Weak Enforcement of Environmental Policies: A Tale of Limited Commitment and Limited Fines*

Yolande Hiriart† David Martimort‡ Jérôme Pouyet§

12th March 2010

Abstract

When a firm undertakes activities which are risky for the environment, the conflict between social and private incentives to exercise safety care requires imposing fines in case a damage occurs. Introducing asymmetric information on the firm's wealth, we show that the fines and probabilities of investigation are systematically too low compared to their optimal level under complete information. This effect is exacerbated when the public agency in charge can no longer commit to an investigation strategy. Compounding asymmetric information with a government failure provides a possible explanation of the significant trend in practice towards a weak enforcement of environmental policies.

Keywords. Risk regulation, moral hazard, adverse selection, enforcement, fines.

JEL Classification. L51.

*We are grateful to Michel Moreaux for having kindly invited us to this special issue of *Annales d'Économie et de Statistique* and to two referees for their insightful comments. All errors are ours.

†Toulouse School of Economics (IDEI-LERNA). Address: IDEI-LERNA, Manufacture des Tabacs, Aile Jean-Jacques Laffont, 21 Allée de Brienne, 31000 Toulouse, France.

‡Toulouse School of Economics (EHESS, IDEI-GREMAQ). Address: IDEI, Manufacture des Tabacs, Aile Jean-Jacques Laffont, 21 Allée de Brienne, 31000 Toulouse, France.

§Paris School of Economics (CNRS). Address: 48 boulevard Jourdan, 75014 Paris, France.

1 Introduction

A common theoretical wisdom in the field of environmental economics, largely inspired by the seminal works of imminent scholars like Coase and Pigou, suggests that a whole array of policy instruments is actually available to induce polluters to internalize the impact of their activities on third-parties. To achieve this goal, regulators can rely on Pigovian taxes, norms and standards designed ex ante to control predictable pollutions. Along the same lines, in case of less predictable environmental accidents, judges may apply liability rules specified by Tort Law to compensate harmed third-parties and punish misconduct ex post.

Yet, casual evidence casts significant doubts on this theoretical paradigm and brings more contrasted evidence on the efficiency of environmental policies. Scholars, regulators, practitioners, interest groups and even the media have repeatedly expressed concerns on whether environmental policies are really enforced and, as such, reach their goal. In particular, the size of punishments inflicted for misconduct and their likelihood is often found to be dramatically low and known to be unable to induce polluters to internalize the true costs they inflict on third-parties. For instance, Ashford and Caldart (2008, Chapter 4, p. 201) reported that *"a 1995 Department of Justice study of 762,000 tort cases found that only 12000 of these went to trial and that only 364 (3 percent) resulted in punitive damages.* The French newspaper *Le Monde* (dated August 2009, 5th) mentioned that NGOs and governmental agencies were keen to figure out of a significant gap between the sharp increase in the number of Laws enacted to protect the environment and their effective enforcement. In our view, the limited enforceability of environmental policies is also a topic that has been to a large extent overlooked by the recent so-called *Grenelle de l'Environnement* that sets up the French stage for environmental policy reforms. Ignoring these limits in public intervention certainly pushes most scholars and practitioners to be overly optimistic about what can really be done with corrective environmental policies.

One of the major issues in environmental economics, both from a theoretical and a practical viewpoint, is thus to understand why and under which circumstances public policies aimed at correcting environmental externalities fail to achieve their goal.

Bulk of the argument. This paper analyzes the reasons why and the circumstances under which strongly inefficient environmental policies arise. The basic thrust of our analysis is that very low powered incentives in taking care of the environment and weak enforcement result from the compounding of two contractual imperfections. The first one is asymmetric information, which is a redhibitory obstacle to any efficient regulatory policy. Asymmetric information first bears on safety care, but also on the financial capacity of firms. Even when polluters can easily be found liable, they may not always be able to pay for the damages inflicted on others. Even worse, these polluters who are wealthy enough may strategically hide assets to escape liability payments. Solving this problem of asymmetric information on the ability to pay for damages requires to give up the traditional command-and-control perspective, highly attractive to practitioners, in order to adopt an incentives-based approach. However, most often, incentives-based mechanisms are not enough by themselves and they need to be accompanied by a whole administrative and institutional apparatus (investigation agencies, monitoring devices, judicial litigation, checks by stakeholders, etc...).[1] The goal of this investigation apparatus is to foster compensatory payments towards harmed third-parties and, more generally, to reduce the costs generated by asymmetric information for society.

This paper shows how the institutional setting, the scope and organization of regulatory agencies in charge, and their ability to enforce their monitoring strategies all affect private incentives for safety care. Variations in this institutional setting and in the strength of government are thus the second key component affecting the intensity of public investigation. In particular, agencies and public bodies which lack a strong ability to commit to their investigation policies may find it harder to solve the asymmetric information problem and raise enough liability payments from misbehaving agents. Ultimately, this reduces the private incentives for undertaking safety care.

To summarize, we argue in this paper that environmental policies are trapped in inefficient outcomes because a market failure is reinforced by a government failure. The market failure is due to asymmetric information on the financial capacity of polluters: this judgment-proofness is a serious impediment to the private Coasean solutions to such environmental problems. The government failure is related to the agencies' limited ability to commit to an investigation policy that could unveil such private information.

Summary of the model and results. This point is developed in a by-now standard model of environmental liability à la Shavell (1984a, 2005). In such an environment, the perspective of being fined up to the level of the damages inflicted on third-parties induces polluters to fully internalize all the costs associated to their activity. This should reduce the probability and/or the size of an environmental accident to their first-best level. A major obstacle to first-best allocative efficiency comes with the firm's limited liability. Assuming that there exist two kinds of firms, some being rich enough to pay for the damages caused and others being unable to cope with them, we investigate the strategic incentives of polluters to hide assets[2] and

[1] Power (1999).

[2] Ringleb and Wiggins (1990) provided some empirical analysis of these incentives. They studied the

the incentives of public bodies to investigate the firms' claims on their asset holdings. This simple benchmark allows us to draw a link between the power of the polluters' incentives to exercise precautionary care and the administrative cost of investigation.

