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Environmental policy as a multi-task principal-agent problem

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Abstract

We use a multi-task principal-agent model with moral hazard to study environmental regulation of a private agent by an EPA that can also allocate its budget to an alternative project with environmental benefits.

In a first possible optimum, the EPA imposes a flat fine that exhausts the agent's participation constraint. In the second, the EPA provides the harshest possible punishment for a "poor" observed environmental performance and the highest possible reward for a "good" observed environmental performance. Increases in the available budget and in the maximally allowed penalty have then an ambiguous effect on total environmental quality.

JEL: D23, D82, K00, Q28

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1 Introduction

When policy-makers started introducing the first environmental taxes, economists discovered that these taxes had very little connections with the textbook ideal. According to Bressers and Huitema [2], for instance:

> (...) most of the levies actually introduced are not intended to achieve a change in behavior, but to generate revenues (...) there is seldom a clear relation between the amount of the sum to be paid and the targeted behavior. Waste tariffs for household, for instance, usually do not vary in proportion to the amount of waste produced.

Recent OECD data [11] confirm that environmental taxes are more often than not earmarked for environmental projects undertaken by the public authorities.

In this paper, we provide a new possible rationale for this observation. At the same time, we aim to provide a new step towards a theory of environmental regulation under asymmetric information. In particular, we focus on the case when the environmental regulator has to distribute his financial resources according to a specific budget and is restricted to make his policy contingent on the *environmental* quality performance only of the parties subject to its regulation.

This latter objective needs some words of explanation.

In the theory of environmental regulation, it is a standard approach to consider the government as a unique, benevolent agency in charge of many different and possibly conflicting regulatory dimensions (environmental costs, producer and consumer surplus, enforcement costs, etc). However, in real life, division of labor is an important feature of government agencies. Rationales for this division of labor have been provided by, for instance, Martimort [8] and Laffont and Martimort [7]. According to these authors, limiting the scope of a regulator's authority may be an optimal response to possible non-benevolence or capture. Martimort [9] has also argued that the separation of power between regulators helps a government to commit.

In this paper, we consider the problem of effort allocation by a (public or private) agent who divides its effort between two tasks: on the one hand, environmental protection, and on the other hand a task that brings only private benefits. The Environmental Protection Agency, EPA, has a fixed budget, that can be used either in order to provide incentives to the agent or for some alternative project undertaken directly by the EPA. Following the literature we just mentionned, we assume that the EPA is only allowed to provide incentives for environmental protecion, without taking other considerations into account.

A concrete example we might think of is the water policy in the Belgian region of Flanders. On the one hand, the Flemish government subsidizes the construction of collective sewerage and abatement installations. On the other hand, both households and firms are subject to water levies that are earmarked for environmental protection.[4] We shall show in the concluding remarks that

[4]The actual scheme is rather complicated, but this is essentially the philosophy behind it - details are available from the authors on request.

our results are coherent with this real life example.

The central result of this paper is that, if the EPA cannot observe the agent's allocation of effort amongst the two tasks, then there are two possible equilibria. In the first possible equilibrium, the agent implements the unregulated effort levels. The EPA imposes the highest lump sum tax that satisfies the agent's participation constraint, and uses the tax receipts to finance its own project. In the second possible equilibrium, the EPA imposes the harshest punishment for any observed environmental performance whose likelihood of observation is decreasing in environmental effort, and transfers its entire budget for any observed environmental performance whose likelihood of observation is increasing in environmental effort. This induces the agent to undertake the highest implementable level of environmental effort, and the lowest possible level of effort on its core tasks. Furthermore, we show that, under plausible assumptions about the cost of effort, the EPA bribes the agent to impose zero effort in its core task if the absolute value of the allowed side payment is high enough.

Technically, we will develop a multi-task principal-agent problem with moral hazard.

This model is closely linked to Holmström's and Milgrom's analysis of incentive contracts and job design in multitask settings [4].[5]

One of the important topics in Holmström and Milgrom is "how a firm might optimally set policies limiting personal business activities on company time". Formally speaking, in our model, the agent's core task is such an "outside" activity from the EPA's point of view: it brings no benefits to the EPA, it affects the marginal cost of environmental protection, and it brings private benefits to the agent. In Holmström and Milgrom [4], the principal has the authority to exclude some or all outside activities. In Section 4 of their paper, it is shown that, depending on the parameters, it might be optimal to allow *some* outside activities but to exclude others. More specifically, they show (Proposition 3) that the agent's freedom to pursue private goals increases when his marginal reward in the main job (this is, the job that brings benefits to the principal) increases.

How does this compare with our analysis?

In the context of our model, the approach proposed by Holmström and Milgrom wouldn't make sense: an EPA definitely does not have the power to *prohibit* the core task of an agent. However, as we just mentioned, in our model, in one possible optimum, the EPA will provide incentives to limit these productive activities as much as possible. On the other hand, we also see that the EPA may choose not to affect the productive activity at all.

[5] Milgrom and Roberts [10] provides an even earlier analysis of multitasking. However, their model considers a very specific problem where employees "can devote time and attention either to increasing output in their current assignments or to establishing their qualifications" for a key job within the organization that needs to be filled. The problem for the organization is then that "it cannot determine whether observed differences in qualifications reflect actual differences in the employees' expected productivities in the key job or are merely the result of one of them having devoted too much time to building his credentials". This is definitely not the problem we are considering here.

Thus, although the EPA does certainly not have the same discretionary power as a firm's owners, the effects of its incentive scheme can be close to what a firm's owner might impose.

2 Presentation of the model

We will now move on to describe our formal model.

Technically, we follow closely the setting chosen by Sinclair-Desgagné [13], and we refer to that paper for more detailed arguments - it can be verified that our conclusions do not depend on these technical details.

