I.S.S.N: 1885-6888

ECONOMIC ANALYSIS WORKING PAPER SERIES

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Working Paper 13/2007

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To Comply or Not To Comply? Pollution Standard Setting Under Costly Monitoring and Sanctioning

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Abstract

In this paper, we characterize optimal regulatory policies composed of pollution standards, probabilities of inspection and fines for non-compliance, in a context where both monitoring and sanctioning are socially costly, and penalties may include gravity and non-gravity components at the regulator's discretion. The optimal policy entails compliance with the standards as long as a quite intuitive condition is met. Non-compliant policies may include standards even below the pollution levels that minimize the sum of abatement costs and external damages. Interestingly, the appropriate structure of penalties under non-compliance is highly progressive, while the best possible shape of the fines under compliance is linear only if non-gravity sanctions are not allowed.

JEL classification: K32, K42, L51, Q28.

Key words: standards, monitoring, convex fines, non-compliance, non-gravity sanctions.

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1 Introduction

Environmental regulations often require polluting agents to comply with pollution limits or *standards*. For example, the EPA's National Pollutant Discharge Elimination System Program of the Clean Water Act requires facilities which discharge pollutants into waters of the US to obtain a permit to release specific amounts of pollution. Such facilities include direct and indirect dischargers, as well as Publicly Owned Treatment Works (POTWs), that is, wastewater treatment plants owned by municipalities and local sewer districts.

According to Harrington (2003), the rates of non-compliance from the mid-1980s to the mid-1990s ranked between 6% and 14% for direct dischargers, between 9% and 11% for POTWs, and about 54% in the case of indirect dischargers.[1] The EPA's OSWER Directive 0610.12 provides some examples of imposed penalties, following the Civil Penalty Policy of the Clean Water Act.[2] These penalties contain a *gravity* component, directly related to the degree of non-compliance; and also a n*on-gravity* part, which considers extra conditions such as the economic impact of the penalty on the violator or economic benefits of non-compliance, such as illegal profits or competitive advantage. According to the mentioned Directive, the final structure of the sanction is case-based: the non-gravity component varies from nearly 3% to almost 84% of the total penalty.[3]

These numbers suggest that non-compliant behavior is significant, and also that there

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[1] This includes violations of standards and other requirements also, such as self-monitoring or reporting. Nevertheless, 35% of the non-compliant indirect dischargers were in violation of the standards.

[2] Consult www.epa.gov for more information on this issue.

[3] In fact, there exists flexibility regarding the final structure of the penalties, with the limit of the violator's statutory maximum civil penalty liability. In particular, under the EPA's Audit Policy, it is possible to reduce up to 100% of the non-gravity-based penalties and 75% of the gravity-based penalties in exchange for firms' good-faith, documented evidence of compliance-promoting activities.

does not exist a clear pattern of the appropriate shape of the penalties. Surprisingly, the existing theoretical literature on optimum enforcement has not considered the mentioned binary structure of the fines.[4] Moreover, non-compliance has not been rationalized; that is, the problem of finding the optimal policy composed of pollution standards, inspection probabilities and fines, considering that the best possible policy may induce non-compliance, has not been solved. In the present paper, we address these issues.[5]

We consider a simple model composed of a regulator and a polluting firm. The regulator sets a pollution standard and a probability of inspection which minimizes social costs (i.e., the sum of abatement costs, external damages and enforcement costs, i.e., monitoring and sanctioning costs), considering the optimal behavior of the firm with respect to the policy. Sanctions for non-compliance contain both a non-gravity and a gravity component, the latter being strictly increasing and convex in the degree of violation. In the first part of the paper, we consider given fines, i.e., chosen by an institution different from the regulator. Later on, we allow the regulator to choose the penalty as well.

Under given fines, we find that the optimal policy induces compliance under low monitoring costs relative to sanctioning costs, and when sanctions are not very progressive

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[4] Consult Polinsky and Shavell (2000) for an excellent survey on public enforcement of the law, which started with Becker (1968). Some examples are Polinsky and Shavell (1979, 1991), Bebchuck and Kaplow (1991) or Bose (1993). Within the environmental context, see the literature reviews by Heyes (2000) and Cohen (1999), and also Heyes (1996), Segerson and Tietenberg (1992) or Arguedas (2005).

