Prevention, Limited Liability and Market Structure

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Abstract

Under a market setting, we analyse the impact of legal liability on prevention, taking into account the possible limited wealth of …rms. We show that under strict liability, …rms may choose ex ante not to be able to fully indemnify victims ex post: whatever the market structure, they may use limited liability strategically by investing in prevention in excess of what is socially optimal. The negligence rule prevents …rms from over-investment. For high levels of damages, under both liability rules, …rms exert an insu¢cient e¤ort of prevention. A welfare analysis establishes that when the judgment proof problem is acute, the optimal public intervention ranges from banning the production to imposing the negligence rule.

1 Introduction

Litigation as a tool to manage external risks, such as environmental risks, has been a common practice in the US since the 1980s (see for instance the CERCLA, Comprehensive Environmental Response Compensation and Liability Act) and is under scrutiny by the European Commission (EC, 2000). Legal liability for damages generally has two goals: providing compensation to victims and limiting risks by creating incentives for lowering the probability and/or the severity of accidents. With respect to compensation, legal liability faces the issue of the "judgement proof" injurer that is an injurer unable to pay some portion of the losses to victims. The fact that a potential injurer's liability is bounded by its wealth and the doctrine of limited liability, by reinforcing the externality, has implications on the prevention activity (Shavell, 1986).

Many prevention e¤orts require better equipment. Modi…ed plants can be costly. For instance, prevention e¤orts by industrial …rms or farmers for reducing water pollution in rivers are very di¢cult to implement, even in developed countries, mainly because of the prohibitive costs (Dinar and Zilberman, 1991). Firms do invest in prevention if their expected pro…ts are high enough. Florida and Davison (2001) show that the voluntary adoption of environmental management systems is associated with factories that are relatively large.

Furthermore, the costly prevention activity may dramatically reduce the available funds for indemni…cation in case of a damage. Victims compensation can also be limited due to the small size of involved producers. By the same token, the delegation of risky activities from big …rms to small and medium …rms with a pronounced limited liability weakens the e¤ectiveness of any legal liability regime. Eventually, liability really threatens and in‡uences the strategies of large …rms. For instance, Aventis recently sold its share of Aventis CropScience to Bayer partly due to pending liability payments because of the new StarLink maize, a genetically modi…ed organism (GMO) case (Financial Times, 2001). Traces of the GMO were found in processed foods, which costs may force Aventis CropScience to compensate farmers and manufacturers up to $200 millions in the USA. Aventis faced too many …nancial di¢culties after the resulting withdrawal of the StarLink maize (EPA, 2000).

In this paper, we investigate the e¢ciency of legal liability, combining insolvency considerations with di¤erent market structure con…gurations. The relationships between liability and insolvency on one hand, and liability and market structure on the other hand, have been treated in previous research, but none has investigated the role of market structure on prevention e¤orts under polluters' potential insolvency.

In one strand of the literature, the issue associated with insolvency assumes that the …rm's net worth is exogenous without any reference to competition. It underlines how incentives to invest in prevention may be diluted. Summers (1983) and Shavell (1987) show that under di¤erent liability rules, potentially insolvent parties exert an e¤ort lower than the socially optimal level since they care only about the costs they might actually have to pay. In contrast, Lipowsky-Posey (1993) and Beard (1990) show that, considering a strict liability rule, potentially insolvent injurers might overinvest in prevention. Since the …rm's wealth is exogenous, they cannot question whether the overinvestment in prevention is desirable from a social point of view. Finally, for some other authors, the judgement proof problem is considered as exogenous (cf. for example Watts, 1998). The second strand of the literature encompasses research focused on liability rules in a market setting, such as Polinsky (1980), Epple and Raviv (1978), Polinsky and Rogerson (1983) and more recently Hamilton (1998) and Hamilton and Sunding (2000). In this research where the assets of the potential injurer come from a market interaction, the judgment proof problem is neglected favoring the competition intensity and/or the …rms' entry aspects. Another strand of literature related to our paper tackles the question of the …rm …nancial structure with respect to the prevention activity (cf. van't Veld et al., 1997, Fees and Hege, 1999a, and Dionne and Spaeter, 2001 for recent contributions). Among others, the liability rules in‡uence the …rms' decisions regarding the equity-debt ratio and generally require the use of extended liability to banks. In our paper, …rm pro…t is the only source of wealth, enabling us to focus on market structure.

We propose an analysis of …rms' incentives to invest in prevention under alternative public regulations, in a case of external damages. An e¢cient regulation needs to carefully consider the following aspects. First, the prevention activity a¤ects …rms' pro…ts: A higher e¤ort reduces the probability of an accident and the pro…ts that are available to pay damages; thus, higher e¤ort increases the probability of being judgment proof. Second, …rms' pro…ts are affected by the market structure: The more concentratred the market, the higher the pro…ts and the higher the assets available for indemni…cation; higher pro…ts reduces the probability of being judgment proof.

Compared to previous approaches, we give a uni…ed framework for studying the impact of legal liability on prevention, enabling to emphasize the strategic use of insolvency by …rms. We propose a complete characterization of …rms' and regulator's decisions. Additionnally, we take into account the extent of damage, the consumers' willingness to pay and the number of active …rms.