Next, we assume that the agency in charge of unveiling the value of the firm's assets has a limited ability to commit and cannot decide on the probability of investigation beforehand, i.e. when designing the set of fines targeted to polluters with different wealth levels. This assumption transforms the Stackelberg game between the agency and polluting firms that arises when public authorities can commit beforehand into a simultaneous moves game. This simultaneous moves game has a mixed-strategy equilibrium: firms cheat by hiding their level of wealth with some positive probability, whereas the agency investigates firms' assets randomly.[3] We analyze this mixed-strategy equilibrium and observe a strong similarity between the outcomes obtained with and without commitment. Under limited commitment, everything happens as if the cost of investigation was scaled up both in absolute terms and at the margin. This has a consequence on the optimal policy of an agency: it reduces the likelihood of an intervention, but also the level of the fines that can be targeted on wealthy firms, and thus, their incentives to take care. The government imperfection reinforces a market failure to end up with very low incentives and excessively weak punishments. Beyond, our analysis shows that there is a one-to-one mapping between the predictions of the model with and without commitment. Indeed, the latter can be obtained by properly modifying the structure of the cost of investigation in the model with full commitment. This transformation incorporates all the complexities of the mixed-strategy equilibria that arise under limited commitment keeping implicit the exact expression of the randomization probabilities used in these equilibria. This result is neither obvious nor trivial, and is of general interest beyond our specific application.

Literature review. The theme of the limited enforcement of environmental policies has long been of interest for environmentalists as the impressive collection of readings put together by Russell (2003) testifies.[4] However, this earlier literature based mostly on variations of Becker

polluting firms' scale of activities and their incentives to vertically divest polluting activities to undercapitalized subsidiaries. Pitchford (2001), Boyer and Laffont (1997) and Hiriart and Martimort (2006, 2007) have studied how extending the liability towards stakeholders linked to the limited liability venture can help, though it may have detrimental effects on incentives by modifying contractual clauses. Also, heterogenity in wealth levels is a cornerstone assumption of the literature that followed Shavell (1984a).

[3] For those readers who feel uncomfortable with the use of such a mixed-strategy equilibrium, we refer to the purification techniques provided by Harsanyi (1973). That paper shows that the probability distributions over strategies induced by the pure-strategy Bayesian equilibria of a game under incomplete information converge towards the distributions induced in the mixed-strategy equilibria of the complete information game. We conjecture that introducing private information on the cost of audit for the regulatory agency and on the cost of exercising effort for the firm would provide such a perturbation.

[4] See also Bontems and Rotillon (1999) for an earlier contribution on this topic.

(1968)'s argument adapted to the environment context is mostly interested in determining optimal enforcement policies and fines assuming no government failures whatsoever. In other words, these second-best policies are derived in a context where the objectives of public agencies and Courts of Law are perfectly aligned with social welfare, and public policies are backed by a strong commitment power.

In the field of economic regulation, limits on this commitment power have been analyzed by Khalil (1997). This paper considers a model à la Baron and Myerson (1982) to which a model of audit is appended. Costly auditing is indeed necessary to check the regulated firm's report on its costs, its own piece of private information. The key assumption that distinguishes this paper from the earlier literature is that there is no commitment to an audit strategy.[5] The regulator mixes between investigating or not the firm's report whereas the firm mixes between reporting truthfully its costs or not. Our model shares these modeling features but is different in terms of the objective functions of public bodies. In Khalil (1997), extracting the firm's information rent is one of the regulator's objectives, whereas our public body only cares about efficiency from an ex ante viewpoint; an assumption which is more in line with the tradition of the Law and Economics literature.[6] This makes the contracting solution to the non-commitment problem significantly easier in our framework. This simplicity is then at the source of the one-to-one correspondence between the solutions to the commitment and the non-commitment games.

Boyer, Lewis and Liu (2000) have also analyzed how regulatory standards must be designed anticipating these mixed strategies of public auditors and private parties which are audited for malfeasance. The probability of being cited for a violation of the standards is an exogenous function of standards and of the strategies of auditors and auditees. A particular attention is given to whether an increase in standards boosts both parties' incentives. Although we share with this paper the concerns for a better design of regulatory policies, anticipating misbehavior of public auditors and audited firms, we endogenize these parties' misbehavior from first principles.

Our focus on limited commitment as a source of government failure contrasts and is complementary of an earlier literature which has analyzed corruption and collusion between public auditors and auditees as a limit to law enforcement. Becker and Stigler (1974) Mookherjee and P'ng (1995), Garoupa (1997), Polinsky and Shavell (2001) have studied the impact of corruption on the likelihood of investigation in various contexts, taking institutions as given.

[5]See for instance Swierzbinski (1996) for a similar regulation model with full commitment to an auditing policy, but also the seminal papers by Townsend (1979), Gale and Hellwig (1985) and Border and Sobel (1987) in the field of financial contracting.

[6]See Shavell (1984a) and Garoupa (1997), for instance.

Instead Hiriart, Martimort and Pouyet (2009b) justify the separation between regulators and judges as an optimal way of preventing collusion. They also draw the consequences of such a fragmented institutional design for monitoring strategies. A common theme of these papers is that collusion, like limited commitment, calls for reducing the regulatory stakes and, in particular, calls for lowering fines for misconduct.

Finally, and on a more technical note, our model contains elements of adverse selection (the wrongdoing firm's wealth is privately known) and moral hazard (its precautionary effort is non-observable). The imperfect knowledge that public agencies have on the firm's wealth puts a limit on the fines and thus, induces a lower effort. This interaction between adverse selection and moral hazard is reminiscent of Hiriart and Martimort (2006). This paper has analyzed the link between the distortions due to an adverse selection problem (hidden marginal cost of production) and a moral hazard problem (choice of safety care) in a model of extended liability, where the contractual relationship between a buyer and a seller is affected by the threat of paying compensatory damages in case of an environmental accident.

Organization of the paper. Section 2 presents our theoretical model. Section 3 develops the benchmark with complete information on the firm's wealth. Section 4 analyzes the game with asymmetric information and full commitment. Section 5 introduces limited commitment on the regulatory agency's side. Section 6 briefly concludes by pointing out alleys for further research. Proofs are relegated to an Appendix.