Formally, we consider the problem of effort allocation by a (public or private) agent. This agent (which, in the remainder of the analysis, will be considered as a monolithic bloc) must divide its effort between two tasks, A and B. An effort level a on A results in an output α_i where $i = 1, \ldots, I$ and α_i is increasing in its index. The likelihood of observing output α_i when the agent delivers an effort a is written $p_i(a)$. The agent's effort on B is noted b and results in an output level β_j where $j = 1, 2, \ldots, J$ and β_j increases in j. The likelihood of observing output β_j when the agent delivers an effort b is written $q_j(b)$.

We shall assume that the agent is only concerned with performance on task B. In a private firm, an obvious candidate for task B would be corporate profits. If the agent is a public organization, the logic of the division of labor inside government we have described in the introduction implies that task B is the unique core task of the agent.

However, there exists an outside principal, the Environmental Protection Agency, EPA, who only cares about performance on task A, which we interpret as environmental performance. We shall assume here that the EPA is the only regulatory institution that is affected by the agent's activities.

The functions $p_i(a)$ and $q_j(b)$ are assumed to be strictly positive and twice continuously differentiable in (a, b); they are also supposed to be independently distributed. Of course, $\sum_{i=1}^{I} p_i(a) = 1$ and $\sum_{j=1}^{J} q_j(b) = 1$.

Thus, $\sum_j q_j(b)\, \beta_j$ is expected performance on the agent's core task, and $\sum_i p_i(a)\, \alpha_i$ is expected environmental performance.

For reasons that will become clear later in the paper, we assume that the conventional monotone likelihood ratio property (MLRP) holds strictly:

Assumption 1 *The ratios* $\frac{\frac{dp_i(a)}{da}}{p_i(a)}$ *and* $\frac{\frac{dq_j(b)}{db}}{q_j(b)}$ *are increasing in* i *and* j*.*

The standard interpretation of this assumption is that the higher α_i (β_j), the higher the likelihood that the agent has chosen a high value of a (resp. b).

It can be shown that strict MLRP implies strict first-order stochastic dominance (SDC). Strict SDC means that for all $i_1 = 0, 1, \ldots, I$, $\sum_{i=i_1}^{I} \frac{dp_{i_1}(a)}{da} > 0$ (resp. that for all $j_1 = 0, 1, \ldots, J$, $\sum_{j=j_1}^{J} \frac{dq_{j_1}(b)}{db} > 0$) where $\sum_{i=i_1}^{I} p_{i_1}(a)$ (resp. $\sum_{j=j_1}^{J} q_{j_1}(b)$) is the cumulative distribution function of α_i (resp. β_j) conditionally on effort level a (resp. b). In words, first-order stochastic dominance means that the cumulative distribution function of α and β moves to the right when a or b increase.

Finally, strict MLRP implies that there exists an $i^* \in]0, I[$ such that for all $i < i^*$, $\frac{dp_i(a)}{da} < 0$ and for all $i > i^*$, $\frac{dp_i(a)}{da} > 0$ (and where $\frac{dp_{i^*}(a)}{da} \geq 0$). Similarly, there exists a $j^* \in]0, J[$ such that for all $j < j^*$, $\frac{dq_j(b)}{db} < 0$ and for all $j > j^*$, $\frac{dq_j(b)}{db} > 0$ (and where $\frac{dq_{j^*}(b)}{db} \geq 0$).

$c(a, b)$ is the agent's cost of effort. It is assumed to be positive, strictly convex and twice continuously differentiable. Thus, $\frac{\partial^2 c(.)}{\partial a^2} > 0$, $\frac{\partial^2 c(.)}{\partial b^2} > 0$ and $\frac{\partial^2 c(.)}{\partial a^2}\frac{\partial^2 c(.)}{\partial b^2} - (\frac{\partial^2 c(.)}{\partial a \partial b})^2 > 0$. There is strict substitutability (supermodularity) in effort: $\frac{\partial^2 c(.)}{\partial a \partial b} > 0$ for all a and b. Thus, a higher effort on one task raises the marginal cost of effort on the other task. Finally, we assume that the agent has no intrinsic motivation at all for environmental protection : $\frac{\partial c(.)}{\partial a} > 0$ for all a and b - we introduce no prior restrictions on the sign of $\frac{\partial c(.)}{\partial b}$.

We want now to investigate how the EPA can affect the agent's incentives to allocate his efforts between the two tasks.

We assume that the EPA has a fixed budget Y. This budget can be used either in order to provide a side payment $y_{i,j}$ (that depends on observed performance) or for some alternative project. We assume that this alternative project is under perfect control by the EPA[6] and brings therefore certain environmental benefits $EB(.)$. These benefits are assumed to be strictly increasing and concave in the sums allocated to this alternative project. Thus: $(EB(.))' > 0$ and $(EB(.))'' < 0$. Finally, if no money is allocated to the alternative project, then it brings no environmental benefit: $EB(0) = 0$.

We impose no prior restrictions on the sign of $y_{i,j}$. Thus, if $y_{i,j} < 0$, then the EPA imposes a penalty and she has now more money to spend on her alternative project.[7] If $y_{i,j} > 0$, then the EPA provides a side payment and there is less money available for the alternative project. However, in both cases, the assumptions with respect to the first and the second derivative are plausible. Finally, we suppose that there are institutional constraints such that $-x_{min}$ is the upper limit to the fines that the EPA can impose on the regulated agent (or such that x_{min} is the minimal transfer).

The structure of the paper is as follows.

First, we analyze the agent's payoff function and optimality conditions for arbitrary contingent financial transfers (Section 3).

Next, we consider the first-best solution with observable effort (Section 4). In this case, we have a situation of incomplete but symmetric information. This means, on the one hand, that a and b can be costlessly observed (and thus that contracts written as a function of a and b are perfectly enforceable in court)

[6]This is an extreme representation of the plausible assumption that the EPA has better information with respect to this alternative project than with respect to the agent's effort allocation.