We show that whatever the market structure, under alternative liability rules, the private optimal level of e¤ort depends on the perspective of pro…ts and more precisely on the maximum willingness to pay for consumers with respect to the magnitude of external damages. For certain parameter values, incentives to invest in prevention are diluted: under strict liability where the injurer is liable regardless of his e¤ort, …rms either underinvest or overinvest in prevention. The overinvestment in prevention appears as a pernicious e¤ect of liability under potential insolvency: It is the result of the strategic use of the limited wealth and limited liability by …rms. It can be corrected with the negligence rule under which the injurer is liable only if the level of "due care" is not taken.

A welfare analysis exhibits that whatever the number of …rms, the optimal public intervention ranges from banning the production (or equivalently product withdrawal of the market) to imposing the negligence rule. Implementing the socially optimal public intervention requires a precise evaluation of some relevant parameters, as the extent of the damage, consumers' maximum willingness to pay and market structure. This suggests that di¤erent types of pollution may not be submitted to the same regulation.

The model is presented in section 2. Section 3 describes the …rms' optimal strategies under di¤erent legal environments. A comparative static analysis is then proposed for addressing the question of the impact of market structure on prevention. The welfare analysis is presented in section 4. Section 5 concludes.

2 The Model

We consider a three stage oligopoly model with n …rms and an utilitarian regulator. In the …rst stage, the regulator chooses a legal environment. Four types of actions are considered: the regulator may choose (i) not to intervene (absence of regulation), (ii) to implement a strict liability rule or (iii) to implement a negligence rule, or (iv) to forbid production. The policy selected by the regulator is publicly known by …rms and consumers. For rules (ii) and (iii), we assume that the Court is able to perfectly identify the responsible …rm and to verify the extent of the damage. In the second stage, …rms simultaneously choose a costly prevention effort and incur the fixed cost of prevention. In the third stage, sellers simultaneously select a quantity (i.e., Cournot competition). For each firm, a damage, D, $D > 0$, representing the cost for the society, may occur during the production process, that is in stage three, affecting a third party: potential victims are not part of the producers-consumers relationship (external damage). We assume that firms as well as consumers and potential victims are risk neutral.

All firms have the same marginal cost of production equal to zero for simplicity. They sell a homogeneous product with inverse demand function $p(Q) = a - Q$. The probability of the external damage event is determined by the firm's choice of effort, $\lambda \in [0, 1]$. Thus $(1 - \lambda)$ denotes the probability that an environmental accident occurs. No damage occurs for a maximal level of effort equal to $\lambda = 1$. By selecting a level of effort, the firm incurs a fixed (independent of quantity) cost equal to $\lambda^2/2$. This cost is sunk and increasing and convex in the level of effort.

Before considering the oligopoly market, we briefly describe the first-best allocation. In this economy, the maximum welfare would be reached with (i) a competitive price equal to the marginal cost of production (namely zero) and (ii) a unique firm (namely $n = 1$). The presence of this single firm would facilitate the maximum economies of scale linked to the fixed cost $\lambda^2/2$ and it would limit the expected damage for the society equal to $(1 - \lambda)D$. The socially optimal level of effort minimizes the total expected cost for the society, $(1 - \lambda)D + \lambda^2/2$, which would lead to an optimal effort equal to $\lambda^e = Min[D, 1]$. If $0 < D < 1$, the effort is $\lambda^e = D$ and the probability of getting a damage is $1 - D$. If $D \geq 1$, the effort is $\lambda^e = 1$ and no damage will occur. Note that the value of λ^e remains unchanged whatever the number of competing firms. Implementing this socially optimal level of effort together with a (socially optimal) competitive price would result in a loss for the seller. This suggests that public intervention seeking to implement a first-best equilibrium would require imposing a price equal to marginal cost and subsidizing the monopolist through public funding of the fixed costs associated with the prevention activity. This also suggests that a second-best (and realistic) policy should take into account the environmental risk (externality) along with the market structure, namely the number of sellers n and the resulting solvency problems. As the prevention effort is costly for the seller, this extra cost can only be covered through a sufficient market price (depending on n).

We now turn to the characterization of the subgame perfect Nash equilibrium of this three stage game and then conduct a welfare analysis allowing the selection among the different regulations.

3 Private choice under alternative rules

As the firm's effort results in a fixed (independent of quantity) cost, it does not interfere with the choice of the output level, so that the production stage (stage 3) can be presented first without loss of generality.

3.1 Production stage

Considering that n firms are active on the market, the per-seller gross profit is $(a - Q)q_i$, with the overall demand given by $Q = \sum_{i=1}^{n} q_i$. The profit maximization gives the first-order condition $a - 2q_i - \sum_{j \neq i}^{n} q_j = 0$. Under a symmetric Cournot-Nash equilibrium, all firms adopt the same strategy. Thus with $q_j = q_i$ substituted in this first-order condition, we get the per-firm equilibrium quantity, $q^* = a/(n+1)$ and the overall quantity offered by the n firms is $Q^* = na/(n+1)$. Thus, the per-seller gross profit is

$$\pi(n) = \left(\frac{a}{n+1}\right)^2 \tag{1}$$

A firm produces a positive quantity as soon as its profit net of the prevention costs, $\pi(n) - \lambda^2/2$, is positive for different values of $\lambda \in [0;1]$. For consumers, surplus is

$$cs(n) = \int_0^{Q^*} [p(Q) - p(Q^*)]dQ = \frac{1}{2}\left(\frac{na}{n+1}\right)^2 \tag{2}$$

3.2 Private Effort Choice

The private effort choice is derived considering the production activity gross profit and the legal environment as given.

