UNITE MIXTE DE RECHERCHE
EN ECONOMIE PUBLIQUE

JOINT RESEARCH UNIT IN
PUBLIC ECONOMICS

2004
CAHIERS DE RECHERCHE
WORKING PAPERS
2004/02

On the limitation of penalties and the non-equivalence of penalties and taxes

S. Marette, E. Gozlan, B. Coestier

UMR Economie Publique
Avenue Lucien Brétignières – 78850 Grignon
16 rue Cl. Bernard – 75005 Paris
Tel. +33 (0)1 30 81 53 30
Fax. +33 (0)1 30 81 53 68
http://www.grignon.inra.fr/economie-publique

On the Limitation of Penalties and the Non-Equivalence of Penalties and Taxes

Stéphan Marette*, Estelle Gozlan† and Bénédicte Coestier ‡§

September 9, 2004

*Corresponding author: UMR Economie Publique INRA INAPG, 16 rue Claude Bernard, 75005 Paris, France. Phone: +33 (0)1 44 08 72 72. e-mail: marette@inapg.inra.fr.

†UMR Economie Publique INRA INA-PG. esgozlan@grignon.inra.fr

‡THEMA, University of Paris X-Nanterre. coestier@u-paris10.fr

§Estelle Gozlan and Stéphan Marette acknowledge financial support from the French Ministry of Ecology and Sustainable Development.

Abstract

This paper compares the impacts of a penalty on accident and a per-unit tax on output, when social damages depend on the output of firms. The choice of the optimal regulation, aiming at internalizing a damage, is influenced both by the market power of firms and by their potential (in)solvency in case of accident. Output strategies influence the solvency situation of firms for paying a penalty, which may lead to multiple equilibria (all firms are either solvent or insolvent in case of accident). When social damages are large, the optimal penalty is capped for avoiding a situation with insolvent firms. In this case, a regulator implements a per-unit tax.

JEL classification code: K13, L13.

Key words: Social damage, externality, liability, judgment-proof firms, magnitude of penalty, tax.

The regulatory choice for controlling production externalities under imperfect competition is complex because market mechanisms influence the risk allocation. A Pigovian tax or/and a penalty on accident, allocated either to the compensation of victims (liability) or to the regulator budget, are financial instruments that aim at internalizing a damage. The main difference between a Pigovian tax and a penalty is that the tax is collected *ex ante* whatever the accident event. If the tax is not paid, a firm is not able to engage in the activity. Conversely, the penalty is paid *ex post*, that is, only in the case of an accident event and if the wealth of firms is high enough to cover the penalty. Indeed, a firm may avoid paying the penalty because of insufficient profits (or wealth) coming from its economic activity.

The efficiency of any penalty/liability system is often faced with the judgment-proof problem (Shavell, 1986): the insolvency of firms impedes a complete payment of the liability fee. According to the Superfund Progress Report (1998), "at almost every Superfund site, some parties responsible for contamination cannot be found, have gone out of business, or are non longer financially able to contribute to cleanup efforts". Carroll et al. (2002) establish that at least 55 firms filed for bankruptcy because of asbestos litigations since the 1980s in the US.

Along with the potential insolvency of firms, examples of incomplete penalties or limited liability are frequently found in practice (Anderson, 1978). The recent oil spill compensations in the European Union, following upon the sinking of the oil tanker Erika off the French coast in December 1999 and the sinking of the tanker Prestige in Spain's north-west coast in November 2002, fell under the remit of the International Maritime Organization's Civil Liability Convention (CLC) and Fund Convention of 1992. The 1992 CLC lays down the principle of strict liability for shipowners and creates a system of compulsory insurance. The 1992 Fund Convention establishes a compensation regime when the compensation under the 1992 CLC is insufficient. For both accidents, the conventions capped the overall compensation to 135 million SDR (IOPCF Annual Report, 2003).[1] This amount included the sum paid by the shipowners and their insurers. In the Prestige case, based on the figures given by the Spanish, French and Portuguese Governments, the estimated total cost of the incident is 1100 million euros. And the required levels of payments by the Fund amount to 15% of the damage suffered by the claimants. Clearly, the IOPCF doesn't fully compensate the victims in the Prestige case. The particularity of the Civil Liability and Fund Conventions is that it mixes a penalty in case of oil spill with a mandatory tax. The IOPCF is financed by contributions payed by the oil industries of countries parties to the Conventions. These contributions are levied on the basis of the quantities of oil.

This article seeks to answer the question: should regulators rely on taxation or on penalties in order to limit dangerous activities? The impacts of a penalty and a tax policy are detailed in a market context (Cournot competition) and compared with the position of a regulator who seeks to maximize welfare, taking into account firm's profits, consumer surplus, social damages and government revenue. We abstract from the amount of care undertaken by firms for focusing on the level of output selected by firms. In case of accident, the social damages depend on the output of firms, so that quantities and prices may be influenced by the selected regulation. Under a penalty regime, the financial situation of a firm, that is either solvent or insolvent in case of accident, depends on the market context. The characterization of the socially optimal policy we provide in this paper contributes to the understanding of limitations in liability awards (as established by the CLC, for instance).

The market mechanisms linked to a given level of penalty are first detailed. A higher operating profit of firms results in an increased ability to pay the penalty in case of damage. The penalty is paid *ex post*, only if the accident occurs and if the profit (equal to the wealth) of firms is high enough to cover the penalty. For medium values of the penalty, the output strategy of firms may influence their profit that determines their financial situation in case of accident.

[1] This amount corresponds to 184 763 149 euros in the Erika case and 171 520 703 euros in the Prestige case.

This results in multiple equilibria, where one possible equilibrium is the solvent output for all firms and the other one is the insolvent Cournot equilibrium. Under the solvent Cournot equilibrium, the penalty is totally covered, whereas it is partially covered under the insolvent Cournot equilibrium.