[7]Alternatively, this fine could just dissappear in the general budget of the government - this possibility is the subject of ongoing research by the authors.

and on the other hand that $p_i(a)$ and $q_j(b)$ are common knowledge. Under this scenario, we obtain the standard result that the EPA chooses the contingent payment schedule and the effort levels that maximize the joint payoffs.

However, in reality, it seems reasonable to assume that the EPA can observe the output vectors, but cannot observe the effort levels (Section 5). Following the suggestion we mentioned in the introduction, we shall now assume that the EPA is only allowed to base its incentive schemes on observed environmental performance. Thus, when the EPA has observed α_i, the agent receives a (possibly negative) payment x_i. We then go on to prove the central result we already mentioned in Section 1.

3 The agent's problem

Let us now look into the agent's objective function.

In order to abstract from any distortion that might arise from other sources than the multi-tasking nature of the problem at hand, we suppose that the agent is risk-neutral.

If the agent receives a monetary payoff y_{ij}, contingent on the realization of α_i and β_j, then its expected payoff is:

$$EP_o = \sum_j q_j(b)\,\beta_j + \sum_{i,j} p_i(a)\,q_j(b)\,y_{ij} - c(a,b)$$

The effort levels chosen by the agent must thus satisfy:

$$\frac{\partial EP_o}{\partial a} = \sum_{i,j} \frac{dp_i(a)}{da}\,q_j(b)\,y_{ij} - \frac{\partial c(a,b)}{\partial a} \leq 0 \quad a \geq 0 \quad \frac{\partial EP_o}{\partial a} a = 0 \tag{1}$$

$$\frac{\partial EP_o}{\partial b} = \sum_{i,j} p_i(a)\,\frac{dq_j(b)}{db}\,(y_{ij} + \beta_j) - \frac{\partial c(a,b)}{\partial b} \leq 0 \quad b \geq 0 \quad \frac{\partial EP_o}{\partial b} b = 0 \tag{2}$$

In general, this objective function is not concave with respect to a and b.

Therefore, following Sinclair-Desgagné [13], we assume from now on the generalized concavity of the distribution function of expected benefits (CDFC) to hold, this is:

Assumption 2 *The matrices $G_{a,b}$ of second-order derivatives of the functions:*

$$G(i,j|a,b) = \sum_{t=j}^{J} \sum_{k=i}^{I} q_t(b)\,p_k(a)$$

are negative semi-definite for all i,j and for all a,b.

The convexity of $c(a, b)$ and generalized CDFC then imply concavity of the agent's objective function with respect to a and b, and thus:

Lemma 1 *For a given contingent monetary payoff schedule y_{ij}, the effort levels chosen by the agent are given by Conditions 1 and 2.*

4 Efficient solution

If efforts levels were observable, then the EPA would provide a contingent payment schedule $y_{i,j}$ ($\sum_{i,j} p_i(a)\, q_j(b)\, y_{i,j}$ is then expected financial transfers to the agent) and demand effort levels a and b such that:

$$\text{maximize}_{y_{i,j};a,b} \quad \text{ES} = \sum_i p_i(a)\, \alpha_i + \sum_{i,j} p_i(a)\, q_j(b)\, EB(Y - y_{i,j}) \tag{3}$$

subject to

$$\sum_j q_j(b)\, \beta_j + \sum_{i,j} p_i(a)\, q_j(b)\, y_{ij} - c(a, b) \geq U^* \tag{4}$$

where Condition 4 is the participation constraint: given the contingent wage schedule $y_{i,j}$ and demanded effort levels a and b, the agent will only participate if its expected utility is higher than the reservation utility U^* that it can get by opting out.

Let γ^P_{ES} be the Lagrange multiplier associated with this participation constraint.

Let us also assume that Y and the absolute value of x_{min} allow for an interior solution for $y_{i,j}$.

For a given a and b, the FOC with respect to $y_{i,j}$ is:

$$\frac{\partial \mathcal{L}_{ES}}{\partial y_{i,j}} = p_i(a)\, q_j(b)\, \frac{d\, EB(Y - y_{i,j})}{d\, y_{i,j}} + \gamma^P_{ES}\, p_i(a)\, q_j(b) \quad = \quad 0 \tag{5}$$

The FOC with respect to $y_{i,j}$ can be rewritten as:

$$\gamma^P_{ES} \quad = \quad -\frac{d\, EB(Y - y_{i,j})}{d\, y_{i,j}} \tag{6}$$

$\frac{d\, EB(Y - y_{i,j})}{d\, y_{i,j}} < 0$ implies that $\gamma^P_{ES} > 0$: the participation constraint must be binding, which is a completely standard result in the case with observable effort. As, moreover, the environmental benefit is strictly concave in the sums allocated to it, Equation 6 implies that $y_{i,j}$ *must* be a constant.

The optimal wage y^* is then such that the participation constraint is binding:

$$y^* \quad = \quad c(a, b) + U^* - \sum_j q_j(b)\, \beta_j \tag{7}$$

Because y^* is a constant, substitution of Equation 7 in 3 gives:

$$\sum_i p_i(a)\,\alpha_i + EB(Y + \sum_j q_j(b)\,\beta_j - c(a,b) - U^*) \tag{8}$$

The efficient effort levels (a^{ES}, b^{ES}) must then satisfy the following first-order conditions:

$$\frac{\partial ES}{\partial a} = \sum_i \frac{dp_i(a)}{da}\,\alpha_i - EB'\,\frac{\partial c(a,b)}{\partial a} \leq 0 \quad a \geq 0 \quad \frac{\partial ES}{\partial a} a = 0 \tag{9}$$

$$\frac{\partial ES}{\partial b} = EB'\{\sum_j \frac{dq_j(b)}{db}\,\beta_j - \frac{\partial c(a,b)}{\partial b}\} \leq 0 \quad b \geq 0 \quad \frac{\partial ES}{\partial b} b = 0 \tag{10}$$

The strict concavity of EB, the convexity of $c(a,b)$ and generalized CDFC then imply concavity of the efficient objective function with respect to a and b. Therefore, the first-best effort levels (a^{ES}, b^{ES}) are given by Conditions 9 and 10.

