Common Agency and Pollution Control[*]

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Abstract

This paper analyzes, using a modified version of the Laffont & Tirole (1993) model, a framework in which an environmental agency and a public utilities agency regulate production and abatement activities of a polluting Public Utility, either cooperating or acting separetely. When symmetric information about costs is assumed, first best in abatement and cost reducing effort levels is achieved, irrespective of cooperation or separation. When, on the other hand, the firm has an informational advantage, cooperation between regulators leads to the standard

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L. & T. results, while non-cooperation tighten the trade off between incentives to efficiency and rent extraction, because the environmental regulator's objective function does not account for the public utility's profits. As a result, both cost-reducing effort level and pollution abatement level required from the inefficient type firm are lower if the two regulators act separately.

1 Introduction.

The regulation of pollution and, in general, of externalities, shares many features with that of public goods. One of these features is the presence of asymmetries of information between regulator(s) and economic agents.

It is, in fact, likely that a regulated firm is better informed than the regulator with respect to the characteristics of its production process and the available abatement technologies[1]. In real life, a further complication is due to the fact that the regulation of externalities is often linked with that of other aspects of the regulated firm activities. This is true, for example, in the electricity sector, where the regulation of pollution and that of efficiency in production are often conducted jointly. For example, we can observe that in many countries the definition of future directions for energy policy accounts for the tight connection between energy efficiency and energy "cleanliness", leading to a "mixing" of competences between environmental and public utilities regulators.

[1] Because, for example, "...the effectiveness of scrubbers is a complex function of the coal burned, the amount of limestone used, the extent of maintenance and the facilities on which they are installed." (Baron (1985))

The aim of this paper is to ascertain how the presence of informational asymmetries can influence optimal environmental policy and public utilities regulation when they are conducted by two separate entities. To do this, we analyse a very simple regulatory framework where an Environmental Regulator (ER), in charge of pollution control, and a Public Utilities Agency (PUA), in charge of efficiency aspects of the production activity, interact on the same hierarchical level in order to control a single Public Utility. As Berhneim and Whinston (1986) called it, this is a problem of Common Agency[2].

As a benchmark, we start assuming that the firm and regulators share all information. The first result of the paper is that the institutional arrangement is irrelevant in the case of complete information, because the two regulators can reach first best both cooperating and acting independently. That is, non cooperative behaviour introduces no distortion if information is symmetric. This is mainly a consequence of the way the model is built up. Our focus is, in fact, on the distortions imposed by non-cooperative behaviour in a moral hazard/adverse selection framework.

Our next step is, therefore, to introduce asymmetries in that only

[2]Dixit, Grossman and Helpman (1997) give a clear definition, that is, at the same time, suitable for the framework built in our paper: "Common agency is a multilateral relationship in which several principals simultaneously try to influence the actions of an agent" [p.752]. We can distinguish between *delegated* and *intrinsic* Common Agency: under *delegated* common agency, the choice of the contractual relationship is delegated to the agent who can choose to contract with one, a part or all the pricipals; when common agency is *intrinsic* instead, the agent's choice is more limited: he can only choose to contract or not with all the principals, and cannot exclude one or more principals from contracting. This is our case, in which a regulated firm can only choose between the option of contracting with all the regulators or the one of not producing.

the firm knows its efficiency and observes the effort exerted in reducing the costs of production and pollution abatement. In this setting, the most efficient firm gains a rent tied to its informational advantage and first best cannot be reached, because regulators have to counterbalance social costs of this rent with gains tied to effort levels being as near as possible to efficiency. This is true both if the two regulators cooperate and if they act independently.

Non cooperative behaviour, however, creates more distortions in environmental policy with respect to the cooperative case. Specifically, the abatement-related level of effort, as well as the abatement level, are distorted downward compared both with the first best and with the second best obtained in the case the two regulators cooperate. This is the main result of our paper, and is a consequence of the fact that the objective function of the environmental regulator, when he acts by himself, does not account for firm's profits. A stricter trade off between incentives to efficiency and rent extraction arise and, therefore, the non cooperating environmental agency perceives the rent accruing to the efficient firm due to asymmetric information as more costly.

Many works address the problem of asymmetric information in pollution control[3], but one of the earliest papers to consider more than one regulator is the one by Baron (1985). In his paper a polluting Public Utility is regulated by a Federal Environmental Protection Office (EPO) that act as a leader and a state Public Utility Commission (PUC) that act as a follower in a Stackelberg game. In this game EPO moves first estabilishing emissions policy while PUC, then, sets

[3]The problem of pollution control under asymmetric information is treated, for example, in Laffont (1994). A survey of pollution control models with asymmetric information may be found in Lewis (1996).

a pricing policy for the firm, that is privately informed about its efficiency in pollution reduction. The main difference between our work and Baron's paper is that here no leadership is assumed between regulators. They act contemporaneously, being able to observe the same message that the firm send about its hidden technological features. Our built up framework is, therefore, suitable to shed some light on the implications of non cooperation in countries, as Canada or Australia, where there are Environmental and Public Utilities Regulators acting both as "state-level" agencies[4]. As we will show, non cooperation between regulators can have opposite consequences on environmental policy in the two different institutional settings.

Finally, the setting developed in this paper turns out to be quite general. If we interpret abatement as a general index of quality, then the model might be used to analyse cases in which quality itself and efficiency in production of an asymmetrically informed firm are regulated by different agencies. In that case, our result concerning effort levels and environmental quality would apply without the need for major changes.

The work is organized as follows: in section 2 we introduce the main features of the model, in section 3 we analyze the case of complete information, and in section 4 that of asymmetric information. Section 5 discusses results and section 6 concludes.

[4] Baron's setting is suitable in describing the institutional framework in the U.S. An important feature of this system is that non cooperation may be induced by the fact that the revenues collected by the EPA do not benefit the same community (and, therefore, firms) affected by public utilities regulation.

2 The Model.

We study a regulated firm that performs an indivisible public project, and, at the same time, has to reduce pollution caused by the production activity. Firm's output is, therefore, exogenously given and normalized to 1. This value may be interpreted, for example as the construction of an electric power generating plant or a dam.

The production activity generates pollution as a by product. The firm engage in emissions reducing activity, the level of abatement being x[5]. An additive total costs function is assumed[6]:

$$C(e_0, e_1, x, \beta) = (\beta - e_0) + (\beta - e_1)x \qquad (1)$$

The RHS of 1 is the sum of production and pollution reducing costs[7], β is a technological parameter that represents the efficiency of the firm in the two activities, with higher values implying higher costs, that is, lower efficiency[8] and e_j, $(j = 0, 1)$ are the levels of effort exerted by the firm in reducing costs of production (activity 0) and pollution reduction (activity 1). These two values may be regarded as a monetary measure of all the possible actions the firm may undertake in

[5] What we call x might be regarded as a measure of environmental quality as, for example, the polluting potential of a new-built electric power plant. In this case, "pollution abatement" means "reduction of potential pollution". We will, however, refer to x generically as "abatement" throughout the paper.

[6] The form of the cost function implies separability in the two effort levels and a normalization in variables in order to guarantee comparability between the two activities' costs.

[7] The second term on the RHS of 1 may be interpreted also as the benefits, in terms of lower costs, from a higher pollution, that is, a lower x.

[8] β is the same in both activities performed by the regulated firm. It might be interepreted as a measure of overall efficiency

order to improve the efficiency in performing its two tasks. For future reference, we call $C_0 = (\beta - e_0)$ the fraction of costs deriving from production activity, and $C_1 = (\beta - e_1)$ that deriving from one unit of pollution reduction.

Two regulators are interested in that the public project takes place: a Public Utilities Agency (PUA) is in charge of the efficiency of the firm in performing the public project, while an Environmental Regulator (ER) is in charge of the environmental problems connected. They can cooperate or act separately, but in both cases they have all the bargaining power, that is, they design the contract offered to the regulated firm, being the latter free only to accept or refuse it. Specifically, in the resulting "regulatory game", they act as Stackelberg leaders with respect to the firm.