3.2.1 Absence of regulation

When no liability regulation is imposed by the regulator, the profit-maximization condition leads firms to make no effort, namely choose $\lambda^* = 0$; so that the probability of accident is equal to one for each firm. The society bears all the risk and the overall externality is equal to nD.

3.2.2 Strict liability

Under strict liability, a firm incurs some liability payments when the damage occurs. This gives a sufficient incentive for each firm to make a prevention effort since the court is able to verify perfectly each firm's action. The liability payments depend on the magnitude of net profits, namely the gross profit given by (1) minus the sunk cost of prevention, $\pi(n) - \lambda^2/2$, with respect to the damage D. More precisely, when the damage occurs (event with probability $(1 - \lambda)$), the firm covers it, as long as the profit net of the damage is positive, namely for $\pi(n) - \lambda^2/2 \geq D$. Let the threshold value

$$\hat{\lambda} = \sqrt{2[\pi(n) - D]}. \tag{3}$$

If $\pi(n) - \lambda^2/2 < D \Leftrightarrow \lambda > \hat{\lambda}$, the firm has insufficient earnings to totally cover the damage: the limited liability constraint is satisfied. In that case, we consider that the firm covers the damage up to the level of its net profits, meaning that it incurs a liability payment of $\pi(n) - \theta^2/2$. It is easy to see that the higher n and D, the lower $\hat{\theta}$. So we get the following definition.

Definition 1 Considering n, a and D as given, a firm is either

- always judgment proof with $\hat{\theta} = 0$ for $D \geq \hat{D}_H(a) = \left(\frac{a}{n+1}\right)^2$,
- always solvent with $\hat{\theta} = 1$ for $D \leq \hat{D}_L(a) = \left(\frac{a}{n+1}\right)^2 - \frac{1}{2}$,
- or potentially judgment proof with $\hat{\theta} \in (0;1)$ for $\hat{D}_H(a) > D > \hat{D}_L(a)$).

This definition states that for low values of a and high values of D, a firm is always judgment proof. For high values of a and low values of D, a firm is always solvent. Finally, for "intermediate" values of a and D, the ex ante choice of effort θ made by each firm may influence its solvency situation. In other words, firms may make a strategic use of insolvency for $\hat{\theta} \in (0;1)$: this case is depicted in Figures 1 and 2 by the area between the dotted lines $\hat{D}_L(a)$ and $\hat{D}_H(a)$. For these particular values of a and D, a firm may have to choose among several prevention levels which influences its solvency situation.

The ex ante choice of effort, θ, determines the ex post liability payments under strict liability:

$$L = \begin{cases} D & \text{if } \theta \leq \hat{\theta} \text{ (solvent firm)} \\ \pi(n) - \theta^2/2 & \text{if } \theta > \hat{\theta} \text{ (judgement proof firm)} \end{cases} \quad (4)$$

Observe that this liability payment depends on the effort level and on the market structure only when the solvency constraint is effective, namely for $\theta > \hat{\theta}$. In that case, the liability payment is a decreasing function in the fixed cost of prevention and in the number of firms that are active on the market. Otherwise, the liability payment only depends on the monetary cost of the accident to victims.

We now detail the per-firm profit according to the different events. With a probability θ, no damage linked to the firm production occurs and the per-firm net profit is $\pi(n) - \theta^2/2$. With a probability $(1 - \theta)$, the damage D linked to the firm production occurs. The profit is $\pi(n) - D - \theta^2/2$ for the solvent firm, and zero for the insolvent firm (since its net profits are taken for victims'compensation. So that under strict liability (S), the net ex ante expected profit (expectation taken with respect to the environmental damage) for a firm writes

$$\pi^S(n) = \begin{cases} \pi(n) - (1-\theta)D - \theta^2/2 \text{ if } \theta \leq \hat{\theta} \\ \theta[\pi(n) - \theta^2/2] \text{ if } \theta > \hat{\theta} \end{cases} \quad (5)$$

where $\pi(n)$ is given by (1). Each firm selects a level of effort that maximizes $\pi^S(n)$. The optimal level of effort indeed selected by the firm will depend on the magnitude of profit, or more precisely on the maximum willingness to pay of consumers, a, with respect to the damage, D. Let

$$\hat{a}(n) = (n+1)\sqrt{3/2}; \tag{6}$$

$$D_1(a) = 1 - \sqrt{1 - 2\left(\frac{a}{n+1}\right)^2 + 2\left(\frac{2}{3}\right)^{3/2}\left(\frac{a}{n+1}\right)^3}; \tag{7}$$

$$D_{eq}(a) = \frac{a}{n+1}\sqrt{\frac{2}{3}}; \tag{8}$$

where frontiers $\hat{a}(n)$ and $D_1(a)$ allow to delimit the sellers choices. Under strict liability, the optimal private choice of effort is characterized in the following proposition:

Proposition 1 Consider first $a \geq \hat{a}(n)$. A firm chooses a socially optimal level of effort, $\lambda^* = \lambda^e = Min[D; 1]$.
Consider now $a < \hat{a}(n)$. A firm that is always solvent chooses a socially optimal level of effort $\lambda^* = \lambda^e = D$. A firm that is potentially judgment proof chooses a socially optimal effort D, if $D \leq D_1(a)$, and an effort equal to $\lambda^* = \frac{a}{n+1}\sqrt{2/3}$ if $D > D_1(a)$. A firm that is always insolvent chooses an effort equal to $\lambda^* = \frac{a}{n+1}\sqrt{2/3}$.
Under potential insolvency, the effort can be higher than the socially optimal effort (if $D_{eq}(a) > D > D_1(a)$) or lower (if $D > D_{eq}(a)$).

Proof: see appendix 1.

Proposition 1 is summarized in Figure 1. The X-axis represents consumers' maximum willingness to pay, a; for the product, and the Y-axis the value of the damage, D. First, for high values of a and D (area I), firms spontaneously make a maximum effort: the perspective of a high gross profit allows a greater investment in prevention, and the threat of a high liability payment is a sufficient incentive to completely eliminate the risk[1]. Second, when the damage value is not too high with respect to consumers' maximum willingness to pay (area II), firms choose the socially optimal effort, D < 1. The damage, if it occurs, will be completely borne by firms that have sufficient earnings. Eventually, when the damage is high but the consumers' maximum willingness to pay is low (area III), the prevention effort is lower than 1 and the solvency constraint is effective: firms won't be able to pay for the whole damage when it occurs. Note that under strict liability, for intermediate values of (a; D) -the hatched part of area III - firms may choose a level of effort that is greater than the socially optimal effort. Potentially judgment proof firms get higher profits by overinvesting in prevention and hence increasing the probability of bankruptcy than by choosing the socially optimal level of effort (equal to D). The strategic use of insolvency is thus underscored.

[1] This holds with a more sophisticated specification of the cost function (e.g. $f\frac{\lambda^2}{2}$), which simply results in a shift in the lower limit of area I (e.g. D = f instead of D = 1).

3.2.3 Negligence rule

Under a negligence liability rule (N), the regulator sets up a kind of standard corresponding to a level of due care that affects the pattern of liability payments. This level of due care is voluntary since it is assumed that (i) this reference previously admitted by the Court sets a precedent and/or (ii) no ex ante control is made before the production stage. If firms respect the level of due care, the liability payment in case of an accident is driven to zero. If the firms do not respect the due care, they will have to incur liability payments similar to the ones made under strict liability. Considering that the due care is set adequately, namely equal to the socially optimal level of effort, $\bar{\lambda} = \lambda^e = Min[D, 1]$[2], a firm's ex ante expected profit is

$$\pi^N(n) = \begin{cases} \pi_3(n) = \pi^S(n) \text{ for } \lambda < \bar{\lambda} \\ \pi_4(n) = \pi(n) - \lambda^2/2 \text{ for } \lambda \geq \bar{\lambda} \end{cases} \tag{9}$$

where $\pi^S(n)$ is given by (5). Note that the profit $\pi_4(n)$ is the highest possible profit since the firm will not incur any liability payment in case of an accident. This enables a firm to increase its level of effort, which would be beneficial for the society. Indeed, a firm has an incentive to respect the standard (namely $\lambda > \bar{\lambda}$) if $\pi_4(n) > \pi_3(n)$. Let :

$$D_2(a) = \frac{a}{n+1}\sqrt{2}\sqrt{1 - \frac{a}{n+1}\left(\frac{2}{3}\right)^{3/2}} \tag{10}$$

Under a negligence rule, the firms' optimal choice leads to the following proposition :

Proposition 2 Consider first $a \geq \hat{a}(n)$. A firm chooses a socially optimal level of effort, $\lambda^* = \lambda^e = Min[D, 1]$.
Consider now $a < \hat{a}(n)$. A firm that is always solvent chooses a socially optimal level of effort $\lambda^* = \lambda^e = D$. A firm that is potentially judgment proof chooses a socially optimal effort D, if $D \leq D_2(a)$, and an effort equal to $\lambda^* = \frac{a}{n+1}\sqrt{2/3} < D$ if $D > D_2(a)$. Idem for a firm that is always insolvent.

Proof: see appendix 1.

Proposition 2 is summarized in Figure 2. In area I (high values of both a and D), firms spontaneously make a maximum effort, just like under strict liability. For low values of D with respect to consumers' maximum willingness to pay (area II), the optimal level of effort is selected and the damage -if it occurs- will be completely borne by firms who have sufficient earnings. Eventually, in area III the solvency constraint is effective, i.e. firms will not be able to pay for the

[2] Setting the negligence due care standard at the socially optimal effort level $Min\{D, 1\}$ is the most relevant choice since this level corresponds to a balanced trade-off between the probability of insolvency and the probability of environmental accident (See Burrows, 1999, for an analysis of the simultaneous use of regulation and liability, considering a negligence due care that may be equal to, above or below the regulated standard).

whole damage, as the consumers' willingness to pay is low and the damage is high. In this last case, the negligence rule is not a sufficient tool for reaching the optimal level of prevention.