2 The Model

Consider a firm running a socially risky activity. The probability of an accident affecting third-parties is reduced when this firm exercises safety care. Moral hazard in choosing this variable calls for imposing fines in case of an environmental damage. The financial capacity of the firm is unobservable. This adverse selection parameter maybe calls for additional public policy devices such as investigations. This package of instruments aims at fostering the firm's prevention effort together with raising as much as possible fines available to compensate victims and/or restore the environment.

Moral hazard. Following an accident, third-parties suffer from a damage of social value $D > 0$. The probability of such an accident, $1 - e$, is decreasing in the firm's effort e. Exercising effort e costs $\psi(e)$ to the firm where $\psi' \geq 0$, $\psi'' > 0$, $\psi(0) = 0$ and $\psi(\cdot)$ satisfies the Inada conditions $\psi'(0) = 0$ and $\psi'(1) = +\infty$.[7] We denote $\varphi = \psi'^{-1}$.

For further references, let us define the first-best level of effort e^{FB} as

$$D = \psi'(e^{FB}).$$

Moral hazard stems both from the non-verifiability of effort and from the conflict between social and private incentives to exercise care.

Of course, imposing to the firm a fine f equal to D in case of an environmental accident would implement the first-best level of effort e^{FB}, even when the effort level is non-verifiable. Note that the first-best level of care obviously does not depend on the firms' financial capacity. However, the firm has limited wealth w and is protected by limited liability. Then, it cannot always cover the damages caused. More specifically, we assume that the firm's seizable assets take values in $\{\underline{w}, \bar{w}\}$ with respective probabilities ν and $1 - \nu$. We denote $\Delta w = \bar{w} - \underline{w} > 0$ the spread of uncertainty on the firm's level of wealth. Although this wealth distribution is common knowledge, the regulatory agency is not aware of the firm's precise asset holdings.[8]

Moreover, we assume that $\underline{w} < D < \bar{w}$. The first inequality means that a poor firm cannot cover the loss incurred by third-parties in case of an accident.[9] The second inequality means that, *a priori*, the richer firm can (and should) pay that amount.[10] As is made clear, this second assumption is made for convenience mostly as it allows to focus on situations where the audit probability is interior: our results would carry over qualitatively to the case $D > \overline{w}$.[11]

Firms running risky activities are generally protected by limits on their liability since the consequences of large scale accidents are so staggering that no insurance companies would fully insure them (see, e.g., the Price-Anderson Act in the U.S. for nuclear activities). Moreover, on top of institutional restrictions, risky ventures often enter into various activities

[7] The cost of effort is non-monetary for simplicity although our modeling could easily be modified to take into account monetary costs without changing our main results.

[8] Lewis and Sappington (2000, 2001) have also analyzed optimal contracting with liability constraints but do not consider the possibility of an investigation strategy that could unveil the true value of assets as we do below.

[9] The case where $D < \underline{w}$ is actually less interesting. The harm done is then small enough so that even the less wealthy firms can pay the Pigovian tax that makes them perfectly internalize the impact of their precautionary effort on the environment. This case is akin to the case where w is common knowledge.

[10] Note that this case may also well capture the possibility that, sometimes, more funds can be seized from contractual partners of the firm by means, for instance, of a regime of extended liability (see Footnote 2 for references). Firms with such wealthy parents or stakeholders are those for which $w = \bar{w}$. It can also capture the case of punitive damages, where an injurer is asked to pay compensatory damages in excess to effective harm (see Shavell (2004), p.243).

[11] See the proof of Proposition 1 in the Appendix for a formal treatment.

("flight-by-night" techniques, spin-offs of subsidiaries, ...) which goal is precisely to hide seizable assets. In the sequel, we are particularly interested in understanding how these strategic incentives to hide assets affect equilibrium fines and investigation strategies.

Contracts and Monitoring. A regulatory incentive scheme stipulates the firm's fine in case of an environmental accident. Given the firm's strategic incentives to shade assets and claim being poorer than what it really is for escaping liability payments, we append the possibility that, with probability p, the agency in charge checks the firm's claim. Such an investigation might for instance result from litigation in Courts of Law.[12] Investigating the firm with probability p has a social cost $C(p)$ such that $C' \geq 0$, $C'' > 0$, $C(0) = 0$ and $C(\cdot)$ satisfying the Inada conditions $C'(0) = 0$ and $C'(1) = +\infty$.

From the Revelation Principle,[13] there is no loss of generality in focusing on direct revelation mechanisms that stipulate a fine $t(\hat{w})$ and a probability of investigation $p(\hat{w})$ as a function of the firm's claim $\hat{w}$ on its wealth.[14]

It is also a trivial observation that necessarily $p(\bar{w}) = 0$. There is no need to investigate a firm that claims being rich enough to cover damages incurred by third-parties. Instead, such an investigation is likely when the firm pretends being undercapitalized and we expect $p(\underline{w}) > 0$, a result that will be confirmed below.

We will first suppose that the environmental agency can commit itself to an investigation probability as a function of the firm's claim beforehand. Then, we will relax this assumption and assume that the agency cannot commit to such a monitoring policy although it can still commit to the fines when inspection unveils more wealth than announced by the firm. As the reader may have already guessed, assuming a limited commitment in an auditing context invalidates the Revelation Principle, at least under its standard form.[15]

Social objective. Social welfare maximization amounts to minimizing the overall social cost of constraining the economic activity and the cost of investigating the firm to check its

[12]We assume that the regulatory and the judicial branches design cooperatively their interventions. For the pros and cons of such a separation, we refer to Hiriart, Martimort and Pouyet (2009a, 2009b).

[13]Myerson (1982).

[14]Townsend (1979), Gale and Helwig (1985) and Border and Sobel (1987) provided analyzes of such incentive mechanisms with costly state verification in a framework of debt contracts where income is unobservable but claims can be checked with some probability.

[15]Bester and Strausz (2001) showed that a weak version of the Revelation Principle holds with the mechanism stipulating as many options as the cardinality of the types space (here 2) but with those types adopting mixed reporting strategies ("untruthful" reporting). We will follow their approach in the sequel.

assets value if needed. Formally, the regulatory agency's objective is simply to minimize[16]

$$SC = (1 - e)(D + C(p)) + \psi(e).$$

Minimizing this social cost is akin to maximizing the sum of the firm's expected profit $U = \Pi - (1-e)f - \psi(e)$, where Π is the social value of the firm's activity (assuming this firm can capture this whole surplus through first-degree price discrimination, for instance, and that it does not depend on the firm's effort choice e), third-party's net expected damages after having been compensated $(1 - e)(f - D)$ and the expected cost of investigation borne by taxpayers $(1 - e)C(p)$.