[5] A recent paper by Stranlund (2007) considers the design of emissions trading programs which induce either compliance or non-compliance, to achieve a fixed aggregate emissions target cost-effectively. Up to our knowledge, this is the closest paper to ours, although the (overall) induced pollution level is fixed in Stranlund (2007), while it is a decision variable of regulators here. Therefore, the present paper also allows to obtain desired pollution levels. Arguedas and Hamoudi (2004) consider a similar framework in the context of pollution standards, where fines are quadratic in the degree of non-compliance and there are no sanctioning costs. The purpose of that paper is not to find the best possible fine structure, but to analyze polluters' incentives to invest in environmentally friendly technologies, given possible fine reductions contingent on adoption and alternative timings for policy announcements.

in the degree of non-compliance. Interestingly, this condition reduces to the requirement found in Stranlund (2007) under his particular assumptions on the penalty function.[6]

However, the pollution level is endogenously determined in our model, while it is given in Stranlund (2007). This allows us to show that compliant policies may be characterized by lenient standards, in contrast with non-compliant policies. In fact, under compliance, we find that the optimal standard is above the pollution level which minimizes the sum of abatement costs and external damages, a result in accordance with the literature which is due to costly monitoring, see Polinsky and Shavell (2000). Conversely, under non-compliance, the optimal standard is below, as long as sanctioning costs are low enough.[7]

Regarding the appropriate shape of the fine, the regulator can cheaply maintain compliance if the marginal sanction of an infinitesimal violation is high enough. This is possible when the *linear* component of the sanction is large. When the optimal policy induces non-compliance, the optimal non-gravity sanction is zero, since it does not marginally affect the behavior of the firm and it only causes sanctioning costs. The preferred shape of the penalty in this case is sufficiently progressive. This result seems contrary to the literature on crime, where an increase in the sanction increases compliance.[8] However, there the standard is given. Here, the standard is endogenously determined, and there-

[6] Stranlund (2007) assumes a perfectly competitive market for tradable permits, where firms are price-takers. Firms cannot strategically react to change penalties (for polluting more than the quantity of permits they hold) in their favor either. In that sense, our paper and Stranlund (2007) have a common feature, that is, to assume that firms act passively in the policy setting. This then leads to a similar condition for the social preference of compliance.

[7] The optimal standard is zero if there are no sanctioning costs, a result shown in Arguedas and Hamoudi (2004), since it is possible to induce a given pollution level constant decreasing both the standard and the probability of inspection. This is equivalent to increasing the fine and decreasing the probability, in accordance with Becker (1968). An example of this practise is the *zero discharge* goal of the Clean Water Act, see Harrington (2003).

[8] Kambhu (1989), Malik (1990a), Harrington (1988) or Livernois and McKenna (1999) are exceptions.

fore, it changes when the sanction changes. A particular pollution level is then induced with a sufficiently large progressiveness of the sanction and a sufficiently low standard.

Given a non-compliant policy, it is always possible to find an equivalent compliant policy which achieves the same outcome at lower social costs. This result is in accordance with Stranlund (2007). We then argue that non-compliance can be justified on political grounds, as long as the pressure from environmental groups is significant with respect to the application of the *polluter pays principle*. Whatever the final outcome, we offer a clear recommendation: collected penalties should be highly progressive gravity-based.

This paper contributes to the literature on standard setting, and more specifically, on non-compliance and the design of optimal fines. Downing and Watson (1974) were the first to present a theoretical model of environmental policy enforcement. Harford (1978) focusses on firms' behavior with respect to imperfectly enforceable emission standards and taxes. In the context of emissions trading policies, several papers assume imperfect enforcement, such as Malik (1990b), Stranlund and Dhanda (1999) or Montero (2002). Ellis (1992), Stranlund and Chavez (2000) and Amacher and Malik (1996) study optimal policies constrained to induce compliance. More recently, Arguedas (2005) finds that optimal policies induce non-compliance, when firms and regulators negotiate on the level of the fines in exchange for firms' adoption of clean technologies.

The remainder of the paper is organized as follows. In the next section, we present the model. In Section 3, we study the optimal behavior of the firm. In Section 4, we analyze the optimal policy under given penalties. In Section 5, we discuss the appropriate shape of the fines. We conclude in Section 6. All the proofs are in the Appendix.

2 The Model

A single firm generates pollution denoted by $e \in [0, e^0]$, where e^0 is the pollution level emitted in the absence of any regulation. Pollution can be abated at a cost $c(e)$, with the usual assumptions $c'(e) < 0$, $c''(e) > 0$ and $c(e^0) = 0$.[9] Pollution generates external damages measured by the function $d(e)$, such that $d'(e) > 0$, $d''(e) \geq 0$ and $d(0) = 0$.

Let e^w be the pollution level that minimizes the sum of abatement costs and external damages, that is, $e^w = \arg\min_{e \geq 0} \{c(e) + d(e)\}$. Our assumptions ensure $0 \leq e^w < e^0$.