Of course, Conditions 9 and 10 simply state that, in an interior solution, marginal benefits should equal marginal costs. Just note that the marginal cost of environmental protection is the product of two marginal costs: the marginal cost of taking sums away from the alternative project, EB', and the marginal cost of effort $\frac{\partial c(a,b)}{\partial a}$.

A natural question to ask here is whether anything can be said on the relation between the point that the agent would choose in the absence of regulation (a^o, b^o) and the efficient solution (a^{ES}, b^{ES}).

As there is no intrinsic motivation at all to undertake environmental effort, complementary slackness in Condition 1 implies that without regulation, $a = 0$. Thus, we are certain that $a^{ES} > a^o$.

However, nothing can be said on the relation between b^{ES} and b^o: the agent's unregulated effort on his core task can be both smaller or larger than the social optimum.

5 The noncooperative game

We now impose that the EPA cannot provide any side payment that depends on task B (neither on the exerted effort nor on the output). However, when the EPA has observed α_i, the agent receives a (possibly negative) payment x_i.

Let (a_{NG}, b_{NG}) be the optimal values of (a,b) under the noncooperative game.

We can now immediately make the following observation:

Lemma 2 *If an increase (a decrease) in effort on task A leads to a higher probability of observing α_i, then an increase (a decrease) of the payment the* *agent receives when α_i is observed, will lead the agent to implement a higher effort on task A, and to implement a lower effort on task B.*

Proof

Conditions 1 and 2 define (a_{NG}, b_{NG}) as an implicit function of the wage schedule x_i offered by the EPA.

Suppose we have an interior solution for (a_{NG}, b_{NG}). As x_i does not depend on j, the agent's FOC can be simplified to:

$$\frac{\partial EP_o}{\partial a} = \sum_i \frac{dp_i(a)}{da} x_i - \frac{\partial c(a,b)}{\partial a} = 0 \tag{11}$$

$$\frac{\partial EP_o}{\partial b} = \sum_j \frac{dq_j(b)}{db} \beta_j - \frac{\partial c(a,b)}{\partial b} = 0 \tag{12}$$

Take the total differential of this system of equations:

$$\begin{aligned} \frac{\partial^2 EP_o}{\partial a^2} da + \frac{\partial^2 EP_o}{\partial a \partial b} db + \sum_i \frac{dp_i(a)}{da} dx_i &= 0 \\ \frac{\partial^2 EP_o}{\partial b^2} db + \frac{\partial^2 EP_o}{\partial a \partial b} da + \sum_j \frac{dq_j(b)}{db} d\beta_j &= 0 \end{aligned}$$

or, in matrix form:

$$\begin{pmatrix} \frac{\partial^2 EP_o}{\partial a^2} & \frac{\partial^2 EP_o}{\partial a \partial b} \\ \frac{\partial^2 EP_o}{\partial a \partial b} & \frac{\partial^2 EP_o}{\partial b^2} \end{pmatrix} \begin{pmatrix} da \\ db \end{pmatrix} = -\begin{pmatrix} \frac{dp_1(a)}{da} & \dots & \frac{dp_I(a)}{da} & 0 & \dots & 0 \\ 0 & \dots & 0 & \frac{dq_1(b)}{db} & \dots & \frac{dq_J(b)}{db} \end{pmatrix} \begin{pmatrix} dx_1 \\ \dots \\ dx_I \\ d\beta_1 \\ \dots \\ d\beta_J \end{pmatrix}$$

From the implicit function theorem, we see that:

$$\frac{\partial a}{\partial x_i} = -\frac{\begin{vmatrix} \frac{dp_i(a)}{da} & \frac{\partial^2 EP_o}{\partial a \partial b} \\ 0 & \frac{\partial^2 EP_o}{\partial b^2} \end{vmatrix}}{\begin{vmatrix} \frac{\partial^2 EP_o}{\partial a^2} & \frac{\partial^2 EP_o}{\partial a \partial b} \\ \frac{\partial^2 EP_o}{\partial a \partial b} & \frac{\partial^2 EP_o}{\partial b^2} \end{vmatrix}} = -\frac{\frac{dp_i(a)}{da}\frac{\partial^2 EP_o}{\partial b^2}}{\begin{vmatrix} \frac{\partial^2 EP_o}{\partial a^2} & \frac{\partial^2 EP_o}{\partial a \partial b} \\ \frac{\partial^2 EP_o}{\partial a \partial b} & \frac{\partial^2 EP_o}{\partial b^2} \end{vmatrix}} \tag{13}$$

The concavity of EP_o implies that $\frac{\partial^2 EP_o}{\partial b^2} < 0$ and that:

$\begin{vmatrix} \frac{\partial^2 EP_o}{\partial a^2} & \frac{\partial^2 EP_o}{\partial a \partial b} \\ \frac{\partial^2 EP_o}{\partial a \partial b} & \frac{\partial^2 EP_o}{\partial b^2} \end{vmatrix} > 0$. Therefore, we obtain that $\frac{\partial a}{\partial x_i} > 0$ iff $\frac{dp_i(a)}{da} > 0$.
On the other hand,

$$\frac{\partial b}{\partial x_i} = -\frac{\begin{vmatrix} \frac{\partial^2 EP_o}{\partial a^2} & \frac{\partial p_j(a)}{\partial a} \\ \frac{\partial^2 EP_o}{\partial a \partial b} & 0 \end{vmatrix}}{\begin{vmatrix} \frac{\partial^2 EP_o}{\partial a^2} & \frac{\partial^2 EP_o}{\partial a \partial b} \\ \frac{\partial^2 EP_o}{\partial a \partial b} & \frac{\partial^2 EP_o}{\partial b^2} \end{vmatrix}} = \frac{\frac{dp_i(a)}{da} \frac{\partial^2 EP_o}{\partial a \partial b}}{\begin{vmatrix} \frac{\partial^2 EP_o}{\partial a^2} & \frac{\partial^2 EP_o}{\partial a \partial b} \\ \frac{\partial^2 EP_o}{\partial a \partial b} & \frac{\partial^2 EP_o}{\partial b^2} \end{vmatrix}} \tag{14}$$

Supermodularity implies that $\frac{\partial^2 EP_o}{\partial a \partial b} = -\frac{\partial^2 c(a,b)}{\partial a \partial b} < 0$, and thus that $\frac{\partial b}{\partial x_i} < 0$ iff $\frac{dp_i(a)}{da} > 0$. □ QED □

Suppose now that the payment schedule is such that $x_i = x_{min}$ for all i such that $\frac{dp_i(a)}{da} < 0$ (thus, for $i < i^*$) and $x_j = Y$ otherwise. From Equation 13 (resp. Equation 14), it is clear that any allowed change in the payment structure will lead to a decrease in environmental effort (resp. increase in effort on the agent's core task). We thus obtain:

Lemma 3 *The agent's effort on environmental protection will be maximal (and its effort on its core task will be minimal) with the following payment schedule:* $x_i = x_{min}$ *for all* $i < i^*$ *and* $x_i = Y$ *otherwise.*

From this analysis, it also follows that the higher the EPA's budget and the higher the fines it can impose, the higher the maximal environmental *effort* (and the lower the minimal effort on the core task). However, we shall show below that, despite these unambiguous effects on effort, an increase in these parameters has an ambiguous effect on total environmental *quality*.

5.1 The "corner" nature of the solution

Anticipating the agent's choice of a_{NG} and b_{NG}, a rational EPA will set a contingent wage schedule x_i in order to maximize the expected difference between performance on task A and the cost of wage payments, such that the agent's objective function is at a maximum, and such that the agent is willing to participate.

A standard method for solving this kind of moral hazard asymmetric information problems is the so-called first-order approach, which consists in adding the agent's FOC as equality constraints to the EPA's maximization problem.

It is, however, only valid under specific assumptions. Sinclair-Desgagné [13] discusses these assumptions in the specific case of a multi-signal problem. MLRP and CDFC imply that the solution to the EPA's problem is given by the solution to the following maximization problem, if this solution does exist for $a > 0$ and $b > 0$:

$$EPA_{NG} = \sum_i p_i(a)(\alpha_i + EB(Y - x_i)) \qquad (15)$$

subject to $\frac{\partial EP_o}{\partial a} = 0$, $\frac{\partial EP_o}{\partial b} = 0$ and $\sum_j q_j(b)\, \beta_j + \sum_i p_i(a)\, x_i - c(a,b) \geq U^*$.

In order to verify whether this solution does indeed exist, we will add the following constraint. From Lemma 3, we know that the existence of a maximal penalty and the EPA's budget constraints imposes constraints on the possible values of b that are implementable. Let b^* be the smallest implementable value of b. Thus, b^* is the smallest value of $b \geq 0$ such that there exists a wage schedule for which $\frac{\partial EP_o}{\partial a} = 0$ and $\frac{\partial EP_o}{\partial b} = 0$.

Let γ^P_{NG} be the Lagrange multiplier associated with the participation constraint, while γ^a_{NG} is the Lagrange multiplier associated with $\frac{\partial EP_o}{\partial a} = 0$ and γ^b_{NG} is the Lagrange multiplier associated with $\frac{\partial EP_o}{\partial b} = 0$. γ_{b^*} is the Lagrange multiplier associated with the condition $b \geq b^*$, requiring b to be implementable. Finally, γ_i is the Lagrange multiplier associated with the EPA's budget constraint $Y \geq x_i$ and θ_i is the Lagrange multiplier associated with $x_i \geq x_{min}$.

The Lagrangian is then:

$$\begin{aligned}
\mathcal{L}^{NG}_{EPA} &= \sum_i p_i(a)(\alpha_i + EB(Y - x_i)) + \gamma^a_{NG}\frac{\partial EP_o}{\partial a} + \gamma^b_{NG}\frac{\partial EP_o}{\partial b} \\
&\quad + \gamma^P_{NG}\{\sum_j q_j(b)\, \beta_j + \sum_i p_i(a)\, x_i - c(a,b) - U^*\} \\
&\quad + \gamma_{b^*}\{b - b^*\} + \sum_i \gamma_i\{Y - x_i\} + \sum_i \theta_i\{x_i - x_{min}\} \qquad (16)
\end{aligned}$$

For a given a and b, the FOC with respect to x_i is:

$$\frac{\partial \mathcal{L}^{NG}_{EPA}}{\partial x_i} = p_i(a)\,\frac{dEB(Y - x_i)}{dx_i} + \gamma^a_{NG}\,\frac{dp_i(a)}{da} + \gamma^P_{NG}\, p_i(a) - \gamma_i + \theta_i = 0$$

If $x_{min} < x_i < Y$, then we have an interior solution, $\gamma_i = 0$, $\theta_i = 0$ and this condition can be rewritten as:

$$\gamma^P_{NG} + \gamma^a_{NG}\frac{\frac{dp_i(a)}{da}}{p_i(a)} = -\frac{dEB(Y - x_i)}{dx_i} \qquad (17)$$

It follows that:

Lemma 4 *If there exists a second-best solution where the agent exerts strictly positive environmental effort, then $\gamma^a_{NG} > 0$ and $\gamma^P_{NG} > 0$.*

This result can be proofed using the procedure developed by Jewitt [5] - see Appendix A for full details.