To be in line with a standard assumption in the Law and Economics literature,[17] the regulatory agency has no ex ante redistributive concerns and only cares about allocative efficiency. Our analysis could easily be extended to allow for such concerns. For instance, the regulatory charter could be more or less aligned with the harmed third-parties depending on whether the risk at stake is global in nature or more local (i.e. whether it affects or not a significant share of the electorate). Our modeling choice is made for simplicity, but our results would hold more generally irrespective of these specifications.

Ex post, i.e. in case an investigation takes place and detects a lie in the firm's announcement, we assume that the agency does not care at all on the firm's payoff. In other words, allocative efficiency is the sole concern of the agency as long as it has a strong commitment ability. Otherwise, public pressures to raise funds to compensate victims and punish misbehavior following detection change the public agency's objectives a bit. This simplifying assumption (that may seem extreme for some readers) will help us to isolate the worst conditions when considering settings with limited commitment.[18]

Timing. Under *full commitment* to an investigation probability by the regulatory agency, the timing of the regulatory game unfolds as follows.

- Date 0. The firm privately learns its wealth level w.
- Date 1. The regulatory agency commits to an incentive scheme $\{(p(\underline{w}), f(\underline{w})), (0, f(\bar{w}))\}$.

[16] It is a matter of normalization whether the administrative cost of investigation is counted ex ante or only ex post, following an investigation.

[17] Shavell (1984a) and Garoupa (1997) among others.

[18] The same results would be obtained by assuming right away that the weight put on the firm's profit both ex ante and ex post remains the same but is less than the weight given to the victims' welfare. Baron and Myerson (1982)'s model of regulation relied on such an assumption. Laffont and Tirole (1993) motivated a similar assumption from budgetary pressures and a positive cost of social funds.

• Date 2. The firm chooses within this menu its most preferred option and exercises an effort $e \in [0,1]$.

• Date 3. An environmental accident may occur. The regulator imposes the fine corresponding to the firm's announcement. In case an environmental accident did take place and if the firm has reported a level of wealth $\underline{w}$, the agency checks that claim with probability $p(\underline{w}) \in [0,1]$.

The previous timing corresponds to the case where the agency plays as a Stackelberg leader and reaches thereby its highest possible payoff. This may be viewed as an overly optimistic assumption on the public authorities capabilities. This is the reason why we give a particular attention to the case of limited commitment.

Under *limited commitment*, the regulator cannot commit to a probability of investigation beforehand. The agency commits to a menu of fines. The firm's report on its wealth level and the agency's probability of investigation result then from simultaneous mixed strategy behavior in a Nash equilibrium taking place at date 2. The firm lies a bit because it expects that the agency will not investigate with probability one a low claim. The agency does not always investigate because it expects the firm to tell the truth with some positive probability.

Note that our timing is robust to the date at which the firm makes a claim on its wealth. Alternatively, and probably more in line with actual institutional practices and, in particular, judicial litigation where such reports are emulated, we could as well have assumed that the announcement stage is made following an environment accident only. This would leave our results unchanged as it can be easily seen. There are also recent legislations that require risky firms to announce their wealth as a prerequisite for running the activity.[19]

3 Complete Information on Wealth

Suppose first that the firm's level of wealth is common knowledge. The optimal policy trivially consists in imposing the fines

$$f^*(\underline{w}) = \underline{w} \text{ and } f^*(\bar{w}) = D. \tag{1}$$

These fines induce the following effort levels

$$e^*(\underline{w}) = \varphi(\underline{w}) < e^{FB} \text{ and } e^*(\bar{w}) = \varphi(D) = e^{FB}. \tag{2}$$

[19]See the french *Loi Bachelot* enacted in 2003.

The fine for a poor firm is limited by its asset holdings, and the corresponding effort level that minimizes its expected private cost is $e^*(\underline{w})$. This level is strictly less than the first-best effort e^{FB}. Instead, a rich firm is known to be able to pay D and is requested to do so in case of an accident. This allows to induce the first-best effort from such a firm.

4 Asymmetric Information on Wealth and Full Commitment

The system of fines described in (1) is not incentive compatible when wealth levels are not common knowledge: a rich firm may want to strategically hide assets to reduce its exposure to possible fines in case of an accident.

An adverse selection incentive compatibility constraint must be satisfied to induce rich firms to tell the truth on their assets. This constraint stipulates that the rich firm prefers to pay the fine $f(\bar{w})$ in case of an accident and never being investigated, rather than paying the lower fine $f(\underline{w}) = \underline{w}$ targeted to a poor firm but being investigated with probability $p(\underline{w})$ and fined for hiding assets. Of course, the *Maximal Punishment Principle*[20] applies to a firm that is caught hiding liabilities: the whole assets of this firm are taken away to foster incentives for truthtelling. This incentive constraint can thus be written as:

$$f(\bar{w}) \leq (1 - p(\underline{w}))\underline{w} + p(\underline{w})\bar{w} = \underline{w} + p(\underline{w})\Delta w. \tag{3}$$

This incentive constraint is necessarily binding at the optimum under asymmetric information. In addition, it is straightforward to see that investigating with some positive probability $p(\underline{w})$ a firm that pretends to be undercapitalized relaxes this constraint.

Note also that the fine level $f(\bar{w})$ imposed on a rich firm, obtained when (3) is binding, is lower than the firm's wealth $\bar{w}$. The *Maximal Punishment Principle* tells us that some extra fines can and should be imposed on this rich firm in case the investigation unveils hidden assets, but no such large fines should be imposed in the case of a truthful report. Indeed and quite intuitively, a rich firm must be somewhat rewarded or, more precisely, punished in a relatively weak way for causing harm, when it had announced to be wealthy enough to cover damages. Hence, it is optimal not to request all the assets of such a firm.

[20] Becker (1968).

