however, the monitoring budget is scarce (case i.b), the agency's second best option is to treat firms differently. This option again implies that firms exceed the standard, and the optimal inspection strategy satisfies the property that the last monetary unit spent in each firm group has the same marginal effect on the sum of environmental damages and weighted abatement costs.

Now, assume that the standard is set at a moderate level (case ii). Contrasting with the previous case, the agency cannot implement its most preferred outcome $\left(e_H^a, e_L^a\right)$, even if the monitoring budget is very large. The reason is because the standard is above e_L^a and firms never select a pollution level below the standard (see Lemma 1). As a consequence, the best the agency can do - if money is not a problem (case ii.a) - is to induce low-cost firms to fully comply with the standard and induce high-cost firms to select the pollution level $\tilde{e}_H$, which minimizes the sum of external damages and weighted abatement costs given that low-cost firms choose $\overline{e}$. Otherwise, the agency selects the interior optimal inspection strategy (case ii.b), except where the last monetary unit spent in inspecting the low-cost firms at the threshold level $\overline{p}_L$ has a larger marginal impact (in absolute terms) on the environmental damages and the weighted abatement costs than that spent in inspecting the high-cost firms at the *residual* probability p_H^R, that is, the one such that $B = m\left[N_H p_H^R + N_L \overline{p}_L\right]$. If this is the case, the optimal strategy is $p_L^* = \overline{p}_L$, $p_H^* = p_H^R$.

Finally, if the standard is lax (case iii), the agency cannot implement its most preferred outcome $\left(e_H^a, e_L^a\right)$ either, and now, the best it can do under a large budget (case iii.a) is motivating both firm types to comply with the standard by selecting the threshold probabilities $p_H^* = \overline{p}_H$, $p_L^* = \overline{p}_L$. However, if the monetary restriction is binding (case iii.b), the agency selects the interior optimal inspection strategy, except in the case where resources are best spent so that one of the types (either the low- or the high-cost one) complies.

IV. Discussion

The above results show that it is pointless to consider the welfare effect of a uniform emission standard as such without taking the mitigating effect of the monitoring strategy into account.

We can first consider the case where the budget available for monitoring is sufficient to implement the agency's *best* option. This corresponds to case a) defined in proposition 1 for each of the three different situations depending on the stringency of the emission standard. These three cases are illustrated in figure 2.