One interesting consequence in that under the negligence rule, firms would never overinvest in prevention as under strict liability (the former hatched area in Figure 1 is now part of area II of Figure 2, where the socially optimal level of prevention is selected). The negligence rule allows each firm to dodge its liability payment by respecting the standard. For a lower level of effort, the liability payment would be made up to the available assets.

Under a negligence rule, the socially optimal level of effort is more often implemented. In particular, for the hatched area in Figure 1, the firm has a higher profit respecting the socially optimal level of effort than choosing a higher level of effort resulting in a higher effort cost and hence an higher probability of insolvency without any benefits in terms of liability payments.

To sum up, the main difference between the two liability rules is that under a negligence rule, the judgment proof problem may lead the firm to exert a suboptimal level of effort, whereas the firm may overinvest (or underinvest) in effort under a strict liability rule.

3.3 The market structure

We now consider the impact of the market structure captured by the number of active firms on private decisions of effort. The higher n; the higher is the threshold value, $\hat{a}(n)$ on the X-axis of Figures 1 and 2. Thus, leaving other parameters unchanged, the maximum effort $\varepsilon^* = 1$ (such that the risk completely disappears) is less likely to be adopted. Recall that this level of effort is selected for $a \geq \hat{a}(n)$ and $D \geq 1$; under any liability rule. More generally, an increase in the number of firms, n; leads to a decrease of areas I and II towards the East and an increase of area III towards the East and the SouthEast (in Figures 1 and 2). In area III, the increase of n entails a decrease of the prevention effort $\varepsilon^* = \frac{a}{n+1}\sqrt{\frac{2}{3}}$.

Proposition 3 The less concentrated the market, the less often the socially optimal level of effort is implemented, and the lower the effort level under insolvency (effective or potential).

This highlights the tradeoff between market structure and risk management.

Proposition 4 The strategic use of insolvency under strict liability is observed whatever the market structure.

The market structure appears as an important parameter for the private firm. First, a monopoly may well choose an inefficient level of effort which contrasts with the common idea that a monopoly will be more efficient with respect to prevention than a duopoly or an oligopoly. In addition, for particular values of a and D, a monopoly may choose to overinvest in prevention whereas for the same values of a and D, a duopoly would choose to underinvest in prevention. Also, the fact that a suboptimal level of effort emerges under both strict liability and negligence rules, whatever the market structure contrasts wih Spulber (1989, Chapter 14) who opposed the efficiency of liability rules under a competitive situation to the inefficiency of liability rules under a monopoly situation.

The case of a competitive situation, excluded up to now, may be captured by making n goes to infinity. When $n \to +\infty$, the optimal private effort choice corresponds to the choice under no regulation, $\lambda^* = 0$, and the strategic use of insolvency disappears (as $D_1(a) \to 0$, $\hat{a}(n) = (n+1)\sqrt{3/2} \to +\infty$ and $\lambda^* = \frac{a}{n+1}\sqrt{\frac{2}{3}} \to 0$).

The market structure may as well be an important parameter for the regulator in his choice of a legal environment as we shall see in the following section.

4 Welfare analysis

We now consider the viewpoint of a utilitarian regulator. Comparison of welfares as well as positivity conditions on various welfares give some informations about the action to be chosen by the government given $(a; D)$. Let

$$D_{SOD}(a) = 1 - \frac{\sqrt{1 - 2a^2 + 2n - a^2 n + n^2}}{1+n} \tag{11}$$

$$D_{JP}(a) = \frac{\left(\frac{a}{n+1}\sqrt{\frac{2}{3}}\right)^2 \left[\frac{2}{3} + \frac{n}{2}\right]}{1 - \frac{a}{n+1}\sqrt{\frac{2}{3}}} \tag{12}$$

Proposition 5 *Consider first $a \geq \hat{a}(n)$. Both liability rules are equivalent and preferred to no regulation.*
Consider now $a < \hat{a}(n)$.
If $D \leq D_1(a)$, both liability rules are equivalent and preferred to no regulation. Idem if $D_{JP}(a) > D > D_2(a)$.
If $Min[D_{SOD}(a); D_2(a)] > D > D_1(a)$, a negligence rule is preferred to a strict liability rule.
Finally, if $D_{SOD}(a) > D > Max[D_2(a); D_{JP}(a)]$, banning the activity is the preferred action. Idem if $D \geq D_{SOD}(a)$.

The proposition 3 is illustrated in Figure 3. The two liability rules are equivalent and preferred to no regulation, for (i) high values of a whatever the damage value D (with an effort equal to one), (ii) relatively low values of D compared to a such that $D < D_1(a)$ (with an effort equal to D), and (iii) relatively high values of D compared to a such that $D < D_{JP}(a)$ and $a < \hat{a}(n)$ (with an effort equal to $\lambda^* = \frac{a}{n+1}\sqrt{\frac{2}{3}}$). For high values of D and small a (hatched area), banning the activity could be welfare maximizing as the solvency problem is really acute. In this case the surplus resulting from the exchange does not offset the expected damages. For values of a and D such that $D_1(a) < D < D_2(a)$, a negligence rule is preferred to a strict liability rule, the former allowing to implement the socially optimal effort. The negligence rule allows the reduction of the inefficiency associated with a strict liability rule which results in a overinvestment in prevention by the firm.[3]

The market structure is important in the choice of a legal environment. For some particular values of a and D, the regulator may choose to ban the activity for a duopoly or even an oligopoly whereas for the same values of a and D, a monopoly may be allowed to produce but subjected for example to a negligence rule. These results suggest that a complete industrial organization analysis must be conducted for selecting the appropriate regulation.