From this, it immediately follows that a rich firm's effort level is:[21]

$$e(\bar{w}) = \arg\min_{e} \ (1-e)f(\bar{w}) + \psi(e) \Leftrightarrow e(\bar{w}) = \varphi(\underline{w} + p(\underline{w})\Delta w). \tag{4}$$

Given that a poor firm pays a fine $\underline{w}$ and exercises the effort level $e(\underline{w}) = \varphi(\underline{w})$, the rest of the minimization of the expected social cost can be summarized as:[22]

$$(\mathcal{P}^{FC}) : \min_{p(\underline{w})\in[0,1]} \Phi^{FC}(p(\underline{w})) \equiv (1-\nu)\{(1-\varphi(\underline{w}+p(\underline{w})\Delta w))D + \psi(\varphi(\underline{w}+p(\underline{w})\Delta w))\}$$

$$+\nu(1-\varphi(\underline{w}))C(p(\underline{w})).$$

Optimizing this objective function and observing that the optimum is always interior, we obtain:

Proposition 1 *Assume asymmetric information on wealth and effort together with full commitment to an investigation probability by the regulatory agency. The optimal effort level for a rich firm is lower than its first-best value,* $e^{FC}(\bar{w}) < e^{FB}$ *with*

$$D - \psi'(e^{FC}(\bar{w})) = \frac{\nu(1-\varphi(\underline{w}))}{1-\nu}\frac{C'(p^{FC}(\underline{w}))}{\Delta w}\psi''(e^{FC}(\bar{w})) > 0 \tag{5}$$

and

$$e^{FC}(\bar{w}) = \varphi(\underline{w} + p^{FC}(\underline{w})\Delta w), \tag{6}$$

where $p^{FC}(\underline{w})$ *is the positive probability of investigation of a poor firm and* $p^{FC}(\underline{w}) < \tilde{p}(\underline{w}) = \frac{D-\underline{w}}{\Delta w}$.

The interpretation of this proposition is straightforward. Observe first that (6) implies that the level of investigation $\tilde{p}(\underline{w})$ together with $f(\bar{w}) = D$ would induce the first-best level of effort for a rich firm. Starting from this high level of investigation, it is optimal to reduce it by a small amount. This has only a second order effect on the marginal social cost of effort when the firm is a rich one, since the effort level is first-best at this level of investigation. However, reducing the probability of investigation has a first-order effect in reducing its administrative cost. *A contrario*, zero investigation would mean that a rich firm pays the same fine $\underline{w}$ as a poor one. This would induce too low the level of effort. Given our Inada conditions on the cost of investigation, it is optimal to increase the probability of investigation for a firm claiming a low level of wealth by a small amount in order to boost a

[21] Recall that, at equilibrium, this firm tells the truth on its financial capacity since the corresponding incentive compatibility constraint is taken into account when defining the optimal policy. Its compensatory payment in case of accident is thus $f(\bar{w})$.

[22] The superscript FC denotes *full commitment*.

rich firm's effort. Overall, the optimal probability of investigation is interior and induces an effort level which is lower than first-best for a rich firm.

The optimality condition (5) that determines jointly with (6) this second-best level of effort and the probability of investigation is an important step in our analysis. It shows that the second-best effort distortion is strongly linked to the investigation technology. From a more technical viewpoint, the solutions to the adverse selection and moral hazard problems are deeply intertwined. A higher marginal cost of investigation reduces its likelihood. This in turn reduces the fine $f(\bar{w})$ towards $f(\underline{w}) = \underline{w}$ so that screening possibilities diminish. Finally, it decreases a rich firm's effort.

The investigation cost function reflects the institutional characteristics. The optimality condition (5) thus offers a channel by which institutional characteristics affect incentives. This channel will attract our attention in the next section when we will weaken the institutional ability and focus instead on the case of limited commitment.

Example. Suppose that $\psi(e) = \frac{e^2}{2\mu}$ and $C(p) = \frac{p^2}{2\lambda}$ with μ and λ being non-negative, and small enough to ensure interior solutions.[23] Then, we can easily compute the following closed-form solution:

$$e^{FC}(\bar{w}) = \frac{\mu D + \frac{\nu \underline{w}(1-\mu\underline{w})}{(1-\nu)\lambda\Delta w^2}}{1 + \frac{\nu(1-\mu\underline{w})}{(1-\nu)\mu\lambda\Delta w^2}},$$

and

$$\tilde{p}(\underline{w}) = p^{FC}(\underline{w}) \left(1 + \frac{\nu(1-\mu\underline{w})}{(1-\nu)\lambda\mu(\Delta w)^2}\right).$$

On these formula, we can immediately check that $p^{FC}(\bar{w})$ and $e^{FC}(\bar{w})$ both increase when λ increases. As the cost of investigation diminishes, it becomes more attractive to investigate, though $p^{FC}(\underline{w})$ remains bounded from above by $\tilde{p}(\underline{w})$. An increase in λ raises the likelihood of investigation which, in turn, allows to increase the fine paid by a rich firm, thereby boosting its effort.

As the disutility of effort increases and the moral hazard problem worsens, i.e. μ decreases, the probability of investigation also decreases, pushing effort down.

Finally, a more disperse distribution of wealth (Δw being greater) relaxes the adverse selection incentive constraint. Indeed, in case of an investigation (even if the latter becomes very unlikely), the extra fine paid by a rich firm whose wealth has been unveiled is so large that strategically hiding assets has little attractiveness. This raises equilibrium fine and effort for such a rich firm. ■

[23]This assumption replaces the Inada conditions that do not hold for these quadratic functions.

5 Asymmetric Information on Wealth and Limited Commitment

The optimal contractual design exhibited in Section 4 supposes that the regulatory agency can fully commit to a probability of investigation. This assumption allowed us to describe an upper bound on the outcome that can be achieved under asymmetric information; an hypothetical setting that can be viewed as being highly optimistic on the way agencies operate in practice.

More precisely, under full commitment, the agency induces information revelation because it commits itself to an investigation probability that is indeed doomed to fail: on the equilibrium path, firms tell the truth. Hence, once a poor firm has actually claimed to be of $\underline{w}$-type, there is no longer any reason for running an investigation since, at the equilibrium of the full commitment game, only such poor firms make such a claim. However, anticipating the absence of investigation, a rich firm would thus certainly change its behavior and pretend to be poor in order to save assets.