With respect to the socially optimal policy, the results are the following. If the expected damage is relatively low or/and the market structure is concentrated, the absence of intervention is optimal since price/quantity distortions are avoided. This is consistent with previous results on taxation (Buchanan, 1969) and liability (Polinsky and Rogerson, 1983) under imperfect competition. For medium values of the damage, an optimal penalty and an optimal tax equivalently allow an internalization of the damage. The levels of penalty or tax are positive and proportional to the value of the damage. When the expected damage is large, the judgment-proof problem (firms' inability to fully pay the penalty after an accident) limits the financial penalty. Should that happen, a limited penalty is dominated from a welfare standpoint by a per-unit tax. Insolvency problems do not arise if a tax is implemented, since the tax is mandatory for producing. Taxation is sufficient for maximizing welfare and reducing consumption. These results suggest that for regulating dangerous activities with potential high expected damages, a per-unit tax is the most appropriate instrument for insolvent firms. In the oil spill context, the IOPCF activity should be reinforced and completed. This is is the case in Europe with the creation of the European Compensation Fund for Oil Pollution in European Waters financed by a tax paid by the oil industries located in Europe (European Commission, 2000).

This characterization of market mechanisms under alternative regulations differs from previous studies in several respects. Polinsky (1980), Polinsky and Rogerson (1983) and Polinsky and Shavell (1994) or Hamilton (1998) studied different liability rules in a market context without considering the endogenous insolvency in case of accident. Tax and penalty are equivalent when firms expect to be solvent and the multiplicity of equilibria in a context of strategic interaction is overlooked in the literature. In our paper, the judgment-proof (or insolvency) problem under penalty is considered as endogenous to the market structure, explaining some limits regarding the optimal financial penalty. Moreover, in a context where no market effect is considered, Boyd and Ingberman (1994) and Lewis and Sappington (1999) have shown that an optimal penalty aims at reducing the potential scale of losses or the probability of accident. Our paper departs from these results since in our setting the limited penalty aims at limiting quantity/price distortions coming from the judgment-proof problem. In Lewis and Sappington (1999), the optimality of penalties decoupled from realized damages was underlined in a case where social damages do not depend on firms quantity. Our results differ from theirs for large values of the damage, since they recommended the delivery of the entire assets of the firm to the victims, while we recommend a limited penalty to circumvent the judgment-proof problem.

The paper is organized as follows. The model is presented in section 2. The influence of the level of penalty on firms' production choice is described in section 3. The optimal regulation, allowing for *ex ante* taxation or *ex post* penalties is detailed in section 4. Some extensions and conclusions are drawn in sections 5 and 6.

1 The model

We begin with a Cournot framework with risky products, where social damages depend on the output of firms. A three-stages oligopoly model is considered with a regulator who maximizes the welfare. Firms as well as the third party incurring all the loss (externalities) are risk neutral.

1.1 The game

In stage 1, the regulator chooses (a) a production ban, (b) a per-unit tax t paid before producing in stage 2 and whatever the accident event, and (c) a per-unit penalty f paid by the injurer in the case of damage in stage 3.[2] For simplicity,

[2]We only focus on the per-unit penalty / tax because it is possible to show that a fixed penalty or a fixed tax (independent of quantities) is dominated from a welfare standpoint,

there is no uncertainty regarding f or t, perfectly known to firms. The penalty or the tax may be allocated either to victims' compensation or to the regulator budget : this is neutral from a welfare standpoint (see the appendix).

In stage 2, n identical firms pay the tax owed to the regulator. If the tax is not paid, a firm is not able to engage in the activity. The n identical firms simultaneously select a quantity (i.e., Cournot competition). They sell a homogeneous product to consumers with an inverse demand $p = a - Q$, where Q denotes the quantities (equal to the production) and p denotes the market price. The parameter $a > 0$ is the maximum per-unit willingness to pay by consumers and it positively influences the profits of firms.

Damages entailed by the production/consumption are perfectly revealed at the beginning of stage 3. For each firm, a damage may occur with a probability $(1 - \lambda)$ for all its products (λ denotes the per-firm probability of no damage). $d \geq 0$ denotes the per-unit social damage linked to the accident. The expected damage for a firm is $(1 - \lambda)dq_i$, where q_i denotes the output of firm i. The probability λ is given (this assumption will be discussed at the end of the paper). Even if the probability λ is the same for the n firms, the occurrence of an accident for each firm is independent from that of the other firms. In this model, the only uncertainty comes from the accident outcome with a probability $(1 - \lambda)$. The regulator knows the value of d and $(1 - \lambda)$ for selecting f or t in stage 1. In stage 3, in case of accident, the regulator imposes a per-unit penalty f on firms. The regulator is able to perfectly identify the responsible firm and to verify the extent of the damage, d, without any cost. We consider that the assets available for paying the penalty only come from the firm's profit. For simplicity, there is no cost of regulation.

Before turning to the characterization of the Subgame Perfect Nash Equilibrium of this game, we describe how a potential penalty can influence firms' production choice.

since such instruments do not influence the output of firms.

1.2 The penalty and firms' output strategy

As the regulator is able to perfectly identify the responsible firm and to verify the extent of the damage, the per-unit penalty $f > 0$ is imposed by the regulator on the firm responsible for an accident (stage 3). Firms take into account this per-unit penalty f in their profits for their quantity choice (stage 2). Corresponding welfares, defined as the sum of profits, consumers surpluses, social damage and government revenue from the penalty, are given in appendix.

The quantity decision depends on the solvency situation of the firm i for paying the penalty fq_i in case of damage. Indeed, when the firm has insufficient earnings, unabling it to totally cover the penalty, the firm is said judgment proof (or insolvent). In that case, it is considered that the firm partially covers the penalty. Otherwise, the firm is solvent. As we shall see, the objective function of a solvent firm is distinct from the objective function of a judgment-proof firm. To derive these profit functions (general formulation), we will consider that firms may have to pay a unit tax as well as a per-unit penalty in the accident event.

The comparison between the gross profit margin, namely the market price minus the per-unit tax, $(p - t)$, and the imposed per-unit penalty f determines the financial situation of a firm in case of damage. For $p - t > f$, each firm is solvent and fully covers the penalty. The firm is judgment proof if $p - t < f$, and partially covers the penalty up to the level of its gross profits $(p - t)q_i$, where q_i denotes the output of the firm i. Each firm rationally expects its potential financial situation, that will influence its behavior.