5 One extension: The internality case

One interesting extension is to investigate the strategic use of insolvency when the damage is at least partially internalized by consumers, as it is the case for products safety.

All assumptions of section 2 are kept. We only modify the assumption linked to the overall damage $(1-\lambda)nD$. Let $\mu \in [0,1]$ denote the share of the damage incurred by the third party and $(1-\mu)$ the share incurred by the consumers. The third party incurs $\mu(1-\lambda)nD$ and the consumers incur $(1-\mu)(1-\lambda)nD$, where consumers have rational expectation concerning this expected damage and perfect information concerning λ. The value $\mu = 0$ refers to a pure internality case, while $\mu = 1$ refers to a pure externality case (studied previously). The consumers' expected indirect utility is now $u(Q,p) = aQ - Q^2/2 - pQ - (1-\mu)(1-\lambda)nD$, where Q denotes the overall demand (equal to the production). Thus, $\partial u_s(Q,p)/\partial Q = 0$, leads to the same inverse demand $p = a - Q$ as before. This leads to the same equilibrium quantity Q^* and price p^* given in section 3.1. However, the consumer now decides to buy some products when the surplus coming from the exchange is higher than the damage that they incur, namely for $u(Q^*,p^*) \geq 0$. Using $cs(n)$ given by (2), the consumers decide to purchase goods when $cs(n) \geq (1-\mu)(1-\lambda)nD$. Firms expect this consumers' behavior.

Compared to the previous study under externality, the same methodology could be applied to the internality case with $\mu = 0$.

Under the absence of rule, firms strategies differ from the externality case (presented in subsection 3.2.1). Each firm maximizes the gross profit given by (1) minus the sunk cost of prevention, namely the net profit $\pi(n) - \lambda^2/2$, subject to the constraint that consumers purchase, $cs(n) \geq (1-\lambda)nD$. This

[3] This welfare analysis could be completed by taking into account the costs of the different regulations, including the cost linked to the Court. For instance, the complete prohibition of the production (with all the associated controls) could be more costly than the liability rules.

last constraint is satisfied for $\theta \geq \theta_l$ with

$$\theta_l = \operatorname{Max}\left[0; 1 - \frac{n}{2D}\left(\frac{a}{n+1}\right)^2\right] \tag{13}$$

The firms choose the level $\theta^* = \theta_l$ as soon as $\pi(n) - \theta_l^2/2 > 0$ that is for $D \leq D_P(a)$ where $D_P(a) = \frac{n}{2}\left(\frac{a}{n+1}\right)^2 \frac{n+1}{n+1-a\sqrt{2}}$. Otherwise, firms choose not to invest in prevention ($\theta = 0$) either because firms get negative profits (this is the case for $D > D_P(a)$) or because the maximum willingness to pay for consumers is so high with respect to the level of damage that incurring the risk is not an issue (this happens for $D < \frac{n}{2}\left(\frac{a}{n+1}\right)^2$). In absence of regulation, incentives to invest in prevention are diluted: firms choose an effort level that differs from the socially optimal one. Moreover, for values of a and D, such that the social optimum effort is 1, as $\theta_l < 1$, firms underinvest in prevention. For values of a and D such that the social optimum effort is D, it could be that firms overinvest in prevention.

How does regulation could reduce these inefficiencies? Under a strict liability rule, in case of an accident, consumers are fully indemnified as long as $\pi(n) - \theta^2/2 \geq D$ that is for $\theta > \hat{\theta}$ where $\hat{\theta} = \sqrt{2[\pi(n) - D]}$. A firm solves the following optimization problem

$$\begin{array}{l} \operatorname{Max} \pi(n) - (1-\theta)D - \theta^2/2 \\ s.t.\ cs(n) \geq 0 \end{array}$$

In case of a judgment proof firm, $\theta \leq \hat{\theta}$, consumers are partially compensated and they buy the product as long as $cs(n) - (1-\theta)\left[nD - \left(\frac{a}{n+1}\right)^2 + \frac{\theta^2}{2}\right] \geq 0$. A potential judgment proof firm will choose an effort level solution to

$$\begin{array}{l} \operatorname{Max}_\theta [\pi(n) - \theta^2/2]^+ \\ s.t.\ cs(n) - (1-\theta)\left[nD - \left(\frac{a}{n+1}\right)^2 + \frac{\theta^2}{2}\right] \geq 0 \end{array}$$

Under liability regulation, results are similar to the externality case : some inefficiencies are reduced. Except for high values of D with respect to a for which consumers prefer not to purchase the good: for these parameters values, one has market closure due to the absence of demand.