We assume there exists a regulator who sets a standard $s \in [0, e^0]$, that is, a maximum amount of permitted pollution. The regulator cannot observe the pollution level selected by the firm unless it engages in a monitoring activity, which is costly and perfectly accurate. The cost *per* inspection is $m > 0$. Due to monitoring costs, it is generally not desirable to inspect the firm in every instance but only occasionally, that is, with probability $p \in [0, 1]$. Once inspected, if the firm is discovered violating the standard $(e > s)$, then it is forced to pay a penalty that depends on the degree of non-compliance, $e - s$, and it is represented by the function $F(e - s) = F_0 + f(e - s)$, where $f(e - s) > 0$, $f'(e - s) > 0$ and $f''(e - s) > 0$ for all $e > s$ and $f(e - s) = 0$ for all $e \leq s$.[10] Thus, $F_0 \geq 0$ is the non-gravity based sanction and $f(e - s)$ is the gravity-based component.

Sanctioning is socially costly, too. Let $t \geq 0$ represent the per-unit social cost of collecting fines. Initially, we assume that the sanction is fixed by a government entity other than the regulator, for example, the judiciary, and study the features of the regulatory problem under given penalty structures. We relax this assumption in Section 5.

[9] Throughout the paper, we assume that third order derivatives are negligible.

[10] When appropriate, we discuss how our results change under linear penalties ($f'' = 0$).

Given $F(e-s)$, we consider a principal-agent framework where the regulator chooses the pollution standard and the inspection probability which minimizes social costs, considering the optimal response of the firm to the policy. We consider the sub-game perfect equilibrium concept. Therefore, we solve the problem backwards, that is, we first find the firm's optimal pollution level, and we then obtain the optimal policy that minimizes social costs considering the firm's optimal response.

Given the policy s, p and $F(e-s)$, the firm chooses the pollution level that minimizes the sum of abatement costs and expected penalties for non-compliance:

$$\begin{aligned} C(s,p) = \min_{e \geq 0} \quad & \{c(e) + p[F_0 + f(e-s)]\}, \\ s.\ t. \quad & e - s \geq 0. \end{aligned} \tag{1}$$

The regulator selects the policy that minimizes social costs, which contain firm's abatement costs, generated damages, expected monitoring costs and expected sanctioning costs:

$$SC(s,p) = c(e) + d(e) + p[m + tF(e-s)], \tag{2}$$

where $e = e(s,p) \leq e^0$ is the firm's optimal response to the policy.

3 The Behavior of the Firm

Given s, p and $F(e-s)$, the firm solves problem (1). The firm never selects a pollution level below the standard. The firm's expected costs are just abatement costs when $e < s$, which are strictly decreasing in the pollution level. Therefore, if the firm complies, it chooses $e = s$. However, if the firm does not comply, it chooses $e = n > s$, given by:

$$c'(n) + pf'(n-s) = 0. \tag{3}$$

Implicitly differentiating (3), we obtain the relationship between the chosen pollution level and, respectively, the probability of inspection and the standard:

$$n_p(s,p) = -\frac{f'(n-s)}{c''(n) + pf''(n-s)} < 0, \tag{4}$$

$$n_s(s,p) = \frac{pf''(n-s)}{c''(n) + pf''(n-s)} > 0. \tag{5}$$

These results are in accordance with Harford (1978). The pollution level selected by the firm is decreasing in the probability of inspection and increasing in the standard. Also, the degree of violation is decreasing in the standard, since $n_s(s,p) < 1$.[11]

Whether the firm decides to comply with the standard depends on the fixed component of the sanction, and also on the relationship between marginal abatement costs and marginal expected fines. The following lemma provides the result.

Lemma 1 *Given s, p and $F(e-s)$, the optimal pollution level $e(s,p)$ is the following:*
(i) If $F_0 = 0$, then $e(s,p) = \begin{cases} s, & \text{if } c'(s) + pf'(0) \geq 0; \\ n, & \text{if } c'(s) + pf'(0) < 0. \end{cases}$
(ii) If $F_0 > 0$, then $e(s,p) = \begin{cases} s, & \text{if } p \geq \frac{c(s)-c(n)}{F_0 + f(n-s)}; \\ n, & \text{if } p < \frac{c(s)-c(n)}{F_0 + f(n-s)}. \end{cases}$

Consider first the case where $F_0 = 0$. The firm complies (does not comply) with the standard if the savings in abatement costs of infinitesimally exceeding the standard are smaller (larger) than the marginal expected penalty. If the sanction includes a non-gravity component $F_0 > 0$, the expected cost function of the firm is discontinuous at $e = s$. In this case, the firm complies (does not comply) with the standard if the expected costs of complying are smaller (larger) than those of non-complying. Everything else equal, a sufficiently large F_0 ensures firm's compliance, since F_0 does not affect marginal behavior and it increases firm's expected costs only in the event of non-compliance.