Strict MLRP also implies that $\frac{\frac{dp_i(a)}{da}}{p_i(a)}$ is increasing in i. Hence, the LHS of Equation 17 is increasing in i. $\frac{d^2EB}{dx_i^2} < 0$ implies then:

Lemma 5 *x_i is increasing in i*

This is a standard result (compare for instance, with Sinclair-Desgagné [13]).

Suppose now that there exists an i^{max} such that $x_{i^{max}-1} < Y \leq x_{i^{max}}$, where $x_{i^{max}-1}$ and $x_{i^{max}}$ are unconstrained solutions to Equation 17. This implies that for all $i \geq i^{max}$, the EPA's budget constraint is binding: the transfer is then independent of i. Similarly, there possibly is a cut-off level i_{min} such that $x_i = x_{min}$ for all $i \leq i_{min}$.

Let us now move to the conditions for the effort levels. If $a > 0$ and $b > 0$, then the FOC with respect to a and b are:

$$\frac{\partial \mathcal{L}_{EPA}^{NG}}{\partial a} = \sum_i \frac{dp_i(a)}{da}(\alpha_i + EB(Y - x_i)) + \gamma_{NG}^a \frac{\partial^2 EP_o}{\partial a^2} + \gamma_{NG}^b \frac{\partial^2 EP_o}{\partial a \partial b} + \gamma_{NG}^P \frac{\partial EP_o}{\partial a} \tag{18}$$

$$\frac{\partial \mathcal{L}_{EPA}^{NG}}{\partial b} = \gamma_{NG}^a \frac{\partial^2 EP_o}{\partial a \partial b} + \gamma_{NG}^b \frac{\partial^2 EP_o}{\partial b^2} + \gamma_{NG}^P \frac{\partial EP_o}{\partial b} + \gamma_{b^*} \tag{19}$$

Finally, the FOC with respect to γ_{b^*} are:

$$b \geq b^* \quad \gamma_{b^*} \geq 0 \quad \gamma_{b^*}\{b - b^*\} = 0 \tag{20}$$

Suppose now that we have an interior solution: $a > 0$ and $b > b^*$.

Complementary slackness in the FOC with respect to γ_{b^*} implies that $\gamma_{b^*} = 0$, while complementary slackness in the agent's FOC implies that $\frac{\partial EP_o}{\partial b} = 0$.

Supermodularity in effort implies that $\frac{\partial^2 EP_o}{\partial a \partial b} = -\frac{\partial^2 c(a,b)}{\partial a \partial b} < 0$. The concavity of the agent's objective function implies that $\frac{\partial^2 EP_o}{\partial b^2} < 0$. However, Sinclair-Desgagné [13] has shown that *if* the first-order approach can be used at all, then γ_{NG}^a and γ_{NG}^b must have the same sign.

Thus, if $a > 0$ and $b > b^*$, then Lemma 4 implies that $\frac{\partial \mathcal{L}_{EPA}^{NG}}{\partial b} < 0$ and the EPA's first-order conditions cannot be satisfied.

Therefore, an equilibrium is only possible for $a = 0$ or $b = b^*$.

Complementary slackness in the agent's FOC (Condition 1) implies that $\frac{\partial EP_o}{\partial a} < 0$ induces $a = 0$. This will certainly be the case if x_i is a constant, say X. The agent's objective function reduces then to: $\sum_j q_j(b)\,\beta_j + X - c(a, b)$. Thus, the agent will act as if there is no regulation at all, and will undertake effort levels $(0, b^o)$.

Note now that the agent will only participate in an unregulated economic activity if its expected net surplus of participation $\sum_j q_j(b^o)\,\beta_j - c(0, b^o) - U^*$ is nonnegative. Therefore, it seems reasonable to assume that $-x_{min} \leq$

$\sum_j q_j(b^o)\,\beta_j - c(0, b^o) - U^*$. Indeed, the alternative (an upper limit to the penalties that is higher than the maximal possible surplus) would not really make sense.

Therefore, the optimal side payment is the highest possible fine x_{min}. In this case, the payment has no incentive effect whatsoever.

The EPA's expected payoff is then:

$$\sum_i p_i(0)\,\alpha_i + EB(Y - x_{min}) \tag{21}$$

The other possible optimum is where $b = b^*$ and where a takes its maximal possible value a^*. The penalty structure then takes the form proposed in Lemma 3. The EPA's expected payoff is then:

$$\sum_i p_i(a^*)\,\alpha_i + EB(Y - x_{min}) \sum_{i<i^*} p_i(a^*) \tag{22}$$

Proposition 1 *If the EPA can provide the agent with a payment schedule that only depends on performance on task A, if the environmental benefit of the alternative project is strictly concave in the sums allocated to it, and if tasks A and B are substitutes in effort, then there are two possible optima:*

- *The EPA imposes a flat fine that exhausts the agent's participation constraint and the agent undertakes the effort levels that correspond to the "no-regulation" case.*
- *The EPA provides the payment schedule described in Lemma 3, and the agent provides the highest implementable environmental effort and the lowest possible implementable effort on its core task. This smallest implementable effort level b is possibly bounded away from zero.*

From (21) and (22), we see that the solution corresponding to the unregulated effort levels will be preferred if and only if:

$$EB(Y - x_{min}) \sum_{i \geq i^*} p_i(a^*) \quad > \quad \sum_i (p_i(a^*) - p_i(0))\,\alpha_i$$

This condition states that the solution corresponding to the unregulated effort levels will be preferred if and only if the environmental gains of higher expected budget for the EPA exceed the direct environmental gain of regulating the agent's environmental effort.