6 Concluding remarks and other possible extensions

Using a very simple model of oligopoly under alternative rules, we have shown that the judgement proof problem can result in an over- or underinvestment in prevention, and that the negligence rule does not necessary solve the judgment proof problem. Our paper underlines that an efficient policy for managing external risks entails a precise analysis of the complete environment which amounts to a cost-benefit analysis. This is particularly true for the cases where the judgment proof appears as a strategic variable for the firms. We showed that both liability rules are limited for impeding the risk of damages, when the extent of damage becomes relatively large compared to the buyers' maximum willingness to pay. The result suggests that alternative instruments such as banning the production and/or limiting the number of firms have to be used.

New instruments in the field of public regulation of environmental risks could also be interesting with respect to the strategic use of insolvency. For example, recent theoretical papers have considered the possible extension of liability to banks or insurance companies (cf. Pitchford, 1995, and Boyer and Laffont, 1997). The requirement that potential polluting industries set monetary guaranties aside (bonds) before the beginning of the industrial activity may be an alternative solution to potential insolvency. More generally, financial responsibility may mitigate the insolvency problem (cf. Fees and Hege, 1999b). Such measures of course modify firms' incentives with respect to prevention.

APPENDIX 1 : Private Strategies

Proof of proposition 1: At interior solutions, first order conditions of profit maximization with respect to the prevention effort level are:

$$
\begin{array}{ll}
D - \theta^* = 0 & \text{if } \theta^* \leq \widehat{\theta} \\
\pi(n) - \theta^{*2}/2 - \theta^{*2} = 0 & \text{if } \theta^* > \widehat{\theta}
\end{array}
$$

where the expression of $\pi(n)$ is given in (1). One gets the following value functions :

$$
\begin{array}{ll}
\Pi_{SOD} = \left(\frac{a}{n+1}\right)^2 - D + D^2/2 & \text{if } \theta^* \leq \widehat{\theta} \\
\Pi_{JP} = \left[\frac{2}{3}\left(\frac{a}{n+1}\right)^2\right]^{3/2} & \text{if } \theta^* > \widehat{\theta}
\end{array}
$$

Consider first $a \geq \widehat{a}(n)$ (where the threshold $\widehat{a}(n)$ is defined by the relation $\theta^* = \frac{a}{n+1}\sqrt{2/3} = 1$). The optimal choice is the socially optimal effort level $\theta^* = \theta^e = Min[D, 1]$ whether one has $D < 1$ or $D > 1$.

Consider now $a < \widehat{a}(n)$. A firm that is solvent for sure chooses the socially optimal effort, $\theta^* = D$. A potentially judgment proof firm may choose between $\theta^* = D$ and $\theta^* = \frac{a}{n+1}\sqrt{2/3}$. It chooses the socially optimal level of effort if $\Pi_{SOD} \geq \Pi_{JP}$ that is if $D \leq D_1(a)$. The optimal effort $\theta^* = \frac{a}{n+1}\sqrt{2/3}$ is selected when $D > D_1(a)$. This level of effort is greater than the socially optimal level $\theta^e = D$ when $D \leq D_{eq}(a)$ and lower otherwise. $\square$

Proof of proposition 2: Consider first that $a \geq \widehat{a}(n)$. The optimal choice is the socially optimal effort level $\theta^* = \theta^e = Min[D, 1]$ whether one has $D < 1$ or $D > 1$.

Now consider values of (a, D) such that $a < \widehat{a}(n)$ and $D < 1$. A firm that is always solvent chooses $\theta^* = D$. A firm either insolvent for sure or potentially insolvent may choose between $\theta^* = \frac{a}{n+1}\sqrt{2/3}$ and $\theta^* = D$. When (a, D) are such that $D \leq D_{eq}(a)$, the optimal private effort is D: with this level of prevention effort, the firm escapes its liability and incurs a minimal effort cost. When $D > D_{eq}(a)$, a firm that is insolvent for sure or potentially insolvent has incentives to meet the standard if the profit net of liability payments is greater while choosing D rather than $\theta^* = \frac{a}{n+1}\sqrt{2/3}$, namely

$$
\left(\frac{a}{n+1}\right)^2 - \frac{D^2}{2} \geq \left[\frac{2}{3}\left(\frac{a}{n+1}\right)^2\right]^{3/2}
$$

that is $D \leq D_2(a)$. Hence, for $D_2(a) \geq D > D_{eq}(a)$, $\theta^* = D$. And for $D > D_2(a)$, $\theta^* = \frac{a}{n+1}\sqrt{2/3} < D$.

For values of (a, D) such that $a < \widehat{a}(n)$ and $D = 1$, that is the standard corresponds to the maximum level of effort, $D = 1$; one has $\theta^* = \frac{a}{n+1}\sqrt{2/3} <$

$D = 1$, and a firm that is either always judgment proof or potentially insolvent has no incentives to respect the standard. Indeed, for such a firm to choose the standard, one must have

$$\left(\frac{a}{n+1}\right)^2 - \frac{1}{2} \geq \left[\frac{2}{3}\left(\frac{a}{n+1}\right)^2\right]^{3/2}$$

an inequality that is never satisfied whatever a. Hence, $e^* = \frac{a}{n+1}\sqrt{2/3}$.