The per-firm profit according to the different events is now detailed. For each firm i, with a probability λ, no damage occurs and the gross profit is $[p - t]q_i$. With a probability $(1 - \lambda)$, the damage linked to the firm production occurs. For the solvent firm able to cover the fine, the profit is $[p - t - f]q_i$. For the insolvent firm, the profit is zero since its gross profit is seized for covering at least one part of the penalty.

Let us denote $Q = q_i + q_{-i}$, with $q_{-i} = \sum_{j=1}^{n-1} q_j$ representing the output of the other sellers $j \neq i$. Depending on the solvency situation, the *ex ante* expected profits are determined before the revelation of the damage. For $p - t >$

f, the net *ex ante* expected profit of a solvent firm is

$$\pi_i^s(q_i, q_{-i}) = [a - q_i - q_{-i} - (1-\lambda)f - t]\, q_i \tag{1}$$

The profit function of a potential solvent firm is influenced by the level of tax as well as the level of penalty. For $p - t < f$, the net *ex ante* expected profit for a judgment-proof (or insolvent) firm writes

$$\pi_i^{jp}(q_i, q_{-i}) = \lambda\, [a - q_i - q_{-i} - t]\, q_i \tag{2}$$

Note that the value of profit $\pi_i^{jp}(q_i, q_{-i})$ is influenced by the level of tax and not by the level of penalty f.

Cournot-quantity equilibria under solvency and insolvency are detailed in appendix. At equilibrium with solvent (respectively insolvent) firms in case of accident, each firm has no incentive to deviate unilaterally by selecting a quantity leading to an insolvent (respectively solvent) situation in case of damage.

2 The penalty and market mechanisms

In this section, we focus on the complex effects coming from the choice of penalty in a market context. The level of penalty influences the firms' production choice and in turn their potential financial situation. The higher the ouput, the lower the profits available for compensation in the accident event. We set the per-unit tax to zero, $t = 0$, in order to focus on market mechanisms with a penalty.

2.1 The multiplicity of equilibria

The following proposition characterizes the relationship between the level of penalty, the firms' production choice and their solvency situation. Let

$$f_1 = \frac{2a}{(1+\sqrt{\lambda})(n+1)} \tag{3}$$

$$f_2 = \frac{2a}{(1+\sqrt{\lambda})\left[\sqrt{\lambda}(n-1)+2\right]} \tag{4}$$

Proposition 1: *For a level of penalty f in case of damage, the Cournot-Nash equilibrium/equilibria are* *(i) a unique Cournot-Nash equilibrium in which all firms are solvent if* $f < f_1$,

(ii) a unique Cournot-Nash equilibrium in which all firms are insolvent in case of damage if $f > f_2$,

(*iii*) *two Cournot-Nash equilibria exist, one in which all firms are solvent and one in which all firms are insolvent in case of damage, if* $f_1 < f < f_2$.

See the proof in Appendix.

As firms are identical, they choose the same equilibrium strategy. The higher the operating profit relatively to the penalty, the more firms are likely to be able to pay the penalty in case of a damage revealed in stage 3 after the output decision in stage 2. For relatively low values of the penalty, f, compared with the profit parameter, a, firms are solvent whatever their possible quantity choice. Profits are high enough to cover a relatively low level of penalty: only the solvent Cournot equilibrium prevails. Each firm has no incentive to deviate unilaterally by selecting a quantity leading to an insolvent situation in the case of damage. The expected penalty is internalized by the market via the quantity/price. Conversely, for relatively high values of the penalty, f, compared with the profit parameter, a, firms are judgment proof whatever their possible quantity choice. Profits are insufficient to cover the damage: only the judgment-proof Cournot equilibrium arises. Each firm has no incentive to deviate unilaterally by selecting a quantity leading to solvency, with the selection of a small quantity coming from the internalization of a large expected penalty. The expected penalty is not internalized by the market via the quantity/price. As the penalty is conditional on the *ex post* accident, firms do not consider this value of f when they select a quantity under a judgment-proof equilibrium. In these two configurations, the strategic choice of quantity does not influence the (in)solvency situation of the firms.

For medium values of penalty f compared with the profit, the quantity choice (via the price) may influence the financial situation of firms. A large (respectively low) quantity selected by each firm entails a relatively low (respectively high) price, that is insufficient (respectively sufficient) for covering the damage.

This results in multiple equilibria, where one possible equilibrium is the solvent output for all firms and the other one is the judgment-proof Cournot equilibrium for all firms. With the other firms following one strategy, no firm has any incentive to deviate unilaterally in order to select the alternative strategy.[3] For a given value of the penalty f, the quantity under the solvent equilibrium is lower than the quantity under the insolvent (judgment-proof) equilibrium, since the expected penalty is internalized with solvent firms. These equilibria correspond to different levels of penalty paid by firms (and received by a government or a fund for victims): under the solvent Cournot equilibrium, the penalty is totally paid, whereas it is partially covered under the insolvent equilibrium. An increase in the number of firms, n, leads to a decrease of f_1 and f_2. A more intense competition reduces the profits and the ability to fully cover the penalty in case of damage.

The problem under the judgment-proof equilibrium is the absence of internalization of the penalty supposed to take into account the expected damage. The equilibrium situation with either solvent or insolvent firms depends on the optimal penalty f selected by the regulator.

2.2 The optimal penalty

In this section, the optimal level of penalty is determined for a tax $t = 0$. The regulator maximizes the welfare, defined by the sum of expected profits, consumers surplus and penalty revenues minus the overall expected damage (see the appendix), by selecting the level of penalty $f > 0$. He takes into account the financial situation of firms that influences welfares via the quantity choice. By maximizing the welfare, the level of penalty f may be selected for thwarting the insolvency problem underlined in proposition 1. A refinement criteria is used for selecting the equilibium when multiple equilibria are possible (see proposition 1). The equilibrium strategies are consistent with the elimination of out-of-

[3] It should be noted that there is no equilibrium in mixed strategies in which some firms remain solvent and others risk insolvency when there is a finite number of firms n. We thank one referee of this paper for underlining this point.