Let us now consider a more realistic setting where the agency cannot commit to an investigation probability. To simplify the analysis, we nevertheless assume that a commitment to the level of fines is still possible.

Under limited commitment, the game between the agency and the rich firm has a mixed-strategy equilibrium: there is no longer any reason to expect a truthful behavior from the firm when it reports its assets. Let us denote by $\varepsilon \in [0, 1]$ the probability that the $\bar{w}$-firm tells the truth at equilibrium when it is indifferent between telling the truth or not, i.e. when the following condition holds:

$$f(\bar{w}) = \underline{w} + p(\underline{w})\Delta w. \tag{7}$$

Conjecturing the mixed-strategy of the regulator and anticipating the corresponding expected fine when either telling the truth or lying on its wealth, a rich firm chooses an effort which is still given by (4): lying or not gives ex post the same payoff to the firm. The precise way by which a rich firm mixes has thus no impact on its ex ante incentives to take care.

Consider now the agency's behavior. It must be indifferent between investigating or not the firm's claim. Given the latter's reporting strategy, the cost of investigation following a $\underline{w}$-announcement and an accident is $C(p(\underline{w}))$.

Since the agency does not care ex post about the firm's payoff, the benefit of such an investigation is to raise some extra money since it may reveal, following an accident, hidden wealth by a rich firm that lied on its asset holdings. Taking (7) into account, this social benefit can be written as

$$\left[\frac{(1-\nu)(1-\varepsilon)(1-\varphi(f(\bar{w}))}{\nu(1-\varphi(\underline{w}))+(1-\nu)(1-\varepsilon)(1-\varphi(f(\bar{w})))}\right]p(\underline{w})\Delta w,$$

where the bracketed term is the posterior probability of facing, following an accident, a rich firm with a low claim on its financial capacity and where $f(\bar{w})$ satisfies (7).

The agency's indifference between investigating or not is finally given by the following equality:

$$C(p(\underline{w}))=\left[\frac{(1-\nu)(1-\varepsilon)(1-\varphi(f(\bar{w}))}{\nu(1-\varphi(\underline{w}))+(1-\nu)(1-\varepsilon)(1-\varphi(f(\bar{w})))}\right]p(\underline{w})\Delta w. \tag{8}$$

Note that this condition can never hold when $\varepsilon=1$, i.e. when a rich firm always reports truthfully its wealth. Making the agency indifferent between investigating or not requires that this firm lies with a strictly positive probability at equilibrium on its asset holdings.

Up to terms which are constant and related to the social value of the effort's choice made by a poor firm, the ex ante social cost for the agency can finally be written as:

$$(1-\nu)((1-\varphi(\underline{w}+p(\underline{w})\Delta w))D+\psi(\varphi(\underline{w}+p(\underline{w})\Delta w)))$$

$$+(\nu(1-\varphi(\underline{w}))+(1-\nu)(1-\varepsilon)(1-\varphi(\underline{w}+p(\underline{w})\Delta w)))C(p(\underline{w})).$$

Note that this expression replicates the full commitment social cost when $\varepsilon=1$. But, remember again that such a truthful revelation of wealth by a rich firm cannot occur without violating the agency's indifference condition (8).

Taking into account the fact that a $\bar{w}$-firm follows a mixed strategy, we get the following expression of the optimization problem under asymmetric information and limited commitment:[24]

$$(\mathcal{P}^{LC}):\quad \min_{\{p(\underline{w})\in[0,1],\varepsilon\in[0,1]\}}(1-\nu)((1-\varphi(\underline{w}+p(\underline{w})\Delta w))D+\psi(\varphi(\underline{w}+p(\underline{w})\Delta w)))$$

$$+(\nu(1-\varphi(\underline{w}))+(1-\nu)(1-\varepsilon)(1-\varphi(\underline{w}+p(\underline{w})\Delta w)))C(p(\underline{w}))$$

$$\text{subject to (8).}$$

The solution to $(\mathcal{P}^{LC})$ can be easily derived after a few simplifying manipulations.[25]

[24] The superscript LC denotes *limited commitment.*

[25] Note that the agency still chooses and commits to transfers beforehand, anticipating the outcomes of the mixed-strategy equilibrium that it plays with the firm at date 2. This explains why ε is an optimization variable in $(\mathcal{P}^{LC})$. In this respect, we follow all the literature on limited contractual commitment and assume that, when indifferent between lying or not, the firm will mix with the very probability that maximizes the agency's ex ante payoff.

First, (8) allows us to get

$$(\nu(1-\varphi(\underline{w}))+(1-\nu)(1-\varepsilon)(1-\varphi(\underline{w}+p(\underline{w})\Delta w)))C(p(\underline{w}))=\nu(1-\varphi(\underline{w}))\mathcal{C}(p(\underline{w})) \quad (9)$$

where, over the relevant range of values for p, we define

$$\mathcal{C}(p)=\frac{C(p)}{1-\frac{C(p)}{p\Delta w}}. \quad (10)$$

It is immediate to check that

$$\mathcal{C}(p)\geq C(p)$$

and

$$\mathcal{C}'(p)=\frac{C'(p)}{1-\frac{C(p)}{p\Delta w}}+\frac{C(p)}{p\Delta w\left(1-\frac{C(p)}{p\Delta w}\right)^2}\left(C'(p)-\frac{C(p)}{p}\right)\geq C'(p).$$

With these notations in hands, it becomes straightforward to check that the same analysis as under full commitment goes through if one takes care of replacing $C(p)$ by $\mathcal{C}(p)$, the new cost of investigation under limited commitment. The cost of investigation has to be scaled up both in absolute terms and at the margin to account for the cost of being unable to commit.

Inserting this expression of $\mathcal{C}(p)$ into ($\mathcal{P}^{LC}$) and mimicking our previous analysis yields the following characterization.