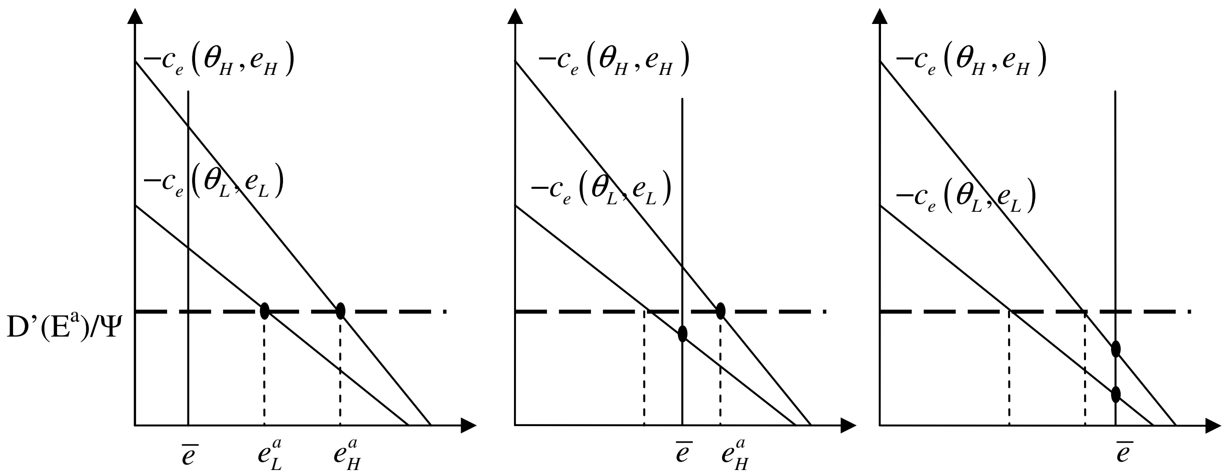

Figure 2

If we consider a stringent uniform standard $\left(\overline{e} < e_L^a\right)$, the agency's optimal strategy is to adopt a uniform inspection probability for all firms. This is set such that the expected marginal sanction for a violating firm is equal to the marginal social damage caused by that violation (weighted by ψ) and, therefore, $p_H^* = p_L^* = \dfrac{D'\left(E^a\right)}{\psi f}$. Hence, the marginal expected fine acts as a non-linear Pigouvian tax (see also Sandmo 2002) and, as a consequence, the agency's monitoring activity counteracts the inefficiency of the uniform emission standard. Jointly the emission standard and the inspection strategy provide the socially optimal solution if $\psi = 1$. For $0 < \psi < 1$, monitoring still ensures cost efficiency, even though it does no longer ensures allocative efficiency.

Next, if we consider a moderate standard $\left(e_L^a \leq \overline{e} < e_H^a\right)$, the inspection agency treats both firm types differently. The low-cost firms are forced to comply with the emission limit, while the high-cost firms are allowed to violate the regulation, such that the induced pollution level is

$\tilde{e}_H$, where $\overline{e} < \tilde{e}_H \leq e_H^a$.[7] The monitoring strategy thus lowers the inefficiency of using a uniform standard to regulate a heterogeneous industry.

Thirdly, if we look at a lax standard $\left(e_H^a \leq \overline{e}\right)$, we find that the optimal inspection strategy again implies a differentiated approach. High-cost firms receive more regulatory attention than low-cost firms and are inspected more frequently. In this instance, the deterrence objective of the agency is dominant and the cost implications of the regulation for the firms are neglected. Both types of firms are therefore induced to comply with the regulation.

Furthermore, when the budgetary constraint is binding and the agency has insufficient resources to implement its preferred inspection strategy, we see that the optimal inspection strategy implies that the last euro spent on inspection in each group has the same marginal effect on the environmental damages and the weighted abatement costs (except in the corner solution cases, as explained in the previous section). Again we find that, despite the uniform emission standard in place, the monitoring strategy leads to a cost efficient outcome.

Finally, we briefly discuss the extreme case where the agency is a strict enforcer (i.e. $\psi = 0$). The agency's optimal monitoring strategy then implies devoting resources to those firms that react most strongly to an increase in inspections. As we know from expression (3), high-cost firms react more than low-cost firms to an increase in the probability of inspection for every possible emission level. Thus, from a strict deterrence point of view, the agency should first dedicate resources to monitoring high-cost firms until $p_H = \overline{p}_H$ and only then start monitoring the low-cost firms. The agency focuses solely on compliance with the emission

[7] Note that the pollution level $\tilde{e}_H$ coincides with e_H^a as long as the damage function is linear.

standard and ignores the effects on firms' abatement cost levels. Again, the presence of heterogeneous firms leads the agency to select a differentiated monitoring strategy, however, this strategy is no longer cost efficient except for a sufficiently lax emission standard and a sufficiently large budget (case iii.a in proposition 1).

V. Conclusion

By looking at both the environmental policy instrument and the associated monitoring strategy, we have found that the efficiency disadvantage of uniform emission standards is substantially alleviated by the agency's inspection policy. Thus the criticism of uniform regulatory standards may be overstated. Important conditions for this improvement in the efficiency of the environmental policy are the availability of sufficient resources for the inspection agency and the incorporation of abatement cost considerations in the agency's objective function. Therefore, it might be desirable to influence the form of the agency's objective function by increasing the weight attached to firms' compliance costs. This could be done, for example, by changing the agency's mission statement combined with independent, external evaluation of the agency's performance.

Our results stress the importance of looking at the complete regulatory chain when evaluating a policy's impact, consisting of the environmental policy instrument as well as the monitoring and enforcement strategy. In fact, the *nominal* standards stipulated in legislative texts might differ from the *effective* standards represented by the pattern of compliance induced by monitoring and enforcement.