equilibria strategies according to the Mailath et al. (1993) refinement criterion, where firms select the equilibrium leading to the highest profit (see the appendix for details). Consider f_2 defined in (4) and let

$$d_1 = \frac{a}{(1-\lambda)(1+n)} \tag{5}$$

$$d_2 = \frac{a\left(2-\sqrt{\lambda}\right)}{(1-\lambda)\left[\sqrt{\lambda}(n-1)+2\right]} \tag{6}$$

$$d_3 = \frac{a\left(\sqrt{\lambda}(n-2)+4\right)}{(1-\lambda)\left[2\sqrt{\lambda}(n-1)+4\right]} \tag{7}$$

$$f^* = Max[\frac{d(1-\lambda)(1+n)-a}{(1-\lambda)n}, 0] \tag{8}$$

Proposition 2: *In the case of damage, the socially optimal penalty is*

(i) the absence of penalty ($f^* = 0$) *if* $d < d_1$,

(ii) a positive level of penalty $f^* < d$*, leading to solvent firms, if* $d_1 < d < d_2$,

(iii) a positive level of penalty $f_2 - \varepsilon$ *(with* ε *positive and close to zero) leading to solvent firms, if* $d_2 < d < d_3$,

(iv) a production ban if $d > d_3$.

Proof: see the appendix.

[Insert figure 1]

Figure 1 illustrates our proposition, by considering that the X-axis represents the maximum per-unit willingness to pay by consumers, namely a, that positively influences the profits of firms, and the Y-axis represents the value of the per-unit damage, d. As firms are identical, they choose the same equilibrium strategy.

The optimal penalty balances two opposite effects: the quantity/price distortion coming from the internalization of the penalty and the level of the overall damage hurting the third party. Both market power and insolvency influence the optimal penalty. For relatively low values of penalty imposed by the regulator, f, compared with the profit depending on a, firms are solvent. Conversely, for relatively high values of penalties, f, compared with the profit positively influenced by a, firms are likely to be insolvent in case of damage (see proposition 1), a situation that leads to the absence of damage internalization.

When the value of the damage, d, is relatively low (see figure 1), the internalization via the price is not optimal, so that the penalty is $f^* = 0$. Indeed the absence of internalization limits the quantity distortion coming from the market power (with solvent firms), while the damage linked to the accident is not high. This explains why the absence of any penalty payment dominates any positive value of penalty despite the firms' solvency. Avoiding the internalization of the cost of accident limits the price distortion due to firms' market power (see e.g. Calabresi (1961), Buchanan (1969) and Polinsky and Rogerson (1983)).

For medium values of d, a positive level of penalty ($0 < f^* < d$ for a finite value of n) allows to partially internalize the damage with solvent firms. The penalty increases with d and n, since it aims at not amplifying the quantity/price distortion resulting from imperfect competition.

When d is relatively large, firms would be insolvent with a penalty $f^* > 0$. It is optimal to select a positive level of penalty $f_2 - \varepsilon < f^*$ (with f_2 given by (4)), for which firms are solvent without any incentive to deviate from this equilibrium. This level $f_2 - \varepsilon$ does not depend on the damage d, since this is the highest level of penalty for which no firm deviates when the other firms are solvent. Firms are solvent with $f_2 - \varepsilon$, which leads to lower levels of production and expected damage compared to a judgment-proof situation, where any penalty $f > f_2 - \varepsilon$ would not be internalized in the quantity choice. A level of penalty that impedes insolvency is necessary for limiting the output level and the scope of the damage that is linked to the output. The optimal policy $f_2 - \varepsilon$ aims at avoiding the judgment-proof situation.

For very large values of d, the welfare is negative with a penalty $f_2 - \varepsilon$, so that banning the production is the best policy. It means that liability with an optimal penalty is inefficient for regulating the risk.

Figure 1 allows to show that the optimal penalty is influenced by the damage d and the solvency situation. The positive penalty f^* is coupled with the social damage d, whereas when $d_2 < d < d_3$, the penalty $f_2 - \varepsilon$ is decoupled from the realized damage d for mitigating the judgment-proof problem. The optimal penalty takes into account the possibility of insolvency, so that the judgment-proof problem is eliminated at the optimum. From these results, it appears that a strict liability rule with a penalty equal to the damage is never optimal when the social damage depends on produced quantities.

We eventually consider the impact of the variation in the number of firms, n. A more intense competition reduces the profits and the ability to fully cover the penalty in case of damage. An increase in the number of firms, n, results in lowering frontiers d_1, d_2 and d_3. The level $f_2 - \varepsilon$ decreases with n, since the judgment proof equilibrium becomes more attractive. Note that when $n \to +\infty$, $d_3 \to \frac{a}{2(1-\lambda)}$, and the optimal penalty $f_2 - \varepsilon \to 0$. This means that in a competitive environment, the optimal policy would be to ban production if d is large ($d > \frac{a}{2(1-\lambda)}$) and allow the activity with judgment-proof firms if d is low ($d < \frac{a}{2(1-\lambda)}$).

3 The optimal regulation

We now turn to the socially optimal regulation by allowing the regulator to select either an *ex post* penalty in case of accident, as detailed in section 3, or a per-unit tax $t > 0$ which is paid *ex ante* by all firms, whatever the later outcome about the accident. Considering the tax allows to complete the analysis. Let

$$t^* = Max[\frac{d(1-\lambda)(1+n)-a}{n}, 0], \quad (9)$$

$$d_4 = \frac{a}{(1-\lambda)}. \quad (10)$$

Proposition 3: *The socially optimal policy is*

(i) the absence of penalty or tax ($t^* = f^* = 0$) if $d < d_1$,

(ii) either a positive level of penalty f^* or a positive level of tax t^* if $d_1 < d < d_2$,

(iii) a positive level of tax t^*, if $d_2 < d < d_4$.

(iv) a production ban if $d > d_4$.

Proof: see the appendix.

[Insert figure 2]

Figure 2 illustrates our proposition, considering that the X-axis represents the maximum per-unit willingness to pay by consumers, namely a, and the Y-axis represents the value of the per-unit damage, d. For $d < d_1$, the tax (or the penalty) is zero, since the absence of internalization limits the quantity distortion coming from the market power.