The PUA is concerned with both the firms' and consumers' welfare deriving from production activity (e.g. from the construction of the power generating plant). We follow the accounting convention that the PUA take all the profits deriving from production activity and reimburses related costs to the firm. To accept to perform the public project, the firm is compensated by a net positive transfer t_{PUA}. The needed resources are raised via ordinary taxation, and this causes a deadweight cost, that we assume strictly positive[9]. Analytically, the PUA offers a take-it-or-leave-it contract, specifying (C_0, t_{PUA}), to the firm, to maximize the following objective function:

$$W_{PUA} = S_{PUA} - (1 + \lambda)(C_0 + t_{PUA}) + U, \tag{2}$$

[9] The needed money transfer might, for example, be raised by (distortionary) general taxation, so that, for the taxpayers, a raised dollar of public funds costs, in terms of welfare, $(1 + \lambda)$ dollars.

where

- λ (assumed > 0) denotes the shadow cost of public funds,
- S_{PUA} is the social surplus PUA assigns to the production acticity, given and supposed sufficiently large[10].
- U is the profit level of the regulated firm, that will be defined shortly.

The Environmental Regulator (ER) is in charge of pollution reduction. We assume that ER does not take into account all the consequences of its actions on the Public Utility's profits[11]. Specifically, it is realistic to assume that the ER attaches a smaller weight than the PUA to the regulated firm's profits. We take the extreme case in which this weight is 0[12]. The ER is therefore interested in the maximization of social welfare deriving from the reduction of pollution and from the completion of the public project. ER has the power to impose an abatement standard, x, reimburses abatement related costs and makes a transfer, t_{ER}, to the firm. As in the case of the PUA, there is a deadweight loss tied to the need to raise the necessary public funds via distortionary taxation. ER, therefore, offers a take-it-or-leave-it

[10] This last assumption is made, as will be clear when we will introduce asymmetric information, to ensure that the regulator(s) do not find it welfare improving to shut down the firm if it is of the worst type.

[11] See, for example, Ebert (1998)

[12] Baron (1985) assumes that the EPA accounts only for compliance costs of the regulated firm, because these will ultimately be reflected in consumers' prices. In our context the consumer is the regulator itself; we account for compliance costs assuming that they are totally reimbursed.

contract, specifying (C_1, x, t_{ER}), to the firm, in order to maximize the following objective function:

$$W_{ER} = V(x) + S_{ER} - (1+\lambda)(C_1 x + t_{ER}), \qquad (3)$$

where:

- S_{ER} is the social "value" the environmental regulator assigns to the production activity[13].
- $V(x)$ is a function representing social benefits tied to pollution reduction, with $V'(x) > 0$ and $V''(x) < 0$, implying decreasing marginal benefits of pollution abatement.

Given total cost reimbursement and net transfers, the firm's profit function may be written as follows:

$$U = t_{PUA} + t_{ER} - [\psi(e_0) + \psi(e_1)], \qquad (4)$$

The term $\psi(e_0) + \psi(e_1)$ is the sum of (monetary measures of) the disutility the firm has to bear in order to reduce costs in both its activities[14]. The disutility of effort is increasing at an increasing rate, that is $\psi' > 0$, $\psi'' > 0$.

[13] Assumed, once again, high enough. The assumption that the ER is interested in the public project to be performed might look unreasonable. It is, however, needed to exclude what would be, to us, an uninteresting case, where the ER does not have any incentive to let the firm perform production activity (if production were 0 there would not be any pollution). It could, for example be the case that the public project implies the building of a "cleaner than the status quo" electric power plant, and that x represents the various pollution potential levels of the new plant.

[14] They may be interpreted, for example, as costs of Reserch and Development towards low cost technologies.

It is important to note that the assumed functional form for firm's profits implies that first order conditions for their maximization with respect to e_0 does not depend on e_1 and vice versa. As a consequence, any distortion caused by the non cooperative behaviour in this framework will turn out to be a strong result[15].

In the rest of the paper we will analyse optimal regulation both when the two regulators cooperate and when they act separately in regulating production activity and pollution control. As will be clear in the following sections, this will lead to two different games. The second stage is the same in both of them: the firm chooses to accept or refuse the contract.[16].

The first stage of the game depends on the behaviour assumed for the regulators: if they cooperate, they offer the firm a "super-contract" in order to maximize the sum of their objective functions; if, on the other hand, they act independently the contracts they offer to the firm will be given by the Nash equilibria of the game played between them in the first stage.

Once presented the main features of the model, we are now going

[15] In this way, in fact, one of the main causes of distortion when the two regulators do not cooperate is removed from the problem. This is done because we are interested in the consequences of the noncooperative behaviour assuming that the two regulators have different objectives, and not in the endogenous causes of the divergence of such objectives, due, for example, to the complementarity or substitutability of effort levels. For an example of the latter kind of analysis see Mezzetti (1997). In that article, the conflict between the two pricipals arise because the asymmetrically informed agent faces countervailing incentives given that the actions he has to perform for the principals are complements in its objective function.

[16] The enforcement of the contract, if it is accepted, could be obtained in reality by imposing a penalty that is "high enough" to the firm that does not produce and perform pollution reduction according to the contract.

to derive results for the case of Complete information (section 3) and that of Incomplete (Asymmetric) information (section 4). In both sections we will use results in the cooperative framework as a benchmark in understanding what kind of distortions are the consequence of non cooperative behaviour between regulators.

3 Complete Information.

We assume, in this section, that regulators observe effort levels, the value of the technological parameter, total costs and the level of pollution.

3.1 Cooperative Case.

Acting as a unique regulator, ER and PUA reimburse all costs and offer a take-it- or-leave-it mechanism (t, C_0, C_1, x) to the firm, in order to maximize the sum of objective functions 2 and 3:

$$\max_{t,C_0,C_1,x} W_{co} = S + V(x) - (1+\lambda)(C_0 + C_1 x + t) + U \tag{5}$$

where $S = S_{PUA} + S_{ER}$ and $t = t_{PUA} + t_{ER}$.
The contract offered by the regulators has to guarantee at least a minimal acceptable level of profits (reservation profits) to the firm, so that it will accept to perform the public project and to engage in pollution reducing activity. Normalizing the regulated firm's reservation level of profits to 0, the so called Incentive Rationality (IR) constraint is:

$$U \geq 0, \tag{6}$$

Problem 5 may be rewritten as[17]:

$$\max_{t,e_0,e_1,x} W_{co} = S + V(x) - (1+\lambda)(\beta - e_0 + (\beta - e_1)x + \psi(e_0) + \psi(e_1)) - \lambda U.$$

The above objective function is strictly decreasing in U because λ is assumed to be greater than zero. This implies:

$$U = 0 \Rightarrow t = \psi(e_0) + \psi(e_1),$$

so that the regulated firm receives no rent (that is, receives only its reservation profits) for its activities of production and pollution abatement. The net transfer received is, in fact, barely enough to cover the (monetary measure) of the disutility of effort. This is a standard result: the perfectly informed regulator finds it socially optimal to leave zero profits to the firm, because of the social "deadweight" cost λ of public funds.
The FOCs for e_0, e_1 and x are, respectively[18]:

$$-(1+\lambda)(-1+\psi'(e_0)) = 0 \Rightarrow \psi'(e_0) = 1$$

$$-(1+\lambda)(-x+\psi'(e_1)) = 0 \Rightarrow \psi'(e_1) = x$$

$$V'(x) - (1+\lambda)(\beta - e_1) = 0 \Rightarrow V'(x) = (1+\lambda)(\beta - e_1)$$

[17] Given complete information, it is indifferent to solve the maximization problem with respect to the values of e or C. We can then solve the maximization problem with respect to e_0 and e_1 and then, given β, derive optimal C_0 and C_1 imposed by the cooperating regulators.

[18] It can be shown that, if $-\psi''(e_1)V''(x) > (1+\lambda)$, first order necessary conditions in the text are also sufficient conditions for a maximum.