Proposition 2 *Assume asymmetric information on wealth and effort together with limited commitment to an investigation probability by the regulatory agency. The optimal effort level for a rich firm is lower than its first-best value,* $e^{LC}(\bar{w})<e^{FB}$ *with*

$$D-\psi'(e^{LC}(\bar{w}))=\frac{\nu(1-\varphi(\underline{w}))}{1-\nu}\frac{\mathcal{C}'(p^{FC}(\underline{w}))}{\Delta w}\psi''(e^{LC}(\bar{w})) \quad (11)$$

and

$$e^{LC}(\bar{w})=\varphi(\underline{w}+p^{LC}(\underline{w})\Delta w), \quad (12)$$

where $p^{LC}(\underline{w})$ *is the positive probability of investigation of a poor firm and* $p^{LC}(\underline{w})<\tilde{p}(\underline{w})=\frac{D-\underline{w}}{\Delta w}$.

Example (continued). For our quadratic example, we find:

$$\mathcal{C}'(p)=\frac{\frac{p}{\lambda}\left(1-\frac{p}{4\lambda\Delta w}\right)}{\left(1-\frac{p}{2\lambda\Delta w}\right)^2}.$$

The probability $p^{LC}(\underline{w})$ is then implicitly defined as a solution to:

$$\tilde{p}(\underline{w}) = p^{LC}(\underline{w}) \left(1 + \frac{\nu(1-\mu\underline{w})\left(1 - \frac{p^{LC}(\underline{w})}{4\lambda\Delta w}\right)}{(1-\nu)\lambda\mu\Delta w \left(1 - \frac{p^{LC}(\underline{w})}{2\lambda(\Delta w)^2}\right)^2} \right).$$

■

Beyond the interpretation of this characterization, which is similar to the one obtained under full commitment, it is important to compare the full and limited commitment solutions.

Proposition 3 *Assume asymmetric information on wealth and effort. Both the effort level and the fine of a rich firm, and the probability of investigation following a low claim on assets are lower under limited commitment:*

$$e^{LC} < e^{FC}, \quad f^{LC}(\bar{w}) < f^{FC}(\bar{w}) \text{ and } p^{LC} < p^{FC}.$$

The effort and fine of a poor firm are kept unchanged.

Of course, the social cost of a limited commitment is lower when $\mathcal{C}(p)$ is closer to $C(p)$, which arises when either Δw is large or $C(p)$ is small. In both cases, the agency can more easily commit because the optimal probability of investigation is low anyway. The equilibrium probability that a rich firm hides assets is now small, but there are also little possibilities for screening a rich firm apart and fines do not depend much on wealth level. More generally, limited commitment reduces effort and equilibrium fines, going thus in the direction of a weak enforcement of environmental policy.

In more general auditing models, the impact of the principal's limited ability to commit on the probability of investigation is generally ambiguous and there is no reason to conclude a priori on how this probability changes with the level of commitment.[26] One could think that our results are quite intuitive and that a limit on commitment always reduces, as in our model, the likelihood of an audit and thus the effort. This reasoning is based on the analysis of the agent's best response but does not take into account that, at equilibrium, the principal expects that the agent exercises a weaker effort and is thus led to intervene more often. Our modeling shows that this second effect is always dominated, leading to low investigation probabilities and efforts *at equilibrium*.

Importantly, the model above shows that the analysis of the game with limited commitment is formally similar to the analysis of the game with full commitment. The mapping between the two games is formally characterized by the cost of audit-transformation defined in (10).

[26]See for instance Khalil (1997).

6 Conclusion

In this paper, we have developed a tractable model showing that low powered incentives for precautionary care, weak punishments and small probability of investigations in environmental policies can be explained altogether by assuming asymmetric information on the polluter's ability to pay for damages and a government's failure under the form of a limited ability to commit.

The lessons of our model have a general appeal beyond the case of environmental policies. They would apply equally well in a I.O. context where regulatory bodies and Antitrust authorities perform random inspections of firm's behavior on a given market. In that respect, our model could for instance be useful to understand Antitrust policies against prices collusion where firms could undertake cost-reducing effort. Although we expect the mechanisms of our model and, in particular, the interaction between the government and the market failures to be similar in those environments, such extensions may also unveil new features due to the possible interactions between several firms on a given market.

Also, many aspects of the game without commitment, in particular the probabilistic failures in auditing successfully the firm, bear some similarities with the case where Courts of Law make errors. It would be worth investigating further these analogies.[27]

In practice, different public bodies may be called for at the ex ante stage, when fines are designed, and ex post, once an investigation is run (a regulatory agency *ex ante* and Courts of Law *ex post*). Further inefficiencies coming from non-coordinated behavior between these bodies may have to be considered and could push the overall policies towards either lower or higher powered incentives, depending on how much information is shared between auditors and their interactions.[28] How those inefficiencies can be translated in terms of a modified cost of investigation as we did above for the case of limited commitment remains an interesting issue worth to be pursued.

Our model so far as been a one-shot game. Repeated interactions between the public sphere and potential polluters open new strategic considerations. For instance, bureaucrats in charge of investigation agencies may want to build reputation for being tough investigators

[27] For a related paper, see Boyer and Porrini (2009).

[28] Taking a multiprincipal mechanism design perspective, Khalil, Martimort and Parigi (2007) develop a model of financial contracting between several auditors and show that there may be more or less audit in equilibrium compared with what would arise under cooperative contracting. Hiriart, Martimort and Pouyet (2009a) investigate the substitutability or the complementarity between various auditors acting either ex ante (before an accident) or ex post (after), whereas Hiriart, Martimort and Pouyet (2009b) endogenize why auditors should be split.

in order to boost their careers in the public sectors or, *a contrario*, may become excessively lenient with the industry because they expect job opportunities to arise from there. These reputation concerns again will change the nature of the inefficiency and may even re-establish a more efficient outcome or worsen incentives, depending on the audience to which the agency directs its policy. Again, our model can be seen as a building block for analyzing these more complex settings.

We look forward to investigating these issues in future research.

References

Ashford, N. and C. Caldart (2008), *Environmental Law, Policy, and Economics*, MIT Press.

Baron, D. and R. Myerson (1982), "Regulating a Monopolist with Unknown Costs," *Econometrica*, 50: 911-930.

Becker, G. (1968), "Crime and Punishment: An Economic Approach", *Journal of Political Economy*, 76: 169-217.

Becker, G. and G. Stigler (1974), "Law, Enforcement, Malfeasance and Compensation of Enforcers", *Journal of Legal Studies*, 3: 1-18.