Proposition 3 underlines that a penalty and a tax are equivalent for intermediate levels of damages that entail solvent firms in case of accident. For higher levels of damage, the optimal policy may rely on the selection of taxes rather than liability. A level of tax t^* is better than the level of penalty $f_2 - \varepsilon$ (presented in proposition 2) if $d_2 < d < d_4$. Indeed, under a regulation relying on *ex ante* taxes instead of penalties, the risk of firms insolvency vanishes since firms cannot avoid the per-unit tax for producing. This tax is paid whatever the accident outcome and is passed on to consumers via the price. The limited level of penalty, $f_2 - \varepsilon$, paid by firms only in case of accident, results in a lower internalization of social damages by firms compared to the internalization with the tax t^*. In other words, the optimal internalization of the expected damage is possible with a tax, while a partial internalization comes from the selection of the penalty $f_2 - \varepsilon$. A tax is preferred to a penalty due to the endogenous insolvency problem.

Note that when $n \to +\infty$, the penalty $f_2 - \varepsilon \to 0$, while the *ex ante* tax $t^* \to d$. This corresponds to the well-known result in a context of externalities under a competitive market: the optimal per-unit tax equals the marginal damage d. This instrument leads to the first-best outcome (see the proof of the proposition 3), namely production for relatively low levels of loss ($d_1 < d < d_4$) and ban of production for relatively large levels of loss ($d > d_4$).

4 Extensions

In defining the analytical framework, very restrictive assumptions were made for simplicity. Extensions to a dynamic context or with injurers differing in size and/or wealth are not treated here. However, the following extensions could be considered.

(*i*) In this model, the regulator knows the value of d and $(1-\lambda)$ for selecting f or t in stage 1. However, this information is often difficult to get, which limits the ability of the regulator to impose a tax compatible with proposition 3. In this case, penalties or strict liability are useful to sanction and regulate an unpredictable damage. However, propositions 1 and 2 underscore some limits of penalties or liability coming from the judgment proof problem. In this case, the regulator should focus on the profitability of firms and the insurance program so as to be sure that some assets exist in case of unpredictable damage. Whatever the magnitude of the financial penalty depending on the welfare objectives (detailed in proposition 2), the judgment-proof problem has to be dodged for large values of social damages. In this case, the optimal penalty directly depends on the possibility of firms to be judgment proof. This suggests that considerations regarding financial aspects such as firms balance sheets and firms' shares prices on the stock market (...), as well as sectorial characteristics, may be important for shaping environmental regulations.

(*ii*) Our analysis showed that the optimal penalty should be capped in order to avoid a situation with judgment-proof firms. For a risky industry, (in)solvency is sometimes very difficult to evaluate when a regulation is implemented, since it depends on many factors. We assumed that the regulator and the court were acting with perfect information about the firms' characteristics or the damage. One extension could examine the consequences of imperfect information about the damage and/or the effort, which could reduce the efficiency of liability due to the cost of inspection and/or expertise.[4] Note that the regulator failure may lead to underestimate the damage, which would result in a capped penalty defined by regulation.[5]

(*iii*) Throughout the model, we maintain the assumption of a damage de-

[4]It would be interesting to see if, in our framework, uncertainty would make liability a complementary regulation of taxation, as predicted by Kolstad et al (1990), instead of an imperfect substitute.

[5]We abstract from any positive costs of litigation/regulation studied by Rubinfeld (1984).

pending on the produced quantity. For a damage independent of produced quantities, the judgment-proof problem still holds. In this case, an analysis could be developed in which the penalty is capped to avoid the judgment-proof problem.

(*iv*) No possibility of private or public financial assurance was considered for relaxing the judgment-proof constraint. Insurance (or financial markets) may be introduced, so that firms, integrating the insurance coverage in their solvency constraint, could be solvent for a level of penalty greater than f_2 given by (4). However, for very large values of the per-unit damage, d, firms and insurance companies could be insolvent, a problem which should be taken into account by the regulator.

(*v*) It is possible to show that the previous results hold with an endogenous level of risk. A welfare comparison with the negligence rule[6] highlights that the strict liability rule with the optimal penalty dominates the negligence rule, when the expected damage and the cost for reducing the risk are very large. In this case also, a strict liability rule with a penalty equal to the damage and the negligence rule do not correspond to the optimal policy. Consider the effort choice to reduce the risk, where few assumptions are added up. Before the production choice stage, each firm chooses whether or not to implement a costly prevention effort (observable by the regulator). This effort, equal to λ for simplicity, influences a marginal cost $c = c(\lambda)$ that is increasing ($c' > 0$), strictly convex ($c'' > 0$) and such that $c(1) \to +\infty$. For $t^* > 0$, the first-best welfare $\overline{W}_s^*(q_s, \lambda, n, 0, t^*)$ given in the proof of the proposition 3 (see the appendix) can be rewritten as $(a - c(\lambda) - (1-\lambda)d)^2/2$ for $d_1 < d < d_4$. By denoting $c'^{-1}(.)$ the inverse function of the marginal cost function, let

$$\lambda^* = c'^{-1}(d) \tag{11}$$

which is the level imposed via a mandatory standard if $d_1 < d < d_4$. A standard λ^* is selected with the optimal policy presented in proposition 3. For $d < d_1$, the tax is zero due to market power, leading to a lower welfare than the first-

[6] The negligence rule shifts the damage to the injurer only if the injurer does not exert a minimum level of effort.

best welfare $\overline{W}_s^*(q_s, \lambda, n, 0, t^*)$ given in the proof of proposition 3. In this case a standard lower than λ^* limits the marginal cost $c(\lambda)$ and allows to approach the first-best welfare.

(vi) Eventually, we considered that the regulator was acting in the public's best interest. One stumbling block for such regulatory "fairness" is the efficiency of the public regulatory authority itself. Public agencies may be doomed to failure if their mandate is not clearly delineated or they suffer from bureaucracy.

5 Conclusion

Since the social cost of the damage is linked to production, it should be integrated in the market price so as to reach social efficiency under large values of damages. We showed that the optimal penalty is either equal to zero or limited, namely lower than the value of social damages. When social damages are large, the optimal penalty is capped to avoid a situation with judgment-proof firms. The social-damages internalization is then limited by the financial situation of firms that depends on the market context. Our model with endogenous insolvency eventually shows the non-equivalence of taxes and penalties and the superiority of taxes when the damage is substantial, since a tax circumvents the judgment-proof risk linked to the choice of penalty.