The first two conditions above implicitly define the optimal levels of e_0^* and e_1^*, requiring the marginal disutility of the two efforts to equal the related marginal cost savings. These are standard first best conditions, that we get here because information is complete and symmetric. Finally, the last condition implies that abatement activity must be pushed to the point where marginal social benefits from lower pollution equal related social marginal costs.

3.2 Non Cooperative case.

When the regulators do not cooperate, each maximizes his own objective function. The contracts they will indipendently offer to the firm will be given by the Nash equilibria of the one shot game played between them, in which PUA takes ER's choices as given and vice versa. Being interested in having the public project completed, both regulators will take into account, in choosing the optimal contract offered to the firm, the participation constraint given in 6[19].

The PUA makes a take-it-or-leave-it-offer (e_0, t_{PUA}) to maximize 2 subject to the IR constraint. This problem may be rewritten as:

$$\max_{e_0, t_{PUA}} W_{PUA} = S - (1+\lambda)[\beta - e_0 + \psi(e_0) + \psi(e_1) - t_{ER}] - \lambda U,$$

subject to:

$$U \geq 0 \Rightarrow t_{PUA} \geq \psi(e_0) + \psi(e_1) - t_{ER}.$$

[19] We will solve maximization problems for the two regulators with respect to effort levels. Being information complete this is equivalent to solving them for cost levels. See footnote 17.

We get the following first order conditions[20]:

$$U = 0 \Rightarrow t_{PUA} = \psi(e_0) + \psi(e_1) - t_{ER}.$$

$$-(1+\lambda)(-1+\psi'(e_0)) = 0 \Rightarrow \psi'(e_0) = 1.$$

Thus, the equilibrium value of production related effort is defined by the same condition as in the cooperative case, that is marginal disutility of effort must equal marginal cost savings.

The environmental regulator makes a take-it-or-leave-it offer (e_1, x, t_{ER}) to the firm, in order to maximize function 3 subject to the IR constraint, given again by 6. ER, therefore solves the following problem:

$$\max_{e_1, x, t_{ER}} W_E = V(x) - (1+\lambda)[(\beta - e_1)x - t_{ER}],$$

subject to:

$$U \geq 0 \Rightarrow t_{ER} \geq \psi(e_0) + \psi(e_1) - t_{PUA}.$$

First order conditions for this problem are[21]:

$$\begin{aligned} U = 0 \rightarrow t_{ER} = \psi(e_0) + \psi(e_1) - t_{PUA}, \\ V'(x) = (1+\lambda)(\beta - e_1), \\ -(1+\lambda)(-x + \psi'(e_1)) = 0 \Rightarrow \psi'(e_1) = x, \end{aligned} \tag{7}$$

[20]It can be shown that these are also sufficient conditions for a maximum.

[21]The conditions for sufficiency are the same as those in footnote 18, for the ccoperative case.

Conditions above are identical to those obtained in the case in which the two regulators cooperate.

This leads us to Proposition 1:

Proposition 1. (No rent property) *If information is complete, non cooperative behaviour between regulators does not produce distortions in the regulatory policy with respect to the cooperative case.*

Noyice that the division of the total transfer between the regulators is indeterminate.

Indeed the result stated in proposition 1 is a consequence of the separability of firm's profit function with respect to effort levels, and it does not hold in general[22]. It is, however, coherent with the existing literature on common agency under complete information[23].

4 Asymmetric Information.

Starting from this section, in order to gain the main results of the paper, we will assume that regulators, acting cooperatively or not, can only verify costs (separately for the two activities) and pollution levels,

[22] For example, in Dixit et al. (1997), in a framework of complete information, the distortions are due to the fact that preferences are not quasi linear, so that the actions of the principals and the agent depend also on the distribution of payoffs. Another example may be found in Martimort and Stole (1999), in which the complete information non cooperative equilibrium is distorted with respect to the cooperative first best because the two actions the agent performs may be complements or substitutes.

[23] See Laussel and Le Breton (2001).

but not the firm's effort levels and technological parameter.

We are, therefore, in a principal/agent framework[24], where the firm is an agent that has an informational advantage and has to perform two activities on behalf of one principal (in the cooperative case) or two principals (in the case the two regulators do not cooperate).

The efficiency parameter β may take two values: $\overline{\beta}$ (inefficient type) and $\underline{\beta}$ (efficient type) with $\overline{\beta} > \underline{\beta}$ and $\Delta\beta = \overline{\beta} - \underline{\beta} > 0$.

The level of efficiency is private information to the firm. The two regulators have identical a priori beliefs about the distribution of β, that is $\beta = \overline{\beta}$ with probability π and $\beta = \underline{\beta}$ with probability $1 - \pi$.

It is, in our view, reasonable to assume that the firm cannot send different messages concerning its type to the regulators. As a consequence, in our model the signal provided does not differ between them[25].

We will start analyzing the cooperative case. We expect the presence of asymmetric information to lead to the usual distortions tied to the moral hazard/adverse selection problem, that is lower than first best effort levels and a higher than first best pollution level[26]. We will then use the results obtained as a benchmark to evaluate "new" distortions introduced by non cooperative behaviour under asymmetric information.

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[24] The standard principal/agent model is treated, for example, in Mas Colell et al.(1995), Ch. 14

[25] This assumption is not needed in the cooperative case, but rules out the chance that the firm manipulate the messages sent to each regulator under non cooperation in order to gain higher profits preventing, at the same time each regulator from making the contract offered conditional on the message sent by the firm to the other regulator.

[26] See Laffont and Tirole (1993), Chaps 1 and 2.

4.1 Cooperative Case.

Notation and results in the cooperative case under asymmetric information heavily follow Laffont and Tirole (1993), Ch.1 and 2.

As in the complete information case, the two regulators, cooperating, act as a unique regulator. When information is incomplete they maximize the expected value of the sum of ER's and PUA's objective functions, given in 2 and 3, evaluated in the two states of nature and weighted with the respective probabilities[27]:

$$\max_{\hat{C},\hat{x},\hat{t}} S + \pi[V(\overline{x}) - (1+\lambda)[\overline{C}_0 - \overline{C}_1\overline{x} + \overline{t}]] +$$

$$+(1-\pi)[V(\underline{x}) - (1+\lambda)[\underline{C}_0 - \underline{C}_1\underline{x} + \underline{t}]] + [\pi\overline{U} + (1-\pi)\underline{U}], \qquad (8)$$

where $\overline{C_0} = \overline{\beta} - \overline{e_0}$, $\overline{C_1} = \overline{\beta} - \overline{e_1}$, $\underline{C_0} = \underline{\beta} - \underline{e_0}$ and $\underline{C_1} = \underline{\beta} - \underline{e_1}$. Recall that production activity is labelled 0, while pollution abatement activity is labelled 1.

The remaining notation is as follows:

- $S = S_{PUA} + S_{ER}$ is the social surplus attached by the "super regulator" to the public project,
- $\overline{t}$ ($\underline{t}$) is the transfer to firm of type $\overline{\beta}(\underline{\beta})$,
- $\overline{e_i}$ ($\underline{e_i}$), $i \in \{0,1\}$, is the effort level in activity i exerted by $\overline{\beta}(\underline{\beta})$ type firm,

[27] To simplify notation in this section we will use the following abbreviations : $\hat{U} = (\overline{U}, \underline{U})$, $\hat{e} = (\overline{e}_0, \underline{e}_0, \overline{e}_1, \underline{e}_1)$, $\hat{C} = (\overline{C}_0, \underline{C}_0, \overline{C}_1, \underline{C}_1)$, $\hat{x} = (\overline{x}, \underline{x})$.

- $\overline{U} = \bar{t} - \psi(\overline{e_0}) - \psi(\overline{e_1})$ are profits of the $\overline{\beta}$ type firm, $\underline{U} = \underline{t} - \psi(\underline{e_0}) - \psi(\underline{e_1})$ are profits of the $\underline{\beta}$ type firm

- $\overline{x}(\underline{x})$ is the level of abatement activity performed by the $\overline{\beta}(\underline{\beta})$ type firm.