[11] Note that $n_s(s,p) = 0$ when either $f'' = 0$ (i.e., when the sanction is linear) or $p = 0$.

From Lemma 1, there exists a threshold probability of inspection above which the firm complies with the standard, given by the expression:

$$p(s) = \begin{cases} -\frac{c'(s)}{f'(0)}, & \text{if } F_0 = 0; \\ p^c(s), & \text{if } F_0 > 0; \end{cases} \tag{6}$$

where $p^c(s)$ is the implicit relationship between p and s when $c(s) = c(n) + pF(n-s)$. There exists a negative relationship between p and s, since $c'(s) < 0$ and $c''(s) > 0$.[12] The larger the standard, the lower the required probability to induce compliance. Also, $p^c(e^0) = 0$, that is, there is no need to monitor the firm if it is required to comply with the pollution level e^0, the one it would emit in the absence of any regulation.

4 The Optimal Policy under Given Penalties

In this section, we assume that the regulator selects $\{s, p\}$, for a given fine structure $F(e-s)$. The problem is the following:

$$\begin{aligned} \min_{s,p} \quad & \{c(e) + d(e) + pm + ptF(e-s)\}, \\ \text{s. t.} \quad & e = e(s,p), \; p \in [0,1], \; s \geq 0, \end{aligned} \tag{7}$$

where $e = e(s,p)$ is the firm's optimal response, characterized in Lemma 1.

The regulator must decide between a policy which induces compliance, with possibly larger monitoring costs but without sanctioning costs; or a policy which induces non-compliance, with sanctioning costs but possibly lower monitoring costs.

We first provide a sufficient condition for the optimal policy to induce compliance.

[12] Totally differentiating $c(s) = c(n) + pF(n-s)$ with respect to p and s yields $\frac{dp^c}{ds} = \frac{c'(s) - c'(n)}{F(n-s)} < 0$.

Proposition 1 *Let* (s^*, p^*) *be the solution of* (7)*. Then,* (s^*, p^*) *induces compliance if*

$$(m + tF_0) \frac{f''(0)}{f'(0)} \leq tf'(0). \tag{8}$$

This result is quite intuitive. Assume that (s^*, p^*) induces compliance, i.e., $e(s^*, p^*) = s^*$. From (4) and (5), pollution increases when the inspection probability decreases and it decreases when the standard decreases. The regulator can maintain the pollution level constant infinitesimally decreasing the standard (this is equivalent to infinitesimally increase the sanction) and decreasing the probability of inspection accordingly. Given an infinitesimal decrease in the standard, the amount of the probability that can be reduced to keep pollution constant is given by $-\frac{n_s}{n_p} \mid_{n=s^*} = \frac{pf''(0)}{f'(0)}$.

But, changing the inspection probability and the standard affect enforcement costs. An infinitesimal decrease in the standard increases sanctioning costs on the amount $tpf'(0)$. The corresponding decrease in the probability decreases both monitoring and sanctioning costs on the amount $(m + tF_0) \frac{pf''(0)}{f'(0)}$. If the enforcement cost savings of decreasing the probability (left hand side of (8)) are lower than the additional enforcement costs of decreasing the standard (right hand side of (8)), then it is not socially convenient to depart from a policy which induces compliance.

Condition (8) is more likely to hold under low monitoring costs relative to sanctioning costs. Then, enough effort can be devoted to induce compliance, since this allows to save on sanctioning costs.

Condition (8) also depends on the specific structure of the sanction. Clearly, a larger marginal sanction (the term $f'(0)$) increases the sanctioning costs of decreasing the standard and decreases the enforcement cost savings of decreasing the probability of inspection (the latter because a larger marginal sanction increases the response of the firm to a change in the probability of inspection, see (4)). Therefore, a larger marginal sanction increases the likelihood of condition (8) . By contrast, the progressiveness of the sanction, (the term $f''(0)$) crucially affects the response of the firm to a change in the standard. A larger progressiveness implies that the corresponding reduction of the probability is larger, and therefore, enforcement cost savings of decreasing the probability are larger. Thus, (8) is more likely to hold when $f''(0)$ is small. Finally, a lower F_0 decreases the social cost savings of decreasing the probability of inspection, and (8) is more likely.