VI. Appendix

Proof of Lemma 1. The first order conditions of this optimization problem are:[8]

$$c_e(\theta_i, e_i) + p_i f - \lambda = 0,$$
$$\lambda \geq 0, e_i - \overline{e} \geq 0, \lambda[e_i - \overline{e}] = 0,$$

where $\lambda \geq 0$ is the Kuhn-Tucker multiplier associated to the inequality restriction. Easily combining these conditions, we obtain the desired result.

Proof of Proposition 1.

The Lagrangian of this optimization problem is the following:

$$L = D(N_H e_H + N_L e_L) + \psi[N_H c(\theta_H, e_H) + N_L c(\theta_L, e_L)] - \sum_{i=H,L} \alpha_i [e_i - \overline{e}] - \sum_{i=H,L} \beta_i [e_i^o - e_i]$$
$$+\gamma[m[N_H p_H + N_L p_L] - B],$$

where $\alpha_i \geq 0, \beta_i \geq 0, \gamma \geq 0$ are the corresponding lagrange multipliers and (e_H, e_L) are implicitly obtained from the expression $c_e(\theta_i, e_i) + p_i f = 0$.[9]

The optimality condition is the following:

$$D' N_i \frac{\partial e_i}{\partial p_i} + \psi N_i c_e(\theta_i, e_i) \frac{\partial e_i}{\partial p_i} - \alpha_i \frac{\partial e_i}{\partial p_i} + \beta_i \frac{\partial e_i}{\partial p_i} + \gamma N_i m = 0, \; i = H, L,$$

where $\frac{\partial e_i}{\partial p_i} < 0$ is given by (3). Assuming positive inspection probabilities (which imply $e_i^o > e_i$), we then have $\beta_i = 0$, which reduces the optimality condition to:

[8] Given the assumptions of our model, these are necessary and sufficient conditions for an optimum. The same applies for the other optimization problem in the paper.

[9] This is obvious under non-compliance. Under compliance, $c_e(\theta_i, \overline{e}) + p_i f > 0$ would imply to spend more monitoring resources than needed to induce firms to comply (see also (2)).

$$\left[D'N_i + \psi N_i c_e\left(\theta_i, e_i\right) - \alpha_i\right]\frac{\partial e_i}{\partial p_i} + \gamma N_i m = 0,\ i = H, L. \quad (6)$$

<u>Case (i)</u>. A stringent standard $\overline{e} < e_L^a$.

First consider $\gamma = 0$ (i.e., the budget constraint is not binding). The optimality condition (6) reduces to:

$$D'N_i + \psi N_i c_e\left(\theta_i, e_i\right) - \alpha_i = 0,\ i = H, L,$$

since $\frac{\partial e_i}{\partial p_i} < 0$. Since $\alpha_i \geq 0$, we then have $D' + \psi c_e\left(\theta_i, e_i\right) \geq 0$, which necessarily implies that $e_i \geq e_i^a$. A stringent standard $\overline{e} < e_L^a$ implies $e_i > \overline{e}$ (full non-compliance) and, therefore, $\alpha_i = 0$. Thus:

$$D' + \psi c_e\left(\theta_i, e_i\right) = 0,\ i = H, L,$$

which implies $e_i = e_i^a$. Since $c_e\left(\theta_i, e_i\right) + p_i f = 0$, we then have $D'\left(E^a\right) - \psi p_i f = 0$, $i = H, L$, which is possible only if $mN\frac{D'\left(E^a\right)}{\psi f} \leq B$.

However, if $mN\frac{D'\left(E^a\right)}{\psi f} > B$, we have $\gamma > 0$ (the budget constraint is binding). If full non-compliance is the desired outcome without budgetary restrictions, inspection probabilities are even lower with monetary constraints. Therefore, full non-compliance is induced as well, that is, $e_i > \overline{e}$ and $\alpha_i = 0$. Thus, the optimality condition (6) reduces to:

$$D'\frac{\partial e_i}{\partial p_i} + \psi c_e\left(\theta_i, e_i\right)\frac{\partial e_i}{\partial p_i} + \gamma m = 0,\ i = H, L.$$

Therefore, we obtain:

$$\left[D' + \psi c_e\left(\theta_H, e_H\right)\right]\frac{\partial e_H}{\partial p_H} = \left[D' + \psi c_e\left(\theta_L, e_L\right)\right]\frac{\partial e_L}{\partial p_L}.$$

Case (ii). A moderate standard $e_L^a \leq \overline{e} < e_H^a$.