The firm sends a message concerning its type to the cooperating regulators.

We will limit our analysis to *direct revelation mechanisms*, that is, the regulator offers a contract in which the transfer, costs and abatement standard specified depend directly on the type "declared" by the firm . The **Revelation Principle**, in fact, guarantees that the regulators have no incentive to deviate to more complicated mechanisms, and that we can further restrict our attention to mechanisms in which it is optimal for the agent to truthfully reveal its type.[28].

In order for the firm to be provided the appropriate incentives, we must ensure that each firm (weakly) prefers the contract designed for its type to the one designed for the other type. The contracts proposed to both types must satisfy the so called **Incentive Compatibility Constraint**.

Incentive compatibility implies that the efficient type must get higher profits from "its" contract than from the one designed for the inefficient type and vice versa. Given the relationship between costs and effort levels, we may express this requirement in the following way:

$$\underline{t} - \psi(\underline{\beta} - \underline{C}_0) - \psi(\underline{\beta} - \underline{C}_1) \geq \bar{t} - \psi(\underline{\beta} - \overline{C}_0) - \psi(\underline{\beta} - \overline{C}_1), \qquad (9)$$

[28] For a treatement of the Revelation Principle see Mas Colell et al.(1995), Ch. 14 and 23. See Laffont and Tirole (1993), ch.1 for its application in a regulatory context.

(we will call this constraint $\underline{IC}$ from now on), and

$$\overline{t} - \psi(\overline{\beta} - \overline{C}_0) - \psi(\overline{\beta} - \overline{C}_1) \geq \underline{t} - \psi(\overline{\beta} - \underline{C}_0) - \psi(\overline{\beta} - \underline{C}_1), \qquad (10)$$

(we will call this constraint $\overline{IC}$ from now on).

Adding up the two inequalities we get, after rearranging:

$$\int_{\underline{C}_0}^{\overline{C}_0} \int_{\underline{\beta}}^{\overline{\beta}} \psi''(\beta - C) d\beta dC + \int_{\underline{C}_1}^{\overline{C}_1} \int_{\underline{\beta}}^{\overline{\beta}} \psi''(\beta - C) d\beta dC \geq 0. \qquad (11)$$

In order to satisfy condition 11, given that $\psi''(.) > 0$, we need that both $\underline{C}_0 \leq \overline{C}_0$ and $\underline{C}_1 \leq \overline{C}_1$ (or at least that one of the two cost functions is sufficiently increasing in β so as to counterbalance the possible decreasing behaviour of the other one).

There are two other constraints, deriving from the fact that the regulator must provide the firm at least with its reservation profit level in each possible state, in order to guarantee that the activities the firm has to perform will effectively take place.
The resulting **Individual Rationality Constraints** impliy:

$$\underline{t} - \psi(\underline{\beta} - \underline{C}_0) - \psi(\underline{\beta} - \underline{C}_1) \geq 0$$
$$\text{(we will call this constraint } \underline{IR} \text{ from now on)} \qquad (12)$$
$$\overline{t} - \psi(\overline{\beta} - \overline{C}_0) - \psi(\overline{\beta} - \overline{C}_1) \geq 0$$
$$\text{(we will call this constraint } \overline{IR} \text{ from now on)} \qquad (13)$$

We can rewrite $\underline{IC}$ as:

$$\underline{U} \geq \overline{U} + \phi(\overline{e}_0) + \phi(\overline{e}_1) \qquad (14)$$

where $\phi(e) = \psi(e) - \psi(e - \Delta\beta)$, $\Delta\beta = \overline{\beta} - \underline{\beta}$.

The function $\phi(.)$ plays a very important role. It is, in fact, the rent the efficient firm gains because of its informational advantage. Given the properties of $\psi(.)$, the rent is increasing in the level of effort exerted by the inefficient type. This is a key property, because the positive correlation between the efficient firm's rent and the inefficient firm's effort creates a tradeoff between this socially costly rent and efficiency in the effort level the regulator requires from the inefficient firm.

To simplify further the analysis, in solving the maximization problem of the regulator, we will use the following Lemma:

Lemma 1 *$\underline{IC}$ and $\overline{IR}$ imply $\underline{IR}$.*

Proof. The proof follows the steps in Laffont and Tirole (1993), (1.16) p.58. From condition (9) we have: $\underline{U} \geq \overline{t} - \psi(\underline{\beta} - \overline{C}_0) - \psi(\underline{\beta} - \overline{C}_1)$; from $\overline{IR}$ we can rewrite this inequality as: $\underline{U} \geq \psi(\overline{\beta} - \overline{C}_0) + \psi(\overline{\beta} - \overline{C}_1) - \psi(\underline{\beta} - \overline{C}_0) - \psi(\underline{\beta} - \overline{C}_1)$, and because $\psi(.)$ is increasing we have: $\underline{U} \geq 0$.

Finally, we will solve the problem ignoring the constraint $\overline{IC}$, verifying afterwards that the solution satisfies condition 11, that is both IC constraints.
Problem 8 may be rewritten as:

$$\max_{\hat{U},\hat{e},\hat{x}} S + \pi[V(\overline{x}) - (1+\lambda)[\overline{\beta} - \overline{e}_0 - (\overline{\beta} - \overline{e}_1)\overline{x} + \psi(\overline{e}_0) + \psi(\overline{e}_1)]] +$$

$$+(1-\pi)[V(\underline{x}) - (1+\lambda)[\underline{\beta} - \underline{e}_0 - (\underline{\beta} - \underline{e}_1)\underline{x} + \psi(\underline{e}_0) + \psi(\underline{e}_1)]] +$$

$$-\lambda[\pi\overline{U} + (1-\pi)\underline{U}],$$

subject to $\overline{IR}$ and $\underline{IC}$ constraints.

The objective function is strictly decreasing in $\overline{U}$ and $\underline{U}$, so that, from the constraints, we get the following conditions for:

$$\overline{U} = 0 \Rightarrow \bar{t} = \psi(\overline{e}_0) + \psi(\overline{e}_1)$$

$$\underline{U} = \phi(\overline{e}_0) + \phi(\overline{e}_1) \Rightarrow \underline{t} = \psi(\underline{e}_0) + \psi(\underline{e}_1) + \phi(\overline{e}_0) + \phi(\overline{e}_1).$$

No rent is, therefore, left to the inefficient type, while, as seen above, the rent accruing to the efficient type is increasing in the effort level of the inefficient one.

Substituting these two conditions in the objective function, it becomes[29]:

$$\begin{aligned}\max_{\hat{U},\hat{e},\hat{x}} S + \pi[V(\overline{x}) - (1+\lambda)[(\overline{\beta} - \overline{e}_0) - (\overline{\beta} - \overline{e}_1)\overline{x} + \psi(\overline{e}_0) + \psi(\overline{e}_1)]] + \\ +(1-\pi)[V(\underline{x}) - (1+\lambda)[(\underline{\beta} - \underline{e}_0) - (\underline{\beta} - \underline{e}_1)\underline{x} + \psi(\underline{e}_0) + \psi(\underline{e}_1)]] + \\ -\lambda(1-\pi)[\phi(\overline{e}_0) + \phi(\overline{e}_1)]. \quad (15)\end{aligned}$$

[29] Given that the firm reveals its type truthfully, solving the problem with respect to e is the same as solving it with respect to C.