From this comparison, we can also understand the ambiguity of the role played by the EPA's budget (or the maximal allowed fine).

From (21), we see that in the unregulated case, the effect of an increase in the EPA's budget (or in the maximal allowed fine) is clear: it unambiguously leads to higher environmental quality. However, from (22), we see that with the penalty structure from Lemma 3, the effects are ambiguous. An increase in the EPA's budget increases the sum that are available, both for providing incentives to the agent, and for the alternative environmental project. However, if environmental effort increases, then the probability of observing high values of environmental performance increases, and thus also the probability that the EPA will not levy the fine, but will transfer its entire budget to the agent instead.

This ambiguity cannot be solved in general.

5.2 Sufficient conditions for the elimination of the agent's core activity

Although the effect of a higher budget (or higher maximal fines) on total environmental performance is ambiguous, its effect on the agent's effort levels is very clear.

Indeed, remember that in the payment schedule proposed in Lemma 3: $x_i = x_{min}$ for all i such that $\frac{dp_i(a)}{da} < 0$ and $x_i = Y$ otherwise.

Equation 11 reduces then to:

$$x_{min} \sum_{i<i^*} \frac{dp_i(a)}{da} + Y \sum_{i \geq i^*} \frac{dp_i(a)}{da} \quad = \quad \frac{\partial c(a,b)}{\partial a} \tag{23}$$

It is clear that without a lower limit to the fines that can be imposed, *and* an upper limit to the EPA's budget, the LHS of this Equation can be made to grow into infinity. However, the RHS must then also grow into infinity, for any value of b. From the properties of the cost function, $\frac{\partial c(a,b)}{\partial a} \to \infty$ for any value of b, requires $a \to \infty$ as well.

Suppose now that $\lim_{a\to\infty} \frac{\partial c(a,0)}{\partial b} = \infty$ as well. This condition means that for very high values of environmental effort, the marginal cost of undertaking the agent's core tasks increases without bounds. Thus, if a is large enough, then $\frac{\partial c(a,b)}{\partial b} > \sum_j \frac{dq_j(b)}{db} \beta_j$ for all b.

However, from Condition 2, the agent will choose $b = 0$ if, for all $b \geq 0$:

$$\sum_j \frac{dq_j(b)}{db} \beta_j - \frac{\partial c(a^*,b)}{\partial b} \quad < \quad 0 \tag{24}$$

Thus, we have shown that there exist conditions for which the EPA will induce zero effort level on task B, thus for which $b^* = 0$.

Proposition 2 *If the EPA's budget (or the maximal allowed penalties) can grow without limits and if* $\lim_{a\to\infty} \frac{\partial c(a,0)}{\partial b} = \infty$*, then, in the regulated optimum, the EPA will induce the agent to require zero effort on task B and a larger than efficient effort on task A.*

The result we obtain here implies a complete collapse of any economic activity that does not contribute to environmental performance - it is particularly striking because the payments only depend on α_i!

Holmström and Milgrom [4] provide some intuition for this result: "when inputs are substitutes, incentives for any given activity t_i can be provided either by rewarding that activity or by reducing its opportunity cost (by reducing the incentives for the other activities)". If there are upper limits, but no lower limits to the financial transfer, then the EPA is unlimited in the penalties it can impose for very low observed environmental performance. On the other hand, if there are lower limits, but no upper limits, then the EPA is unlimited in the rewards it can give for high observed environmental performance. As the effort levels are substitutes in the cost function, this means that in both cases, the EPA can increase the expected cost of positive effort on the core task without limits.

This result is of course not credible: how could the EPA bribe all the other actors in society not to undertake their core tasks? However, it shows the importance of imposing the right constraints on government agencies.

6 Conclusion

We have considered the regulation of a (private or public) agent by an EPA. This EPA is constrained to basing its incentive schemes (both rewards and punishments) on environmental performance, and can also allocate funds to an alternative project with environmental benefits.

The private agent can allocate its efforts either to environmental protection or to its core tasks. If these two tasks are substitutes in effort, then there are two possible optima:

- The EPA imposes a flat fine that exhausts the agent's participation constraint and the agent undertakes the effort levels that correspond to the "no-regulation" case. This flat fine is then used completely to finance the alternative project.
- The EPA provides the harshest possible punishment for any observed environmental performance whose likelihood of observation is decreasing in environmental effort and the highest possible reward for any observed environmental performance whose likelihood of observation is increasing in environmental effort. The agent provides the highest implementable environmental effort and the lowest possible implementable effort on its core task. In this case, increases in the available budget and in the maximally allowed penalty have an ambiguous effect on total environmental quality, but can lead to a situation where the effort on the agent's core task is reduced to zero.

The first optimum might appear at first sight to be just a theoretical curiosity. The remarkable point, however, is that it is actually quite close to the actual experience with the Flemish water levies we have described in the introduction: Van Humbeeck [16] has argued extensively that, in practice, the Flemish water levies have had no discernible incentive effect and were used as pure financing levies. Similarly, the vast majority of Flemish municipal environmental taxes are just lump sum taxes that contribute to the financing of garbage collection and treatment [1].

Of course, the strongest results depend crucially on the assumptions we have made with respect to the agent's cost of effort. For instance, if the agent has some intrinsic motivation with respect to the environment or if both tasks are complements rather than substitutes in effort, then Proposition 1 does not hold.

The weakest point of this analysis is probably that the maximal fines and the EPA's budget have not been fully endogenized. A fruitful point for further research could be to determine these variables as the result of a political process.

Also, a typical EPA must supervise several agents. In a classic paper, Holmström [3] has shown that any agent's wage schedule must depend on any observed behavior of the other agents that is informative of his performance. This constitutes another obvious area for further research.