6 Appendix

Profits and welfare are presented, before detailing the proof of propositions 1, 2 and 3.

By using (2), profit maximization when firm i expects to be judgment-proof results in the following reactin function :

$$b_i^{jp}(q_{-i}) = \frac{a - q_{-i} - t}{2} \tag{12}$$

for all i. It follows that a judgment-proof Cournot equilibrium is an output vector $q^{jp} = (q_i^{jp}, ..., q_i^{jp})$ with

$$q_i^{jp} = \frac{a-t}{n+1} \quad \text{for all } i. \tag{13}$$

The equilibrium price is $p^{jp} = a - nq_i^{jp}$. At equilibrium, all firms are judgment-proof for $f > p^{jp} - t$. The per-firm profit is

$$\pi_i^{jp}(q^{jp}, \lambda, n, t) = \lambda \left(\frac{a-t}{n+1}\right)^2 \tag{14}$$

Using the overall quantities nq^{jp}, and the equilibrium price $p^{jp} = a - nq^{jp}$, consumers' expected surplus is,

$$cs(q^{jp}) = \int_0^{nq_i^{jp}} [a - Q - p^{jp}]dQ = \frac{n^2 [a-t]^2}{2(n+1)^2} \tag{15}$$

Under strict liability, the welfare with judgment-proof firms is $W_{jp}^*(q_{jp}, \lambda, n) = n\pi_i^{jp}(q^{jp}, \lambda, n, t) + cs(q^{jp}) + \left\{t + (1-\lambda)[(p^{jp} - t) - d]\right\} nq_i^{jp}$, where tnq_i^{jp} is the overall-tax revenue, $(1-\lambda)dnq_i^{jp}$ is the overall expected loss linked to the damage and $(1-\lambda)(p^{jp} - t)nq_i^{jp}$ the overall-expected revenue coming from the penalty paid by firms.[7] Recall that all the profit of a firm, $(p^{jp} - t)q_i^{jp} = \pi_i^{jp}(q^{jp}, \lambda, n, t)$ is seized for penalty in case of damage. The fact that the penalty or the tax are allocated either to victims compensation or to the regulator budget is neutral from the welfare point of view. Then

$$W_{jp}^*(q_{jp}, \lambda, n, t) = n(1 + \frac{n}{2})\frac{[a-t]^2}{(n+1)^2} + [t - (1-\lambda)d]\, n\frac{a-t}{(n+1)} \tag{16}$$

[7]The n firms select the same output and the accident outcome for a firm, with a probability $(1-\lambda)$, is independent from the that of the other firms.

By using (1), profit maximization under the solvent situation gives firm i reaction function,

$$b_i^s(q_{-i}) = \frac{a - t - q_{-i} - (1-\lambda)f}{2} \tag{17}$$

for all i. It follows that a solvent Cournot equilibrium is an output vector $q^s = (q_i^s, ..., q_i^s)$ with

$$q_i^s = \frac{(a - t - (1-\lambda)f)}{n+1} \quad \text{for all } i. \tag{18}$$

The equilibrium price is $p^s = a - nq_i^s$. At equilibrium, all firms are solvent for $f < p^s - t$. The per-firm profit is

$$\pi_i^s(q^s, \lambda, n, f, t) = \left(\frac{a - (1-\lambda)f - t}{n+1}\right)^2 \tag{19}$$

Using the overall quantities nq_i^s, and the equilibrium price $p^s = a - nq_i^s$, consumers' expected surplus is,

$$cs(q^s) = \int_0^{nq_i^s} [a - Q - p^s]dQ = \frac{n^2\left[a - (1-\lambda)f - t\right]^2}{2(n+1)^2} \tag{20}$$

The welfare is $W_s^*(q_s, \lambda, n, f, t) = n\pi_i^s(q^s, \lambda, n, f, t) + cs(q^s) + \{t + (1-\lambda)[f - d]\}\, nq_i^s$, where tnq_i^s is the overall-tax revenue, $(1-\lambda)dnq_i^s$ is the overall expected loss linked to the damage, and $(1-\lambda)fnq_i^s$ the overall-expected revenue coming from the penalty paid by firms. The fact that the penalty or the tax are allocated either to victims compensation or to the regulator budget is neutral from the welfare point of view. Then,

$$W_s^*(q_s, \lambda, n, f, t) = n(1+\frac{n}{2})\frac{[a - (1-\lambda)f - t]^2}{(n+1)^2} + \{t - (1-\lambda)(d - f)\}\, n\frac{a - (1-\lambda)f - t}{(n+1)}. \tag{21}$$

We now turn to to the proofs of propositions.

6.1 Proof of proposition 1

Recall that we consider the tax $t = 0$. Consider that each firm has two pure strategies. We start by detailing the multiple equilibria case (*iii*).

(iii) Two Cournot-Nash equilibria exist simultaneously, one in which all firms are solvent and one in which all firms insolvency risk exists, if the following

conditions are satisfied:

$$\pi_i^s(q^s, \lambda, n, f, 0) \quad > \quad \pi_i^{jp}(b_i^{jp}(q_{-i}^s), \lambda, n, 0) \ \forall i, \tag{22}$$

$$\pi_i^{jp}(q^{jp}, \lambda, n, 0) \quad > \quad \pi_i^s(b_i^s(q_{-i}^{jp}), \lambda, n, f, 0) \ \forall i. \tag{23}$$

The condition (22) means that a firms has no incentive to deviate for selecting a quantity $b_i^{jp}(q_{-i}^s)$ leading to a risk of insolvency, when the $(n-1)$ firms select a quantity leading to solvency. The selected quantity $b_i^{jp}(q_{-i})$ is given by (12) with a vector $q_{-i}^s = (q_j^s, ..., q_j^s)$ for $j \neq i$ and $q_j^s = q_i^s$ defined by (18). Thus the profit of this judgment-proof seller defined by $\lambda[a - b_i^{jp}(q_{-i}^s) - (n-1)q_j^s]b_i^{jp}(q_{-i}^s)$ is $\pi_i^{jp}(b_i^{jp}(q_{-i}^s), \lambda, n, 0) = \lambda \left(\frac{2a+(n-1)(1-\lambda)f-2c}{2(n+1)}\right)^2$. The condition (23) means that a firms has no incentive to deviate for selecting a quantity $b_i^s(q_{-i}^{jp})$ leading to a situation of solvency, when the $(n-1)$ firms select a quantity leading to the insolvency risk . The selected quantity $b_i^s(q_{-i}^{jp})$ is given by (12) with a vector $q_{-i}^{jp} = (q_j^{jp}, ..., q_j^{jp})$ for $j \neq i$ and q_j^{jp} defined by (13).