First Order Conditions for this problem, are[30]:

$$\psi'(\overline{e}_0) = 1 - \frac{\lambda}{1+\lambda}\frac{1-\pi}{\pi}\phi'(\overline{e}_0), \tag{16}$$

$$\psi'(\underline{e}_0) = 1. \tag{17}$$

$$\psi'(\overline{e}_1) = \overline{x} - \frac{\lambda}{1+\lambda}\frac{1-\pi}{\pi}\phi'(\overline{e}_1), \tag{18}$$

$$\psi'(\underline{e}_1) = \underline{x}, \tag{19}$$

$$V'(\overline{x}) = (1+\lambda)(\overline{\beta} - \overline{e}_1),$$

$$V'(\underline{x}) = (1+\lambda)(\underline{\beta} - \underline{e}_1).$$

The last two conditions imply that optimal pollution abatement is, for each type, at the level that equals marginal social loss from emissions with marginal social cost savings. The optimal efforts are at their first best levels for the efficient type, because, from conditions 17 and 19, $\underline{e}_0 = e_0^*$ and $\underline{e}_1 = e_1^*$. On the other hand they are inefficiently low, from conditions 16 and 18, for the inefficient type[31]. This is due to the fact that the only way for the regulator to gain more efficiency in the type $\overline{\beta}$ effort level is to leave more socially costly rent to type $\underline{\beta}$. There is a trade off, caused by the direct relation between the rent accruing to the efficient firm, given by the function $\phi(.)$, and the effort level specified in the contract offered to the inefficient firm.

Conditions above are a consequence of this trade off, coherently with the standard principal/agent models under moral hazard and

[30] Objective function 15 is concave if $\psi''' \geq 0$ and $-V''\psi'' > (1+\lambda)$. We assume, to ensure *strict* concavity, that these conditions hold everywhere, that is, for all values of effort and abatement levels.

[31] We omit the proof, being it quite similar to that in Laffont and Tirole (1993). See Ch.2, pp 134-137.

adverse selection.

Type $\overline{\beta}$ will be, therefore, required by the cooperating regulators to exert an effort level as high as to equate the related marginal social gains to the loss deriving from the marginal rent left to the efficient type.

Finally, we need to check that the solution to this problem satisfies condition 11 for Incentive Compatibility.

Being $\overline{\beta} > \underline{\beta}$ and given that conditions (16-19) tell us that $\underline{e}_0 > \overline{e}_0$ and $\underline{e}_1 \geq \overline{e}_1$, we have:

$$(\overline{\beta} - \overline{e}_0) > (\underline{\beta} - \underline{e}_0) \Rightarrow \overline{C}_0 > \underline{C}_0,$$
$$(\overline{\beta} - \overline{e}_1) > (\underline{\beta} - \underline{e}_1) \Rightarrow \overline{C}_1 > \underline{C}_1,$$

so that condition 11 is satisfied.

4.2 Non cooperative case.

Following the steps in section 3, using results concerning the cooperative case as a benchmark, we turn to evaluate the consequences of assuming non cooperation.

As well as in the cooperative case, we assume that the Revelation Principle holds.

Assumption 1. *The two principals base their proposed contracts on the direct announcement of the firm's type. The Revelation Principle will ensure that:*

(i) the two regulators cannot gain by deviating from these proposed contracts,

(ii) the firm will reveal its type truthfully.

This is indeed a strong assumption. In fact, an important problem in the Common Agency literature arise because with more than one principal, each of whom observes only the report to him, for incentive compatibility to be effective the agent has to report its type truthfully to a principal given he reported it truthfully to the other principal(s).

A consequence of this fact is that the revelation principle is no longer applicable in a straightforward way; much care has to be taken [Martimort and Stole (1999), Stole (1997)].

The possibility for the firm to send different messages is ruled out here. We assumed, in fact, that the message sent to the two principals (regulators) by the agent (firm) cannot differ.

This does not solve all the problems. In a multi-principal framework, the principals are competing to get the best possible action from the agent, and their "best action" might be different and conflicting. Even if we assumed separability between efforts in the firm's profit function, in fact, the two regulators are competing in the level of the transfer each of them has to pay.

In general, in a common agency framework, the agent contracts with each principal with the knowledge of the mechanism(s) that the other principal(s) have offered [Peters (2000), Epstein and Peters (1999)]. Thus the contract each principal offers may depend on that offered by other principal(s) and so on in an "infinite regress".

Epstein and Peters (1999) solve theoretically this problem "enlarging" the message space in such a way that the revelation principle is valid. In particular, in the framework developed there, the agents' type space include the mechanisms offered by other principals. This "universal message space" is, however, difficult to apply in practice.

Analitically, the non applicability of the Revelation Principle when there is more than one principal creates the need to check if the restriction to *direct revelation mechanisms* is such that there is no possible *indirect mechanism* to which the regulators could deviate, in order to gain in terms of their objective functions. An example of *indirect mechanism* could be the offer of a contract conditional on the announcement of the firm's type *and* the costs realized in the activity performed in the interest of the other regulator.

As a consequence, in analyzing the non cooperative case results, we have to bear in mind the caveat that assumption 1, and the consequent application of the Revelation Principle in our context, may lead to some loss of generality.

Our next step is to solve the two disjoint regulatory problems.

When PUA and ER act in a non cooperative way, each of them has to offer a contract such that the firm finds it convenient to reveal its true type.

Both regulators, in defining the contracts, take as given the mechanism chosen by the other regulator. The pair of contracts finally offered, as seen in section 2, will be given by the Nash equilibria of the one shot game, in which the two regulators' strategies are the efforts levels, the pollution abatement required and the transfers proposed. This might pose problems in defining the constraints to be imposed in solving the two regulators' maximization problems separately. It is shown, however, in Appendix 1 that Incentive Compatibility and Individual Rationality imply the same set of constraints as in the cooperative case. We will therefore solve the PUA and ER problems imposing the $\overline{IR}$ constraint

$$\bar{t} - \psi(\overline{\beta} - \overline{C}_0) - \psi(\overline{\beta} - \overline{C}_1) \geq 0,$$

and the $\underline{IC}$ constraint

$$\underline{U} \geq \overline{U} + \phi(\overline{e}_0) + \phi(\overline{e}_1),$$

where $\phi(e) = \psi(e) - \psi(e - \Delta\beta)$, $\Delta\beta = \overline{\beta} - \underline{\beta}$, checking next that the solutions verify $\overline{IC}$.

4.2.1 The problem of the Public Utilities Agency

The PUA offers a take-it-or-leave-it mechanism $(\overline{t}_{PUA}, \underline{t}_{PUA}, \overline{e}_0, \underline{e}_0)$, specifying a value for transfer and effort level in production activity for each type, to maximize the expected value of 2, given the a priori beliefs about the distribution of the firm's possible types[32]:

$$\max_{\overline{U},\underline{U},\overline{e}_0,\underline{e}_0} S - (1+\lambda)[\pi(\overline{\beta} - \overline{e}_0 + \overline{t}_{PUA}) - (1-\pi)(\underline{\beta} - \underline{e}_0 + \underline{t}_{PUA})] + \pi\overline{U} + (1-\pi)\underline{U},$$

subject to $\overline{IR}$ and $\underline{IC}$.
This problem may be rewritten as:

$$\max_{\overline{U},\underline{U},\overline{e}_0,\underline{e}_0} S - (1+\lambda)[\pi(\beta - \overline{e}_0 + \psi(\overline{e}_0) + \psi(\overline{e}_1) - \overline{t}_{ER})+$$

$$+(1-\pi)(\beta - \underline{e}_0 + \psi(\underline{e}_0) + \psi(\underline{e}_1) - \underline{t}_{ER})] - \lambda(\pi\overline{U} + (1-\pi)\underline{U}). \qquad (20)$$

Objective function 20 is strictly decreasing in both profits and is then at its maximum when:

$$\overline{U} = 0 \Rightarrow \overline{t}_{PUA} = \psi(\overline{e}_0) + \psi(\overline{e}_1) - \overline{t}_{ER},$$

[32]Moreover, provided Assumption 1 holds, the contract can be specified indifferently in terms of costs or in terms of effort levels.

$\underline{U} = \phi(\overline{e}_0) + \phi(\overline{e}_1) \Rightarrow \underline{t}_{PUA} = \psi(\underline{e}_0) + \psi(\underline{e}_1) + \phi(\overline{e}_0) + \phi(\overline{e}_1) - \underline{t}_{ER}$.