While (8) is also necessary for compliance to be optimal when $F_0 = 0$, however it is not when $F_0 > 0$, since social costs are discontinuous at $e = s$. Then, a sufficiently large F_0 might be enough for the optimal policy to induce compliance: it decreases the minimum probability to induce compliance (which decreases enforcement costs in the event of compliance, see (6)) and it increases sanctioning costs under non-compliance.

Next, we present the features of the optimal policy constrained to induce compliance.

Proposition 2 *If the optimal policy* (s^*, p^*) *induces compliance, it is characterized by* $c'(s^*) + d'(s^*) + m\frac{dp(s^*)}{ds} = 0$, *where* $p^* = p(s^*)$ *is given by* (6).

The optimal compliant policy balances abatement costs and expected damages against monitoring costs. Since $\frac{dp(s)}{ds} < 0$, $c'(s^*) + d'(s^*) > 0$. The optimal standard must be set above e^w, the pollution level which minimizes the sum of abatement costs and external damages. This result is in accordance with the literature, see Polinsky and Shavell (2000), and it is only due to costly monitoring and not to the particular fine structure.

We now characterize the optimal policy that entails non-compliance.

Proposition 3 *If the optimal policy (s^*, p^*) induces non-compliance, it is given by:*

$$c'(n) + d'(n) + tp^* f'(n - s^*) + \frac{m + t(F(n - s^*))}{n_p} = 0, \tag{9}$$

$$c'(n) + p^* f'(n - s^*) = 0, \tag{10}$$

$$(m + t(F(n - s^*))) \frac{f''(n - s^*)}{f'(n - s^*)} - tf'(n - s^*) \geq 0, \tag{11}$$

$$s^* \left[(m + t(F(n - s^*))) \frac{f''(n - s^*)}{f'(n - s^*)} - tf'(n - s^*) \right] = 0. \tag{12}$$

If sanctioning is socially costless ($t = 0$), condition (11) reduces to $m\frac{pf''}{f'} > 0$, which implies $s^* = 0$, by (4), (5) and (12). Therefore, the regulator always find it convenient to decrease the standard and the probability of inspection to save on monitoring costs.[13]

Under costly sanctioning, an interior standard is possible, as long as (11) holds with equality. The standard and the probability are decreased until the cost savings of decreasing the probability equal the additional costs of decreasing the standard.[14]

Combining (9) and (11), we conclude that $c'(n) + d'(n) > 0$.[15] The optimal non-compliant policy induces a pollution level above e^w, the pollution level which minimizes the sum of abatement costs and environmental damages. However, in contrast with the policy that induces compliance, the standard can be set below e^w as long as sanctioning costs are low enough. To see this, consider the following:

Example 1 *Abatement costs are $c(e) = \frac{e^2}{2} - 2e$ and external damages are $d(e) = \frac{e^2}{2}$.*

[13] Under linear fines, we have $m\frac{pf''}{f'} = 0$, $s^* \in [0, n)$ and $p^* = -\frac{c'(n)}{f'(n)}$. Intuitively, the level of the standard does not affect the decision of the firm, since the marginal fine is constant. Therefore, any standard which induces non-compliance is optimal in that case.

[14] Under linear fines, condition (11) never holds, since our assumptions ensure $tf'(n - s) > 0$. Therefore, under linear penalties and costly sanctioning, the optimal policy always induces compliance.

[15] Using (4), we obtain $tpf' + \frac{m+tF}{n_p} = -\frac{tf'c''}{f''} < 0$, which then implies $c'(n) + d'(n) > 0$, by (9).

Then, $e^w = 1$*. The penalty is* $F(e-s) = (e-s)^2$*. Since* $f'(0) = 0$ *and* $F_0 = 0$*, the optimal policy induces non-compliance for any* $m > 0$*,* $t > 0$*. From* (10)*,* $n - 2 + 2p(n-s) = 0 \Rightarrow n = \frac{2+2ps}{1+2p}$*. An interior solution for* s *follows from* (11) *and* (12)*, which lead to* $m = t(n-s)^2$*. Since* $n_p = -\frac{f'}{c''+pf''} = -\frac{2(n-s)}{1+2p}$ *from* (4)*,* (9) *reduces to* $n = \frac{2-ts}{2-t} > s$*. The latter implies* $s < (>) 1$ *as long as* $t < (>) 2$*. In any case,* $n > 1$*. For example, when* $m = 1$ *and* $t = 1$*, the optimal policy is* $\left[s = \frac{1}{2}; p = \frac{1}{4}\right]$*, which induces* $n = \frac{3}{2}$*. The resulting penalty is* $(n-s)^2 = 1$ *and the marginal penalty is* $2(n-s) = 2$*.*

5 The Choice of the Appropriate Penalties

In this section, we discuss the selection of the penalty shape, as part of the regulatory policy. A fine $F(e-s)$ can be approximated by a second order degree polynomial:

$$F(e-s) \simeq F_0 + f'(0)(e-s) + \frac{f''(0)}{2}(e-s)^2, \tag{13}$$

where $F_0 \geq 0$ is the non-gravity part of the sanction, and $f'(0) \geq 0$ and $f''(0) \geq 0$ are, respectively, the linear and progressive gravity components.