Bester, H. and R. Strausz (2001), "Contracting with Imperfect Commitment and the Revelation Principle: The Single Agent Case," *Econometrica* 69, 1077-1098.

Bontems, P. and G. Rotillon (1999), "Conformité aux Prescriptions Environnementales et son Contrôle", *Revue d'Économie Politique,* 109: 1-34.

Border, K. and J. Sobel (1987), "Samourai Accountant: A Theory of Auditing and Plunder", *Review of Economic Studies,* 54: 525-540.

Boyer, M. and J.-J. Laffont (1997), "Environmental Risks and Bank Liability", *European Economic Review*, 41: 1427-1459.

Boyer, M., T. Lewis and W.L. Liu (2000), "Setting Standards for Credible Compliance and Law Enforcement," *Canadian Journal of Economics*, 33: 319-340.

Boyer, M. and D. Porrini (2009), "Optimal Liability Sharing and Court Errors: An Exploratory Analysis", Working Paper University of Montréal.

Garoupa, N. (1997), "The Theory of Optimal Law Enforcement", *Journal of Economic Surveys*, 11: 267-295.

Gale, D. and M. Hellwig (1985), “Incentive-Compatible Debt Contracts: The One-Period Problem,” *Review of Economic Studies*, 52: 647-663.

Harsanyi, J., (1973), “Games with Randomly Disturbed Payoffs: A New Rationale for Mixed-Strategy Equilibrium Points,” *International Journal of Game Theory*, 2: 1-23.

Hiriart, Y. and D. Martimort (2006), “Environmental Risk Regulation and Liability under Adverse Selection and Moral Hazard”, in *Frontiers in the Economics of Environmental Regulation and Liability,* M. Boyer, Y. Hiriart, and D. Martimort eds., 209-233, Ashgate.

Hiriart, Y. and D. Martimort (2007), “The Benefits of Extended Liability”, *Rand Journal of Economics,* 37: 562-582.

Hiriart, Y., D. Martimort and J. Pouyet (2009a), “The Regulator and the Judge: Complements or Substitutes in the Control of Risky Industrial Activities”, *Revue d’Economie Politique*, 6: 941-967.

Hiriart, Y., D. Martimort and J. Pouyet (2009b), “The Public Management of Risk: Separating Ex Ante and Ex Post Monitors”, mimeo TSE-PSE.

Khalil, F. (1997), “Auditing without Commitment”, *RAND Journal of Economics*, 28: 629-640.

Khalil, F., D. Martimort and B. Parigi (2007), “Monitoring a Common Agent: Implications for Financial Contracting”, avec Fahad Khalil et Bruno Parigi, *Journal of Economic Theory*, 135: 35-67.

Laffont, J.-J. and J. Tirole (1993), *A Theory of Incentives in Procurement and Regulation*, MIT Press.

Lewis, T. and D. Sappington (2000), “Contracting with Wealth-Constrained Agents,” *International Economic Review*, 41: 743-767.

Lewis, T., and D. Sappington, (2001), “Optimal Contracting with Private Knowledge of Wealth and Ability,” *Review of Economic Studies*, 68: 21-45.

Mookherjee, D. and I. P’Ng (1995), “Corruptible Law Enforcers: How Should They Be Compensated?”, *The Economic Journal*, 105: 145-159.

Myerson, R. (1982), “Optimal Coordination Mechanisms in Generalized Principal-Agent Problems,” *Journal of Mathematical Economics,* 10: 67-81.

Pitchford, R. (2001), “How Liable Should a Lender be? The Case of Judgment-Proof Firms and Environmental Risks: Reply,” *American Economic Review*, 91: 739-745.

Polinsky, M. and S. Shavell (2001), "Corruption and Optimal Law Enforcement", *Journal of Public Economics*, 81: 1-24.

Power, M. (1999), *The Audit Society*, Oxford University Press.

Ringleb, A. and S. Wiggins (1990), "Liability and Large Scale, Long-Term Hazards," *Journal of Political Economy*, 98: 574-595.

Russell, C. (2003), *The Economics of Environmental Monitoring and Enforcement*, Ashgate Press.

Shavell, S. (1984a), "A Model of the Optimal Use of Liability and Safety Regulation", *RAND Journal of Economics*, 15: 271-280.

Shavell, S. (2004), *Foundations of Economic Analysis of Law*, Harvard University Press.

Shavell, S. (2005), "Minimum Asset Requirements and Compulsory Liability Insurance as Solutions to the Judgment-Proof Problem", *Rand Journal of Economics*, 36: 63-77.

Swierzbinski J. (1996), "Guilty until Proven Innocent: Regulation with Costly and Limited Enforcement", in *Agricultural Markets: Mechanisms, Failures and Regulations*, D. Martimort ed., 455-483, Ashgate.

Townsend, R. (1979), "Optimal Contracts and Competitive Markets with Costly State Verification", *Journal of Economic Theory*, 21: 417-425.

Appendix

Proof of Proposition 1. The proof is immediate and follows from simple optimization. Observe that:

$\dot{\Phi}^{FC}(0) = (1-\nu)(\underline{w} - D)\varphi'(\underline{w} + p(\underline{w})\Delta w) < 0$ and $\dot{\Phi}^{FC}(\tilde{p}(\underline{w})) = \nu(1-\varphi(\underline{w}))C'(\tilde{p}(\underline{w})) > 0.$

So that the solution $p^{FC}(\underline{w})$ is interior and satisfies

$$\dot{\Phi}^{FC}(p^{FC}(\underline{w})) = 0.$$

Simplifying yields (5).

Consider now Example 2 (with $\mu = 1$ to streamline the argument). We observe that the condition for the optimal audit probability to be smaller than 1 rewrites as:

$$D - \overline{w} \leq \frac{\nu}{1-\nu} \frac{1-\underline{w}}{\lambda \Delta w}. \tag{13}$$

When $D < \overline{w}$, this inequality is always satisfied (as argued previously beyond the specification of Example 2). When $D > \overline{w}$, our analysis carries over and when (13) is not satisfied then a corner solution emerges in which audit takes places systematically. The analysis is thus qualitatively similar except for the possibility of a corner solution. ■

Proof of Proposition 3. The proof is immediate and follows from the observation that $\mathcal{C}'(p) > C'(p)$ for $p > 0$. ■