Substituting in equation 20, the problem becomes:

$$\max_{\overline{e}_0, \underline{e}_0} S - (1+\lambda)[\pi(\overline{\beta} - \overline{e}_0 + \psi(\overline{e}_0) + \psi(\overline{e}_1) - \overline{t}_{ER}) +$$

$$+(1-\pi)(\beta - \underline{e}_0 + \psi(\underline{e}_0) + \psi(\underline{e}_1) - \underline{t}_{ER})] - \lambda(1-\pi)[\phi(\overline{e}_0) + \phi(\overline{e}_1)]. \quad (21)$$

The FOCs for this problem are[33]:

$$\psi'(\overline{e}_0) = 1 - \frac{\lambda}{1+\lambda}\frac{1-\pi}{\pi}\phi'(\overline{e}_0),$$

$$\psi'(\underline{e}_0) = 1.$$

We will comment all results in section 5. We can notice, however, that the above FOCs lead to the same results obtained in the cooperative case.

4.2.2 The problem of the Environmental Regulator

The environmental regulator (ER) offers a mechanism ($\overline{e}_1$,$\underline{e}_1$,$\overline{x}$,$\underline{x}$, $\overline{t}_{ER}$,$\underline{t}_{ER}$)[34], specifying a value for transfer, pollution reduction and

[33] It can be shown that the resulting objective function is concave in $\overline{e}_0$ and $\underline{e}_0$ if $\psi''' \geq 0$. To ensure *strict* concavity we assume this to hold everywhere.

[34] Again, provided Assumption 1 holds, we can indifferently solve the maximization problem w.r.t. e or C.

effort level in abatement activity for each type, to maximize the expected value of objective function 3, given a priori beliefs about the distribution of the firm's efficiency parameter:

$$\max_{\overline{e}_1,\underline{e}_1,\overline{x},\underline{x},\overline{t}_{ER},\underline{t}_{ER}} \pi[V(\overline{x}) - (1+\lambda)((\beta - \overline{e}_1)\overline{x} + \overline{t}_{ER})] + \\ +(1-\pi)[V(\underline{x}) - (1+\lambda)((\underline{\beta} - \underline{e}_1)\underline{x} + \underline{t}_{ER})], \quad (22)$$

subject to $\overline{IR}$ and $\underline{IC}$.

Being E's problem strictly decreasing in $\overline{t}_{ER}$ and $\underline{t}_{ER}$, from the constraints we get:

$$\overline{t}_{ER} = \psi(\overline{e}_0) + \psi(\overline{e}_1) - \overline{t}_{PUA},$$
$$\underline{t}_{ER} = \psi(\underline{e}_0) + \psi(\underline{e}_1) + \phi(\overline{e}_0) + \phi(\overline{e}_1) - \underline{t}_{PUA}.$$

Substituting in 22, ER's problem becomes:

$$\max_{\overline{e}_1,\underline{e}_1,\overline{x},\underline{x}} \pi[V(\overline{x}) - (1+\lambda)[(\overline{\beta} - \overline{e}_1)\overline{x} + \psi(\overline{e}_0) + \psi(\overline{e}_1) - \overline{t}_{PUA}] + \\ +(1-\pi)[V(\underline{x}) - (1+\lambda)[(\underline{\beta} - \underline{e}_1)\underline{x} + \psi(\underline{e}_0) + \psi(\underline{e}_1) - \underline{t}_{PUA}] + \\ -(1-\pi)(1+\lambda)[\phi(\overline{e}_0) + \phi(\overline{e}_1)]. \quad (23)$$

The FOCs for problem 23 are[35]:

$$\psi'(\overline{e}_1) = \overline{x} - \frac{1-\pi}{\pi}\phi'(\overline{e}_1), \quad (24)$$

$$\psi'(\underline{e}_1) = \underline{x}, \quad (25)$$

[35] For concavity and strict concavity conditions see footnote 29

$$V'(\overline{x}) = (1+\lambda)(\overline{\beta} - \overline{e}_1), \tag{26}$$

$$V'(\underline{x}) = (1+\lambda)(\underline{\beta} - \underline{e}_1). \tag{27}$$

Conditions (24-27) have important implications. Note that, while 25, 26 and 27 give us the same conditions as in the cooperative case, condition 24 is different (compare it with 18), and is the key result of the paper, that we state in the following proposition:

Proposition 2. *Given Assumption 1, non cooperative behaviour under asymmetric information creates, compared to the cooperative case, a distortion in the cost reducing effort level required to the inefficient firm in pollution abatement activity.*

Consequences of Proposition 2 will be deeply analyzed in the next section. It is, however important, at this stage, to note that the result stated in Proposition 2 turns out to be quite strong, because even in a framework in which the agent has a profit function that is completely separable in the two kinds of "actions" he performs, non cooperative behaviour distorts the resulting abatement-related effort away from the second best. Furthermore, it is worth noting that, as in the symmetric information case, the way in which the two regulators divide the total transfer, for each type, is indeterminate.

To conclude this section we have to check that incentive compatibility is satisfied.

It can be shown that the effort level implied by 24 cannot be higher than the first best level implied by 25[36]. From these two first order

[36] Again (see footnote 30) we omit the proof, that follows the steps in Laffont and Tirole (1993, Ch.2 pp. 134-137)

conditions we can see that, because $\psi(.)$ and $\phi(.)$ are increasing functions, and given that $\overline{\beta} > \underline{\beta}$, then:

$$(\overline{\beta} - \overline{e}_0) > (\underline{\beta} - \underline{e}_0) \Rightarrow \overline{C}_0 > \underline{C}_0,$$
$$(\overline{\beta} - \overline{e}_1) > (\underline{\beta} - \underline{e}_1) \Rightarrow \overline{C}_1 > \underline{C}_1,$$

and, therefore, condition 11 and, then, 30 and 31 are satisfied.

5 Discussion of Results

5.1 Distortions related to non cooperative behaviour under asymmetric information.

We are now going to discuss the implications and extentions of Proposition 2. Comparing the FOCs in the two regulators and in the "summed up" regulator cases, it is clear that we could have different optimal levels of cost reducing effort in the inefficient firm's pollution abatement activity.

In the cooperative case, the condition determining the optimal $\overline{e}_1$, call it $\overline{e}_1^{co}$, is:

$$\psi'(\overline{e}_1) = \overline{x} - \frac{\lambda}{1+\lambda}\frac{1-\pi}{\pi}\phi'(\overline{e}_1), \tag{28}$$

while in the non cooperative framework, the optimal effort, call it $\overline{e}_1^{nc}$, is determined by:

$$\psi'(\overline{e}_1) = \overline{x} - \frac{1-\pi}{\pi}\phi'(\overline{e}_1), \tag{29}$$

We show in Appendix 2 that:

$$\overline{e}_1^{nc} \leq \overline{e}_1^{co}.$$

The effort level imposed by the regulator(s) and exerted by the inefficient firm in reducing the (marginal and average) cost of pollution abatement activity is thus (weakly) lower if the two regulators do not cooperate.

The lower effort level that results from non cooperative behaviour leads also to a higher level of pollution. We can see this from condition 26, that defines implicitly how $\overline{x}$ depends on $\overline{e}_1$ in equilibrium. Taking the total differential, and solving with respect to $\frac{d\overline{x}}{d\overline{e}_1}$ we get:

$$V''(x)\frac{d\overline{x}}{d\overline{e}_1} = -(1+\lambda) \Rightarrow$$
$$\Rightarrow \frac{d\overline{x}}{d\overline{e}_1} = -\frac{(1+\lambda)}{V''(\overline{x})} > 0,$$

because $V''(\overline{x})$ is assumed to be negative.

We can sum up the main results in the following Proposition:

Proposition 3. *Non cooperative behaviour between regulators under asymmetric information causes:*

(i) the optimal level of cost reducing effort, exerted by the inefficient firm in pollution abatement activity, to be distorted downward

both w.r.t. the first best and w.r.t. the second best cooperative case;

(ii) pollution (abatement) level of the inefficient type firm to be distorted in the same (opposite) direction.