The most appropriate shape of the penalties is presented in the following:

Proposition 4 *If the optimal policy induces compliance, a linear fine is (weakly) preferred to any other fine structure. Conversely, if the optimal policy induces non-compliance, then the best shape is sufficiently progressive and such that* $F_0 = 0$*.*

First, assume that the optimal policy induces compliance. As long as $F_0 > 0$, the firm complies at the optimal inspection probability $p^c(s)$, see (6). The larger the fine, the lower the probability, and consequently, the lower the monitoring costs. But only the total amount of the fine matters, since the particular structure does not affect firm's behavior (other than complying versus non-complying). However, if $F_0 = 0$, the optimal probability satisfies $p = -\frac{c'(s)}{f'(0)}$. The probability can be decreased increasing the linear component $f'(0)$, in exchange for a lower progressive component $f''(0)$.

Things change when the optimal policy induces non-compliance. The regulator should not impose non-gravity sanctions, since they affect sanctioning costs but not firm's behavior (other than complying versus non-complying). The level of non-compliance can be better controlled under a large progressive sanction. By (5), the larger f'', the smaller the degree of non-compliance when s decreases. Therefore, enforcement costs can be lowered if the progressive part of the sanction is increased at the expense of the linear part.

But, is compliance socially better than non-compliance once the shape of the penalties can be chosen accordingly? From a strict social cost minimizing perspective, the answer is yes.[16] Stranlund (2007) shows that for any non-compliant policy, there exists a compliant policy which achieves the same emissions target with lower marginal penalties. This result can be immediately translated to our context, even when the induced pollution level is endogenously determined here and exogenously given in Stranlund (2007).

However, the regulator might be confronted with a political dilemma. Industry groups prefer compliant policies. In that case, standards should be relaxed and penalties should be linear. However, environmental groups may question the *polluter pays principle* and may prefer policies that make firms responsible for (most of) the damages caused. If the social pressure of these later groups is high, non-compliant policies composed of sufficiently progressive penalties and rather low standards should be implemented.

[16] Continuing with Example 1, for $m = 1$ and $t = 1$, a policy $\left[s = \frac{3}{2}, p = \frac{1}{4}\right]$ with a linear penalty $F(e-s) = 2(e-s)$ induces compliance and it is socially preferred, since there are no sanctioning costs.

6 Conclusions

In this paper, we have studied optimal policies composed of pollution standards, inspection probabilities and sanctions dependant both on gravity and non-gravity-based components. From a strict social point of view, the optimal policy consists of a standard above the pollution level which minimizes the sum of abatement costs and external damages, the minimum probability needed to induce compliance and a linear gravity sanction.

We have also characterized the policies which induce non-compliance. As long as sanctioning costs are sufficiently low, the optimal standard is below the pollution level which minimizes the sum of abatement costs and external damages and the penalty is sufficiently progressive in the degree of non-compliance. Fixed sanctions should not be imposed, since they only cause sanctioning costs but no change in firms' behavior.

Non-compliant policies agree with the *polluter-pays-principle*, and can be justified on political grounds. Some recent settlements seem to be consistent with our findings, where almost all the penalty is gravity-based. In January 2007, M.G. Waldbaum Company agreed to pay a $1 million penalty to resolve Clean Water Act violations and around $16 million to construct a wastewater treatment plant. In September 2006, the EPA and Pflueger reached a settlement of over $7.5 million, $5.3 of which were expenses in environmental improvement projects associated with Pflueger's company activities in Hawaii.

Non-compliance can be surely justified in a dynamic context, where firms also decide to invest in new technologies. Non-compliant policies create incentives to invest, since firms' expected costs are larger. Information imperfections such as inaccurate monitoring can be alternative causes. All these considerations are left for further research.