The condition (22) is satisfied when $f < f_2$ and the condition (23) is satisfied when $f > f_1$. It is easy to check that for $f_1 < f < f_2$ all firms are insolvent, namely $f > p^{jp}$ when all firms select q_i^{jp} defined by (13), or all firms are solvent, namely $f < p^s$, when all firms select q_j^s defined by (18).

(i) For the solvent Cournot equilibrium to be unique, it is necessary and sufficient that (22) holds with

$$\pi_i^{jp}(q^{jp}, \lambda, n, 0) < \pi_i^s(b_i^s(q_{-i}^{jp}), \lambda, n, f, 0) \ \forall i, \tag{24}$$

where the notations were previously detailed. This conditions (24) means that each seller has an incentive to deviate from a situation, where all other sellers would choose the quantity q_j^{jp} (defined by (13)) leading to an insolvency risk. The conditions (22) and (24) are satisfied if $f < f_1(< f_2)$. In this case, all firms are solvent, namely $f < p^s$, when all firms select q_j^s defined by (18).

(ii) Finally, for the judgment-proof Cournot outcome to be the unique Nash equilibrium, it is necessary and sufficient that (23) holds with,

$$\pi_i^s(q^s, \lambda, n, f, 0) < \pi_i^{jp}(b_i^{jp}(q_{-i}^s), \lambda, n, 0) \ \forall i, \tag{25}$$

where the notations were previously detailed. This conditions (25), means that each seller has an incentive to deviate from a situation, where all other sellers would choose the quantity q_j^s (defined by (18)) leading to a solvency situation. The conditions (22) and (25) are satisfied if $f > f_2 (> f_1)$. In this case, all firms are insolvent, namely $f > p^{jp}$ when all firms select q_i^{jp} defined by (13).

■

6.2 Proof of proposition 2:

Recall that we consider $t = 0$.

Point (i). The maximization of the concave function $W_s^*(q_s, \lambda, n, f, 0)$ leads to f *given by (8). This fee is lower than zero for $d < d_1$ so that the optimal penalty is $f^* = 0$ for $d < d_1$. f * is positive for $d > d_1$.

Point (ii). We now detail conditions for which f * leads to a solvency situation for firms. The case of multiple equilibria underlined in proposition 1 arises for a penalty f such that $f_1 < f < f_2$. The equilibrium is selected according to the Mailath et al. (1993) refinement criterion, where firms select the equilibrium leading to the highest profit. For a penalty f, it is easy to check that $\pi_i^s(q^s, \lambda, n, f, 0) \geq \pi_i^{jp}(q^{jp}, \lambda, n, 0)$, equivalent to $f < a/(1 + \sqrt{\lambda})$ (by using expressions (19) and (14)). As $a/(1 + \sqrt{\lambda}) > f_2$, the solvent equilibrium is preferred by firms when $f_1 < f < f_2$. The level of penalty f_2 is such that condition (22) is binding (see the point (iii) proposition 1). The selection of a penalty $f_2 - \varepsilon$, with ε positive and close to zero impedes any unilateral deviation for the selection of a judgment-proof quantity when the other firms select a solvent quantity, since the condition (22) is satisfied. All firms strictly prefer the solvency situation to the insolvency situation with $f_2 - \varepsilon$. The profit $\pi_i^s(q^s, \lambda, n, f_2 - \varepsilon)$ is always positive, which means that the firm is always solvent (the inequality $f_2 - \varepsilon < p^s - t$ holds). The solvent Cournot equilibrium is an equilibrium if $f = f_2 - \varepsilon$.

Now the equality $f^* = f_2$ leads to $d = d_2$. For $d < d_2$, the penalty f^* is selected. For $d > d_2$, firms are judgment proof with the penalty f^*. So that f^* is the optimal penalty for $d_1 < d < d_2$.

Point (iii). For $d > d_2$, the compensation $f \geq f^*$ leads to the judgment-proof situation with a welfare $W^*_{jp}(q_{jp}, \lambda, n, 0)$ given by (16). For $d > d_2$, the welfare with a penalty $f_2 - \varepsilon$ allowing solvent firms, $W^*_s(q_s, \lambda, n, f_2 - \varepsilon, 0)$, is given by

$$W^*_s(q_s, \lambda, n, f_2, 0) = \frac{an\sqrt{\lambda}\left[a\left(4+\sqrt{\lambda}(n-2)\right) - 2d(1-\lambda)\left(2+\sqrt{\lambda}(n-1)\right)\right]}{2\left[\sqrt{\lambda}(n-1)+2\right]^2}. \tag{26}$$

and is greater than the judgment-proof welfare $W^*_{jp}(q_{jp}, \lambda, n, 0)$. Indeed, the equality $W^*_s(q_s, \lambda, n, f_2 - \varepsilon, 0) \geq W^*_{jp}(q_{jp}, \lambda, n, 0)$ leads to a constraint $d \geq \overline{d} = \frac{a\left(2-\sqrt{\lambda}+n\right)}{(1-\lambda)\left[\sqrt{\lambda}(n-1)+2\right](1+n)}$. As $\overline{d} < d_2$, the inequality $W^*_s(q_s, \lambda, n, f_2 - \varepsilon, 0) \geq W^*_{jp}(q_{jp}, \lambda, n, 0)$ holds as soon as $f_2 - \varepsilon$ is selected.

Point (*iv*). $W^*_s(q_s, \lambda, n, f_2 - \varepsilon, 0) < 0$ for $d > d_3$.

Eventually, the inequality $d_1 < d_2 < d_3$ always holds whatever a, λ, t, n, which completes the proof.