These results are surprising, and different with respect to those obtained by Baron (1985). In that paper, a polluting Public Utility is regulated by a Federal Environmental Protection Office (EPO) that act as a leader and a state Public Utility Commission (PUC) that act as a follower in a Stackelberg game. In this game EPO moves first estabilishing emission policy while PUC, then, sets a pricing policy for the firm, that is privately informed about its efficiency in pollution reduction. His conclusions are that the burden of information rent extraction is "born" by the PUC's pricing policy, while the EPO can act as a free rider, making his policy contingent on the resulting price regulation. In this way the EPO can impose a higher degree of emission abatement, due to the fact that rent extraction is "performed" entirely by the PUC's policy. Therefore, noncooperative regulation results in a stricter emission standard than in the case of cooperation between the two agencies.

The consequences of our assumption that the two regulators are on the same hierarchical level are strong: the level of cost reducing effort in abatement activity and the level of pollution reduction are, at least in the case of the inefficient firm, downward biased, even with respect to the asymmetric information cooperative case. In our framework, environmental policy is, therefore, weaker if the asymmetry of information is confronted by two non cooperating regulators.

The downward bias resulting in our setting is due to the fact that the two regulators "divide" between themselves asymmetrically the tasks they would have pursued together in the cooperative case.

The regulator resulting from cooperation is concerned both with the social costs of net transfer and cost reimbursement, and with the firm's profits. When there is no cooperation instead, the PUA, that is not in charge of "environment related" efforts, takes into account firm's profits, while ER does not. Intuitively, the "summed up" regulator, in choosing the levels of effort required to the inefficient type, faces three partially countervailing incentives:

- the incentive to keep $\underline{t}$ and $\bar{t}$ as low as possible, and, then, to keep the efforts of the inefficient type as low as possible, because the rent and the "disutility function" are increasing in them; this pushes effort levels of the inefficient firm down;

- the incentive to keep the inefficient firm's effort levels as near as possible to first best, in order to keep cost reimbursement low; this pushes inefficient firm's efforts up;

- the incentive, given that the rent of the efficient firm is positively valued in the objective function of the "summed up" regulator, to keep expected firm's profits as high as possible; this pushes inefficient firm's efforts up.

On the other hand, ER's objective function does not include firm's profits, so that the third effect shown above for the "super regulator" does not arise when ER determines, non cooperatively, its transfer and effort policies. This is why the level of effort in the abatement activity, for which ER is in charge, is lower under non cooperative behaviour.

The same does not happen to the effort exerted by the inefficient firm in production activity, because PUA "inherits" the profit of the firm in its objective function. As a consequence, PUA has the same incentives as the "aggregate" regulator, resulting from cooperation, in designing the scheme and choosing, for both firm types, the level of effort he is in charge of.

The analytical consequences may be evaluated looking at the objective functions as rewritten, respectively, in 15, 21 and 23. While in the first two the efficient firm's expected rent has a negative weight $-\lambda$, in ER's objective function the negative weight is $-(1+\lambda)$. The environmental regulator does not attach any value to the firm's profits and, as a consequence, he perceives the rent as more socially costly.

It is, finally, interesting to investigate the consequences of Proposition 3 on the level of costs the regulators has to reimburse to the inefficient firm.

While the lower effort level raises average and marginal costs of pollution abatement, the higher level of pollution (lower level of abatement) leads to a decrease in overall costs for the abatement (pollution reducing) activity.

Total costs of abatement for the inefficient firm are:

$$\overline{TAC} = (\overline{\beta} - \overline{e}_1)\overline{x},$$

Suppose that the shift from a cooperative regime to a non cooperative one causes, from Proposition 3, a negative and sufficiently small $d\overline{e}_1$. Differentiating we get:

$$\frac{d\overline{TAC}}{d\overline{e}} = (\overline{\beta} - \overline{e}_1)x'(e) - x(e),$$

where $x(e)$ is implicitly defined by the equilibrium condition 24.

Given the assumptions regarding the positive value of x and the fact that we showed that $x'(e) > 0$, we get that the effect on expected abatement costs is ambiguous. It deserves further investigation whether, and under which conditions, the total costs of the inefficient firm's abatement raise or fall.

This is not the case, instead, of the transfer levels: a lower effort level will lower both the optimal transfers to the inefficient firm, and those to the efficient one.

We can state these results in the following proposition:

Proposition 4. *Under asymmetric information, non cooperative behaviour between regulators generates:*

(i) ambiguous effects on expected abatement costs ;

(ii) lower net transfers both to the efficient and to the inefficient firm.

5.2 Welfare and policy implications.

The welfare analysis is relatively straightforward.

When we assume non cooperative behaviour between regulators, the disjoint maximization of social welfare is subject to an additional constraint with respect to the cooperative maximization case. Namely, the solutions to the problem must be one of the possible Nash equilibria of the game the two regulators play. Social welfare is, therefore, unambiguously higher under cooperation between regulators.

This result is coherent with common sense. We can conclude that, from a social welfare point of view, when there is no hierarchical order between regulators, it is welfare improving to have the two regulators cooperating in estabilishing production and environmental policy.

More interesting insights can be derived under an "institutional" point of view. Our results suggest, in fact, "political economy" considerations in the shaping of the regulatory framework of a state or a federation of states, when environmental and public utilities policies share common features, as is the case, for example, in the electricity sector.

First of all, as alrady stressed, Proposition 3 suggests that the choice between cooperation and non cooperation can have very important consequences when two strongly linked matters are regulated by two different bodies. In this sense, we can label our analysis as positive.

Furthermore, through the evaluation of the effects of non cooperation on transfers, effort and pollution levels, our work could provide some insights on the forces determining regulatory structures in real life.

We may expect more cooperation between public bodies, in fact, if environmentalists' interests are strongly represented in the "board" that is in charge of shaping the regulatory framework (that is, for example, a central government), because under cooperation environmental policy is tighter.

On the other hand, if the overall regulatory structure is strongly oriented toward budget reducing policies, and if the transfers are sufficiently lower under non cooperation, we may expect a decentralization of competences.

6 Conclusions

We have developed a principal/agent framework to model a regulatory process in which a firm has to perform production and pollution reduction and these two activities are subject to control by two different regulators. We have, in particular, extended the standard principal/agent model with moral hazard and adverse selection (Laffont and Tirole (1993)) to account both for cooperation and for non cooperation in the regulatory process.

The main conclusions we reached are:

1. if the firm has no informational advantage, cost reducing efforts and pollution are at their first best level; non cooperation does not introduce any distortion;

2. in the case of asymmetric information, that is, when only the firm observes its efficiency and effort levels, if the two regulators cooperate we get the "standard" distortions: the trade off between rent extraction and efficiency causes lower cost reducing effort levels in both activities by the high-cost firm, while its pollution is higher. Non cooperative behaviour between regulators introduces a further downward distortion in the effort the inefficient firm exerts to reduce the cost of pollution reduction, and a further upward shift in its pollution level. The effect on total abatement costs of the inefficient firm is ambiguous, while net transfers, for both firm types, are lower in the non cooperative case.

Our analysis is subject to some *caveats*: the main shortcoming is tied to the assumption of the applicability of the Revelation Principle in a multi-principal framework. The evaluation of possible losses of generality is a topic of our current research. A strictly connected problem we are currently analysing is the indeterminacy of the transfer "division rule" between the non cooperating regulators. Furthermore, the assumption of additive separability of firm's profits in the two efforts might look strong; it is, however, useful to rule out common agency related distortions that are not due to asymmetries of information. As a consequence, the main result of our paper turns out to be rather strong.

Finally, it is very important to underline that the framework developed in this paper is quite general, and could be extended to any issue in which production efficiency and quality regulations are tightly linked.

A Appendix 1

The aim of this appendix is to show that the problems of the two regulators in the non cooperative case can be solved imposing the same set of constraints as in the cooperative case.

PUA makes a transfer to the firm to guarantee that it reveals its true type and that it gets at least its reservation profit level (normalized to 0).