7 Appendix

Proof of Lemma 1. The Lagrangian of (1) is $L(e,\kappa) = c(e) + pF(e-s) - \kappa(e-s)$, where $\kappa \geq 0$ is the Kuhn-Tucker multiplier. The optimality conditions are $c'(e) + pf'(e-s) - \kappa = 0$; $\kappa(e-s) = 0$; $\kappa \geq 0$; and $e - s \geq 0$.[17]

First consider $F_0 = 0$ and $\kappa \geq 0$, $e = s$. Then, $\kappa = c'(s) + pf'(0) \geq 0$. If this does not hold, then $\kappa = 0$ and $e = n$, such that $c'(n) + pf'(n-s) = 0$. If $F_0 > 0$, $e(s,p) = s$ as long as $c(s) \leq c(n) + pF(n-s)$, and $e(s,p) = n$, otherwise.

Proof of Proposition 1. To prove the result, we find the condition under which the induced pollution level converges to s. The Lagrangian of the problem is $L(s,p,\lambda,\mu_i) = c(e) + d(e) + pm + ptF(e-s) + \lambda\{c'(e) + pf'(e-s)\} - \mu_1(e-s) - \mu_2 s$.

The optimality conditions with respect to (n,s,p) are, respectively, the following:[18]

$$[c'(n) + d'(n) + tpf'] + \lambda[c''(n) + pf''] - \mu_1 = 0 \tag{14}$$

$$m + tF + \lambda f' = 0 \tag{15}$$

$$\mu_1 - \mu_2 - tpf' - \lambda pf'' = 0 \tag{16}$$

$$\mu_1(n-s) = 0;\ \ \mu_2 s = 0. \tag{17}$$

The induced pollution level converges to s when $\mu_1 \geq 0$ and $\mu_2 \geq 0$. Combining (15) and (16), and substituting n by s, we have $\mu_2 - \mu_1 = -tpf'(0) + \frac{m+tF_0}{f'(0)}pf''(0) \geq 0$. Since $n = s$ and $n > 0$, we then have $\mu_2 = 0$. Thus, $\mu_1 \geq 0$ implies $-tpf'(0) + \frac{m+tF_0}{f'(0)}pf''(0) \leq 0$.

[17] These conditions are necessary and sufficient for an optimum, since the objective function is strictly convex and the inequality constraint is linear in e. Sufficient conditions are also guaranteed in the regulator's optimality problem, below.

[18] For analytical convenience, we consider the pollution level as a choice variable of the regulator, although this variable is decided by the firm in response to the regulatory policy, as noted in (3). The problem we consider here is mathematically equivalent to the one where the regulator chooses (s,p) knowing that the firm chooses $n = e(s,p)$ in response to the policy.

Proof of Proposition 2. The result is easily obtained from (7), substituting $e(s,p) = s$ and $p = p(s)$ given by (6).[19]

Proof of Proposition 3. The result follows considering the case where $\mu_1 = 0$ (i.e., $n > s$) and combining the conditions (14) to (17), such that $\mu_2 \geq 0$.

Proof of Proposition 4. From (13), we have $F'(e-s) = f'(e-s) \simeq f'(0) + f''(0)(e-s)$ and $F''(e-s) = f''(e-s) \simeq f''(0)$.

If the optimal policy induces compliance, fines are not collected and, consequently, there are sanctioning costs. Therefore, the larger the fines, the lower the probability (see (6)) and, consequently, the lower the social costs. If $F_0 > 0$, once an exogenous limit of the fine has been achieved, it is not possible to decrease social costs changing the penalty, since $p = \frac{c(s)-c(n)}{F_0+f(n-s)}$. Conversely, if $F_0 = 0$, the optimal probability is $p = -\frac{c'(s)}{f'(0)}$. Therefore, the optimal fine is one where $f'(0)$ is as high as possible and $f''(0)$ is as low as possible, since only the first component affects the probability.

If the optimal policy induces non-compliance, from the Lagrangian of Proposition 1, then $F_0 = 0$. The fine is kept constant as long as $df'(0) + \frac{n-s}{2} df''(0) = 0$. Differentiating the Lagrangian of of Proposition 1 with respect to $f'(0)$ and $f''(0)$, and considering the relationship between the two gravity components, we obtain:

$$\begin{aligned}
\frac{dL}{df'(0)} &= \frac{\partial L}{\partial f'(0)} + \frac{\partial L}{\partial f''(0)} \frac{df''(0)}{df'(0)} = \\
&= p\{t(n-s) + \lambda\} df'(0) - p\{t(n-s) + 2\lambda\} df'(0) = \\
&= -\lambda p df'(0) > 0,
\end{aligned}$$

since $\lambda < 0$, see (15). Then, decreasing $f'(0)$ and increasing $f''(0)$ reduces social costs.