■

6.3 Proof of proposition 3

We first detail the choice of t, when $f = 0$. The selection of t is such that $\partial W^*_s(q_s, \lambda, n, 0, t)/\partial t = 0$, which leads to the selection of a per-unit tax t^* given by (9).[8] This tax is lower than zero for $d < d_1$ so that the optimal penalty is $t^* = 0$ for $d < d_1$. t^* is positive for $d > d_1$.

For $t^* > 0$ the welfare is $\overline{W}^*_s(q_s, \lambda, n, 0, t^*) = (a - (1-\lambda)d)^2/2$, namely the first-best welfare. In this case, it is easy to check that $\overline{W}^*_s(q_s, \lambda, n, 0, t^*) = W^*_s(q_s, \lambda, n, f^*, 0)$ for $d_1 < d < d_2$.It is easy to check that $\overline{W}^*_s(q_s, \lambda, n, 0, t^*) > W^*_s(q_s, \lambda, n, f_2 - \varepsilon, 0)$ for $d > d_2$. It is easy to check that $\overline{W}^*_s(q_s, \lambda, n, 0, t^*) > 0$ for $d < d_4$, which leads to the proposition 3.

■

[8]It is easy to show that $\partial^2 W^*_s(q_s, \lambda, n, 0, t)/\partial t^2 < 0$.

References

[1] Anderson D. (1978). "Limits on Liability: the Price-Anderson Act Versus Other Laws." *The Journal of Risk and Insurance.*45, 4: 651-674.

[2] Boyd J. (2001). "Financial Assurance Rules and Natural Resource Damage Liability: A Working Marriage?" *Resources for the Future Discussion Paper.* 01-11.

[3] Boyd J. and D. Ingberman (1994). "Noncompensatory Damages and Potential Insolvency." *Journal of Legal Studies.* 23: 895-910.

[4] Buchanan J. (1969). "External diseconomies, corrective taxes, and market structure." *American Economic Review.* 59:174-77.

[5] Calabresi G. (1961). "Some Thoughts on Risk Distribution and the Law of Torts." *Yale Law Journal.* 70,4: 499-553.

[6] Carroll S., Hensler D., Abrahamse A., Gross J., White M., Ashwood S. and E. Sloss (2002). "Asbestos Litigation Costs and Compensation." Rand Institute for Civil Justice, Santa Monica, CA.

[7] European Commission (2000). "On a Second Set of Community Measures on Maritime Safety Following the Sinking of the Oil Tanker Erika." COM(2000) 802 final, Brussels, Belgium.

[8] Hamilton S. (1998). "Taxation, Fines, and Producer Liability Rules: Efficiency and Market Structure Implications." *Southern Economic Journal.* 65(1), 140-150.

[9] International Tanker Owners Pollution Federation Limited. "The Costs of Oil Spills." http://www.itopf.com/costs.html (accessed February 20, 2003).

[10] International Oil Pollution Compensation Funds, (2003). Annual Report.

[11] Kolstad, C., Ulen, T., and Johnson, G. (1990). "Ex Post Liability for Harm vs. Ex Ante Safety Regulation: Substitutes or Complements ?" *American Economic review* 80(4):888-901.

[12] Lewis T. and D. Sappington (1999). "Using Decoupling and Deep Pockets to Mitigate Judgment-proof Problems." *International Review of Law and Economics.* 19, 275-293.

[13] Malaith, G., M. Okino-Fujiwara and A. Postlewaite (1993). "Belief Based Refinments in Signaling Games." *Journal of Economic Theory.* 60:241-275.

[14] Polinsky M. (1980). "Strict Liability vs. Negligence in a Market Setting." *American Economic Review.* 70, 363-367.

[15] Polinsky M. and W. Rogerson (1983). "Products Liability, Consumer Misperceptions, and Market Power." *The Bell Journal of Economics.* 581-589.

[16] Polinsky M. and S. Shavell (1979). "The Optimal Trade-off between the Probability and Magnitude of Fines", *American Economic Review.* 69, 5: 880-891.

[17] Rubinfeld D. (1984). "On the Optimal Magnitude and Length of Liability in Torts." *Journal of Legal Studies.* 15, 551-563.

[18] Shavell, S. (1986). "The Judgment Proof Problem." *International Review of Law and Economics.* 6, 45-58.

[19] Superfund Progress Report: 1980-1997, US EPA, 540-R-98-044 October. Environmental Protection Agency, Washington DC (1998)

Figure 1: Optimal Penalty

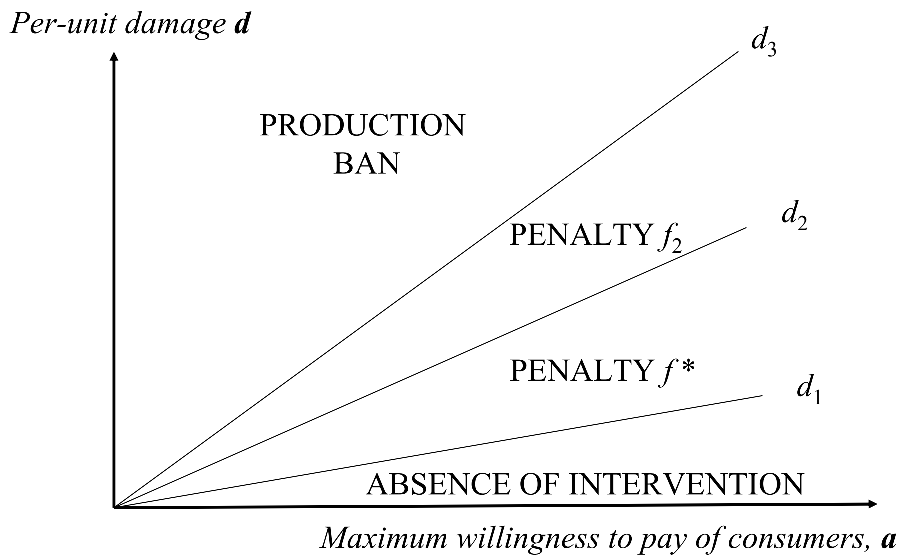

Figure 2: Optimal Policy