References

[1] Ashworth J., Geys B. and Heyndels B (2003), Political Fragmentation and tax innovation: the case of environmental taxes in Flemish municipalities, paper presented at the Annual Meeting of the European Public Choice Society, Aarhus

[2] Bressers, H.T.A. and Huitema, D. (2000), What the doctors should know: politicians are special patients. The impact of the policy-making process on the design of economic instruments, in: Andersen, M.S. and Sprenger, R-U (eds), Market-based Instruments for Environmental Management, Politics and Institutions, Edward Elgar, Cheltenham

[3] Holmström, B (1979), Moral hazard and observability, Bell Journal of Economics, 10(1), pp.74-91

[4] Holmström, B and Milgrom, P (1991), Multitask principal agent analysis: incentive contracts, assets ownership and job design, Journal of Law, Economics and Organization, 7, 24-52

[5] Jewitt, I (1988), Justifying the First-Order Approach to Principal-Agent Problems, Econometrica 56: 1177-1190

[6] Landis Gabel, H. and Sinclair-Desgagné, B. (1993), Managerial Incentives and Environmental Compliance, Journal of Environmental Economics and Management, 24, pp. 229-240

[7] Laffont J-J and Martimort, D.(1999), "Separation of Regulators against Collusive Behavior" Rand Journal of Economics, 30, 232-262

[8] Martimort, D. (1996), The Multiprincipal Nature of the Government, European Economic Review, 40 (1996), 673-685

[9] Martimort, D. (1999), Renegotiation Design with Multiple Regulators, Journal of Economic Theory, 88(2), 261-294

[10] Milgrom, P. and Roberts, J. (1988), An Economic Approach to Influence Actvities in Organizations, American Journal of Sociology, 94, S154-S179

[11] OECD, Environmentally Related Taxes database, available on-line on: http://www.oecd.org/EN/document/0,,EN-document-8-nodirectorate-no-1-3016-8,00.html

[12] Sinclair-Desgagné, B. (1994), The first-order approach to multi-signal principal-agent problems, Econometrica, Vol 62, No 2, pp. 459-465

[13] Sinclair-Desgagné, B. (1999), How to Restore Higher-Powered Incentives in Multitask Agencies, Journal of Law, Economics and Organization, V15, N2, pp. 418-433

[14] Sinclair-Desgagné, B. and Landis Gabel, H. (1996), Environmental Auditing in Management Systems and Public Policy, CIRANO Working Paper 96s-21

[15] Sinclair-Desgagné, B. (2001), Incentives in Common Agency, CIRANO, Scientific Series, 2001s-66

[16] Van Humbeeck, P. (2001), Milieuheffingen in de praktijk, mimeo, Flanders' Social and Economic Council

A Proof of Lemma 4

Let a^R be the solution to the EPA's optimisation problem, if such a solution exists.

First, multiply Equation 17 by $p_i(a^R)$ for all i and sum all these equations to obtain:

$$\gamma^P_{NG} + \gamma^a_{NG} \sum_{i=1}^{I} \frac{\partial p_i(a^R)}{\partial a} = -\sum_{i=1}^{I} p_i(a^R) \frac{dEB(Y - x_i(a^R))}{dx_i} \qquad (25)$$

$\sum_{i=1}^{I} p_i(a^R) = 1$ implies that $\sum_{i=1}^{I} \frac{\partial p_i(a^R)}{\partial a} = 0$ and we thus obtain:

$$\gamma^P_{NG} = -E_{a^R}(\frac{dEB(Y - x_i(a^R)}{dx_i}) \qquad (26)$$

where $E_{a^R}(.)$ is the expectations operator conditionnal on a^R. Equation 26 implies immediately that $\gamma^P_{NG} > 0$: the participation constraint is binding.

We can now rewrite Equation 17 as follows:

$$\gamma_{NG}^{a}\frac{\frac{\partial p_i(a^R)}{\partial a}}{p_i(a^R)} = E_{a^R}(\frac{dEB(Y-x_i(a^R)}{dx_i}) - \frac{dEB(Y-x_i(a^R)}{dx_i} \tag{27}$$

Multiply this expression by $x_i(a^R)\,p_i(a^R)$ for all i and sum all these equations to obtain:

$$\gamma_{NG}^{a}\sum_{i=1}^{I}\frac{\partial p_i(a^R)}{\partial a}x_i(a^R) = \sum_{i=1}^{I}p_i(a^R)\,x_i(a^R)\{E_{a^R}(\frac{dEB(Y-x_i(a^R)}{dx_i}) - \frac{dEB(Y-x_i(a^R)}{dx_i}\}$$

If $a^R > 0$, the complementary slackness condition $\gamma_{NG}^{a}\frac{\partial EP_o}{\partial a} = 0$ implies $\gamma_{NG}^{a}\sum_{i=1}^{I}\frac{\partial p_i(a^R)}{\partial a}x_i(a^R) = \gamma_{NG}^{a}\frac{\partial c(a^R,b)}{\partial a}$. We thus get:

$$\gamma_{NG}^{a}\frac{\partial c(a^R,b)}{\partial a} = -cov\{x_i(a^R),\frac{dEB(Y-x_i(a^R)}{dx_i}\} \tag{28}$$

On the one hand, our basic assumption $\frac{dEB(Y-x_i(a^R)}{dx_i} < 0$ implies that $cov\{x_i(a^R),\frac{dEB(Y-x_i(a^R)}{dx_i}\} \leq 0$ - and this inequality holds strictly unless $x_i(a^R)$ is constant. On the other hand, in the absence of any intrinsic motivation, $\frac{\partial c(a^R,b)}{\partial a} > 0$.

Thus, if $a^R > 0$, then $\gamma_{NG}^{a} > 0$. [8]

[8]Note that this result also follows directly from Sinclair-Desgagné [13] - we prefer to give an explicit proof here, as it clearly shows where this result comes from.

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