[19] For simplicity, we assume that the solution for the probability of inspection is interior, i.e., $p^* \in (0,1)$. This remains valid in Proposition 3, below.

References

[1] Amacher,G.S. and A.S. Malik (1996), “Bargaining in Environmental Regulation and the Ideal Regulator”, *Journal of Environmental Economics and Management*, 30, 233-253.

[2] Arguedas, C. (2005), “Bargaining in Environmental Regulation Revisited”, *Journal of Environmental Economics and Management*, 50, 422-433.

[3] Arguedas, C. and H. Hamoudi (2004), “Controlling Pollution with Relaxed Regulations”, *Journal of Regulatory Economics*, 26, 85-104.

[4] Bebchuk, L.A. and L. Kaplow (1991), “Optimal Sanctions when Individuals are Imperfectly Informed about the Probability of Apprehension”, Discussion Paper 4/91, Harvard Law School.

[5] Becker, G.S. (1968), “Crime and Punishment: an Economic Approach”, *Journal of Political Economy*, 76, 169-217.

[6] Bose, P. (1993), "Regulatory Errors, Optimal Fines and the Level of Compliance", *Journal of Public Economics*, 56, 475-484.

[7] Cohen, M.A. (1999), "Monitoring and Enforcement of Environmental Policy", in: H. Folmer, T. Tietemberg (Eds.), *The International Year-book of Environmental Resource Economics 1999/2000*, Edward Elgar Publishing.

[8] Downing, P.B., and W.D. Watson (1974), "The Economics of Enforcing Air Pollution Controls", *Journal of Environmental Economics and Management*, 1, 219-236.

[9] Ellis, G.M. (1992), "Incentive Compatible Environmental Regulations", *Natural Resource Modelling*, 6, 225-255.

[10] Harford, J.D. (1978), "Firm Behavior Under Imperfectly Enforceable Pollution Standards and Taxes." *Journal of Environmental Economics and Management* 5, 26-43.

[11] Harrington, W. (1988), "Enforcement Leverage When Penalties Are Restricted", *Journal of Public Economics* 37, 29-53.

[12] Harrington, W. (2003), "Regulating Industrial Water Pollution in the United States", Discussion Paper 03-03, Resources for the Future.

[13] Heyes, A.G. (1996), "Cutting Environmental Policies to Protect the Environment", *Journal of Public Economics* 60, 251-265.

[14] Heyes, A.G. (2000), "Implementing Environmental Regulation: Enforcement and Compliance", *Journal of Regulatory Economics* 17, 107-129.

[15] Kambhu, J. (1989), "Regulatory Standards, Noncompliance and Enforcement", *Journal of Regulatory Economics* 1, 103-114.

[16] Livernois, J. and C.J. McKenna (1999), "Truth or Consequences: Enforcing Pollution Standards with Self-Reporting", *Journal of Public Economics* 71, 415-440.

[17] Malik, A.S. (1990a), "Avoidance, Screening and Optimum Enforcement", *The RAND Journal of Economics* 21, 341-353.

[18] Malik, A.S. (1990b), "Markets for Pollution Control When Firms are Noncompliant", *Journal of Environmental Economics and Management* 18, 97-106.

[19] Montero, J.P. (2002), "Prices versus Quantities with Incomplete Enforcement", *Journal of Public Economics* 85, 435-454.

[20] Polinsky, A.M. and S. Shavell (1979), "The Optimal Trade-Off Between the Probability and the Magnitude of the Fines", *American Economic Review* 69, 880-891.

[21] Polinsky, A.M. and S. Shavell (1991), "A Note on Optimal Fines when Wealth Varies Among Individuals", *American Economic Review* 81, 618-621.

[22] Polinsky, A.M. and S. Shavell (2000), "The Economic Theory of Public Enforcement of Law", *Journal of Economic Literature* 38, 45-76.

[23] Segerson, K. and T. Tietenberg (1992), "The Structure of Penalties in Environmental Enforcement: An Economic Analysis", *Journal of Environmental Economics and Management* 23, 179-200.

[24] Stranlund, J.K. (2007), "The Regulatory Choice of Noncompliance in Emission Trading Programs", *Environmental and Resource Economics*, *forthcoming*.

[25] Stranlund, J.K. and C.A. Chavez (2000), "Effective Enforcement of a Transferable Emissions Permit System with a Self-Reporting Requirement", *Journal of Environmental Economics and Management* 18, 113-131.

[26] Stranlund, J.K. and K.K. Dhanda (1999), "Endogenous Monitoring and Enforcement of a Transferable Emissions Permit System", *Journal of Environmental Economics and Management* 38, 267-282.