First consider $\gamma = 0$. The optimality condition (6) reduces to:

$$D' N_i + \psi N_i c_e\left(\theta_i, e_i\right) - \alpha_i = 0,\ i = H, L,$$

since $\frac{\partial e_i}{\partial p_i} < 0$. Since $\alpha_i \geq 0$, we then have $D' + \psi c_e\left(\theta_i, e_i\right) \geq 0$, which necessarily implies $e_i \geq e_i^a$. A moderate standard $e_L^a \leq \overline{e} < e_H^a$ implies $e_H > \overline{e}$ and $e_L = \overline{e}$ and, therefore, $\alpha_H = 0$ and $\alpha_L \geq 0$. Thus, $e_H = \tilde{e}_H$, where $D'\left(N_H \tilde{e}_H + N_L \overline{e}\right) + \psi c_e\left(\theta_H, \tilde{e}_H\right) = 0$. Then, $p_H = \frac{D'\left(\tilde{E}\right)}{\psi f}$ and $p_L = \overline{p}_L$, where $\tilde{E} = N_H \tilde{e}_H + N_L \overline{e}$, which is possible only if $m\left[N_H \frac{D'\left(\tilde{E}\right)}{\psi f} + N_L \overline{p}_L\right] \leq B$.

However, if $m\left[N_H \frac{D'\left(\tilde{E}\right)}{\psi f} + N_L \overline{p}_L\right] > B$, we have $\gamma > 0$. With enough monitoring resources, it is desirable to induce high-cost firms to exceed the standard, as we have just proven. Therefore, with less resources, this is also the case and, therefore, $e_H > \overline{e}$ and $\alpha_H = 0$. Now, condition (6) varies with the type of firm:

$$\left[D' + \psi c_e\left(\theta_H, e_H\right)\right]\frac{\partial e_H}{\partial p_H} + \gamma m = 0,$$

$$\left[D' + \psi c_e\left(\theta_L, e_L\right)\right]\frac{\partial e_L}{\partial p_L} + \gamma m = \alpha_L \frac{\partial e_L}{\partial p_L} \leq 0.$$

First, $\alpha_L = 0$ implies $e_L > \overline{e}$, and the interior condition obtained in case (i) above is also derived here. However, $\alpha_L \geq 0$ implies $e_L = \overline{e}$, which is possible only if

$\left[D'(E)+\psi c_e(\theta_H,e_H)\right]\frac{\partial e_H}{\partial p_H} \geq \left[D'(E)+\psi c_e(\theta_L,\bar{e})\right]\frac{\partial e_L}{\partial p_L}$. In this case, we have $p_H^* = p_H^R$, $p_L^* = \bar{p}_L$, where $p_H^R = \frac{B - mN_L\bar{p}_L}{mN_H}$.

<u>Case (iii)</u>. A lax standard $e_H^a \leq \bar{e}$.

First consider $\gamma = 0$. The optimality condition (6) reduces to:

$$D'N_i + \psi N_i c_e(\theta_i, e_i) - \alpha_i = 0,\ i = H, L,$$

since $\frac{\partial e_i}{\partial p_i} < 0$. Since $\alpha_i \geq 0$, we then have $D' + \psi c_e(\theta_i, e_i) \geq 0$, which necessarily implies $e_i \geq e_i^a$. A lax standard $e_H^a \leq \bar{e}$ then implies $e_i = \bar{e}$ and $\alpha_i \geq 0$. Thus, $p_i = \bar{p}_i$, which is possible only if $m\left[N_H\bar{p}_H + N_L\bar{p}_L\right] \leq B$.

However, if $m\left[N_H\bar{p}_H + N_L\bar{p}_L\right] > B$, we have $\gamma > 0$. Now, the result follows using the same procedure as in case (ii) above, and considering the two possible cases of full non-compliance ($\alpha_H = \alpha_L = 0$) and partial compliance ($\alpha_i > 0$, $\alpha_j = 0$).

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