Incentive compatibility requires that:

$$\underline{t}_{PUA} + \underline{t}_{ER} - \psi(\underline{\beta} - \underline{C}_0) - \psi(\underline{\beta} - \underline{C}_1) \geq \overline{t}_{PUA} + \overline{t}_{ER} - \psi(\underline{\beta} - \overline{C}_0) - \psi(\underline{\beta} - \overline{C}_1) \ (\underline{IC}),$$

$$\overline{t}_{PUA} + \overline{t}_{ER} - \psi(\overline{\beta} - \overline{C}_0) - \psi(\overline{\beta} - \overline{C}_1) \geq \underline{t}_{PUA} + \underline{t}_{ER} - \psi(\overline{\beta} - \underline{C}_0) - \psi(\overline{\beta} - \underline{C}_1) \ (\overline{IC}),$$

but PUA considers $\bar{t}_{ER}$, $\underline{t}_{ER}$, $\overline{C}_1$ and $\underline{C}_1$ as given. Adding up these two inequalities and moving to the RHS all the constants we get:

$$\int_{\underline{C}_0}^{\overline{C}_0} \int_{\underline{\beta}}^{\overline{\beta}} \psi''(\beta - C) d\beta dC \geq - \int_{\underline{C}_1}^{\overline{C}_1} \int_{\underline{\beta}}^{\overline{\beta}} \psi''(\beta - C) d\beta dC. \quad (30)$$

The problem here is that we cannot say anything about conditions on costs of activity 0 without knowing what happens to costs of activity 1 (that depend on ER's problem).

The ER, on the other hand, takes $\bar{t}_{PUA}$, $\underline{t}_{PUA}$, $\overline{C}_0$ and $\underline{C}_0$ as given. The IC constraint for ER may be written as:

$$\int_{\underline{C}_1}^{\overline{C}_1} \int_{\underline{\beta}}^{\overline{\beta}} \psi''(\beta - C) d\beta dC \geq - \int_{\underline{C}_0}^{\overline{C}_0} \int_{\underline{\beta}}^{\overline{\beta}} \psi''(\beta - C) d\beta dC. \quad (31)$$

Thus, we cannot impose conditions on costs of activity 1 without knowing what happens to costs of activity 0. Notice however that conditions (30) and (31) may both be rewritten as condition (11), with $\bar{t} = \bar{t}_{PUA} + \bar{t}_{ER}$ and $\underline{t} = \underline{t}_{PUA} + \underline{t}_{ER}$. Incentive Compatibility will therefore hold under the same conditions as in the cooperative case.

Individual Rationality constraints for the firm require that:

$$\underline{t}_{PUA} + \underline{t}_{ER} - \psi(\underline{e}_0) - \psi(\underline{e}_1) \geq 0 \ (\underline{IR}),$$
$$\bar{t}_{PUA} + \bar{t}_{ER} - \psi(\bar{e}_0) - \psi(\bar{e}_1) \geq 0 \ (\overline{IR})$$

It can be shown that Lemma 1 holds, so that $\overline{IR}$ and $\underline{IC}$ imply $\underline{IR}$.

We can follow, then, the same procedure as in the cooperative case. We solve the two regulators' disjoint maximization problems excluding

$\underline{IR}$, because redundant, and imposing only $\overline{IR}$ and $\underline{IC}$, showing then that the solutions verify $\overline{IC}$.

B Appendix 2

We are going to show the proof of the following result:

$$\overline{e}_1^{nc} \leq \overline{e}_1^{co},$$

where $\overline{e}_1^{co}$ (optimal effort level required, in the cooperative case, to the inefficient type firm in pollution reducing activity) is implicitly defined by

$$\psi'(\overline{e}_1^{co}) = \overline{x}^*(\overline{e}_1^{co}) - \frac{\lambda}{1+\lambda}\frac{1-\pi}{\pi}\phi'(\overline{e}_1^{co}),$$

while $\overline{e}_1^{nc}$ (optimal effort level required, in the non cooperative case,

to the inefficient type firm in pollution reducing activity) is implicitly defined by

$$\psi'(\overline{e}_1^{nc}) = \overline{x}^*(\overline{e}_1^{nc}) - \frac{1-\pi}{\pi}\phi'(\overline{e}_1^{nc}).$$

We call $\overline{x}^*(\overline{e}_1)$ the optimal value of $\overline{x}$ corresponding to each value of $\overline{e}_1$, implicitly defined by the first order condition:

$$V'(\overline{x}^*(\overline{e}_1)) = (1+\lambda)(\overline{\beta} - \overline{e}_1)$$

Therefore, $\overline{x}^*(\overline{e}_1^{co})$ is the value of $\overline{x}$ implicitly defined by the above FOC in the cooperative case and $\overline{x}^*(\overline{e}_1^{nc})$ is the value implicitly defined by the above FOC in the non cooperative case.

Define the following "pseudo objective function":

$$\mathcal{W}(\overline{e}_1, \overline{\beta}, \xi) = V(\overline{x}^*(\overline{e}_1)) - (1+\lambda)\left[(\overline{\beta} - \overline{e}_1)\overline{x}^*(\overline{e}_1) + \psi(\overline{e}_1)\right] - (\xi + \lambda)\frac{1-\pi}{\pi}\phi(\overline{e}_1),$$

where $\xi = 0$ in the cooperative case, while $\xi = 1$ in the non cooperative case. Given $\overline{\beta}$, it can be shown that $\overline{e}_1^{co}$ maximizes $\mathcal{W}(\overline{e}_1, \overline{\beta}, \xi = 0)$ while $\overline{e}_1^{nc}$ maximizes $\mathcal{W}(\overline{e}_1, \overline{\beta}, \xi = 1)$. Revealed preferences imply, therefore, that:

$$\mathcal{W}(\overline{e}_1^{co}, \overline{\beta}, 0) \geq \mathcal{W}(\overline{e}_1^{nc}, \overline{\beta}, 0).$$

$$\mathcal{W}(\overline{e}_1^{nc}, \overline{\beta}, 1) \geq \mathcal{W}(\overline{e}_1^{co}, \overline{\beta}, 1).$$

that is,

$$\begin{aligned} & V(\overline{x}^*(\overline{e}_1^{co})) - (1+\lambda)\left[(\overline{\beta} - \overline{e}_1^{co})\overline{x}^*(\overline{e}_1^{co}) + \psi(\overline{e}_1^{co})\right] - \lambda\frac{1-\pi}{\pi}\phi(\overline{e}_1^{co}) + \\ & -V(\overline{x}^*(\overline{e}_1^{nc})) + (1+\lambda)\left[(\overline{\beta} - \overline{e}_1^{nc})\overline{x}^*(\overline{e}_1^{nc}) + \psi(\overline{e}_1^{nc})\right] + \lambda\frac{1-\pi}{\pi}\phi(\overline{e}_1^{nc}) \geq 0 \end{aligned}$$

$$\begin{aligned} & V(\overline{x}^*(\overline{e}_1^{nc})) - (1+\lambda)\left[(\overline{\beta} - \overline{e}_1^{nc})\overline{x}^*(\overline{e}_1^{nc}) + \psi(\overline{e}_1^{nc})\right] - (1+\lambda)\frac{1-\pi}{\pi}\phi(\overline{e}_1^{nc}) + \\ & -V(\overline{x}^*(\overline{e}_1^{co})) + (1+\lambda)\left[(\overline{\beta} - \overline{e}_1^{co})\overline{x}^*(\overline{e}_1^{co}) + \psi(\overline{e}_1^{co})\right] + (1+\lambda)\frac{1-\pi}{\pi}\phi(\overline{e}_1^{co}) \geq 0 \end{aligned}$$

Summing up these two conditions we get:

$$\frac{1-\pi}{\pi}\left[\phi(\overline{e}_1^{co})-\phi(\overline{e}_1^{nc})\right]\geq 0 \rightarrow \overline{e}_1^{co}\geq \overline{e}_1^{nc}$$

as in the text.

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