Finally, for values of $(a; D)$ such that $a < \hat{a}(n)$ and $D > 1$, only $e^* = \frac{a}{n+1}\sqrt{2/3}$ can be implemented. ∎

Proof of proposition 3: Direct considering the derivative of $e^* = \frac{a}{n+1}\sqrt{2/3}$ and $\hat{a}(n)$ with respect to n. ∎

Proof of proposition 4: Direct since the relevant expressions characterizing the strategic use of bankruptcy under strict liability, $D_{eq}(a)$ and $D_1(a)$ depend on n. ∎

APPENDIX 2 : Welfare Analysis

By taking into account the fact that the prohibition of the production leads to a welfare equal to zero, the following table gives the optimal welfare for the different level of effort selected by the firms.

Prevention Effort	Welfare
$e^* = 0$	$W_0(n) = n\left(\frac{a}{n+1}\right)^2[1+\frac{n}{2}] - nD$:
$e^* = D$	$W_{SOD} = n\left(\frac{a}{n+1}\right)^2[1+\frac{n}{2}] - n(D - \frac{D^2}{2})$
$e^* = \frac{a}{n+1}\sqrt{2/3}$	$W_{JP} = n\left(\frac{a}{n+1}\right)^2[\frac{2}{3}+\frac{n}{2}] - nD\left(1 - \frac{a}{n+1}\sqrt{2/3}\right)$
$e^* = 1$	$W_{SO1} = n\left(\frac{a}{n+1}\right)^2[1+\frac{n}{2}] - \frac{n}{2}$

Proof of proposition 5: Consider first $a \geq \hat{a}(n)$, both liability rules prescribe the socially optimal level of effort, either D or 1. As $W_{SOD} > W_0 > 0$ and $W_{SO1} > W_0 > 0$, both rules are equivalent and preferred to no regulation.

Let now consider $a < \hat{a}(n)$.

If $D < D_1(a)$, both liability rules prescribe D and one as $W_{SOD} > W_0 > 0$ so that both liability rules are equivalent and preferred to no regulation. Idem if $D_{JP}(a) > D > D_2(a)$: both liability rules prescribe $e^* = \frac{a}{n+1}\sqrt{2/3}$ and one has $W_{JP} > W_0$.

If $\mathrm{Min}[D_{SOD}(a); D_2(a)] > D > D_1(a)$, a negligence rule prescribes D whereas a strict liability rule prescribes $e^* = \frac{a}{n+1}\sqrt{2/3}$. As $W_{SOD} > W_{JP}$, a negligence rule is preferred to a strict liability rule. And as $W_{SOD} > W_0$, a negligence rule is also preferred to no regulation.

If $D_{SOD}(a) > D > Max[D_2(a); D_{JP}(a)]$, both rules prescribe $\lambda^* = \frac{a}{n+1}\sqrt{2/3}$. But implementing $\lambda^* = \frac{a}{n+1}\sqrt{2/3}$ leads to a negative welfare. So that to forbid the activity is the optimal action for the regulator. Idem if $D \geq D_{SOD}(a)$: for $D_2(a) > D \geq D_{SOD}(a)$, D is prescribed under a negligence rule, $\lambda^* = \frac{a}{n+1}\sqrt{2/3}$ under a strict liability rule and $W_{JP} < W_{SOD} < 0$. And for $D \geq Max[D_2(a); D_{SOD}(a)]$, both liability prescribe $\lambda^* = \frac{a}{n+1}\sqrt{2/3}$ and $W_{JP} < 0$. $\square$

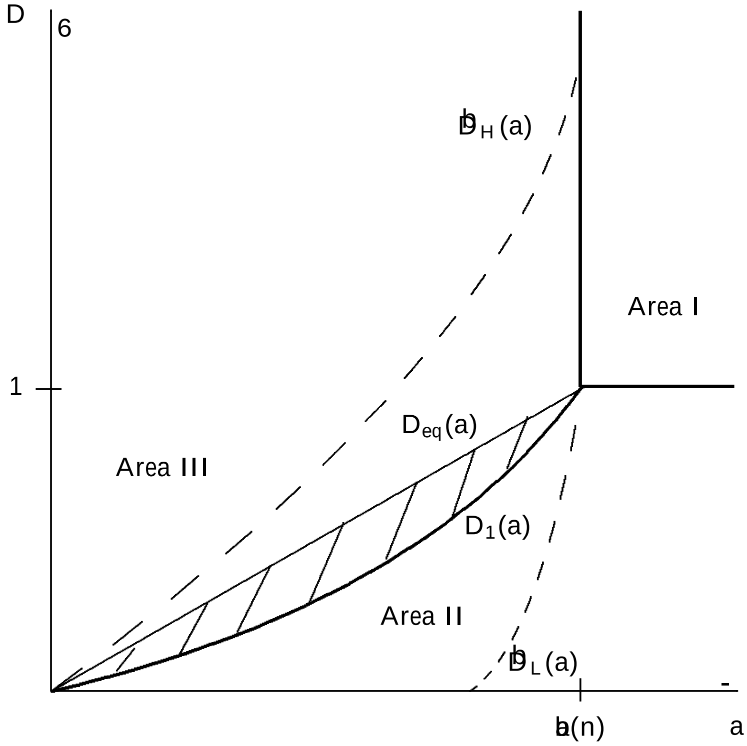

Figure 1: Private choice of e¤ort under strict liability

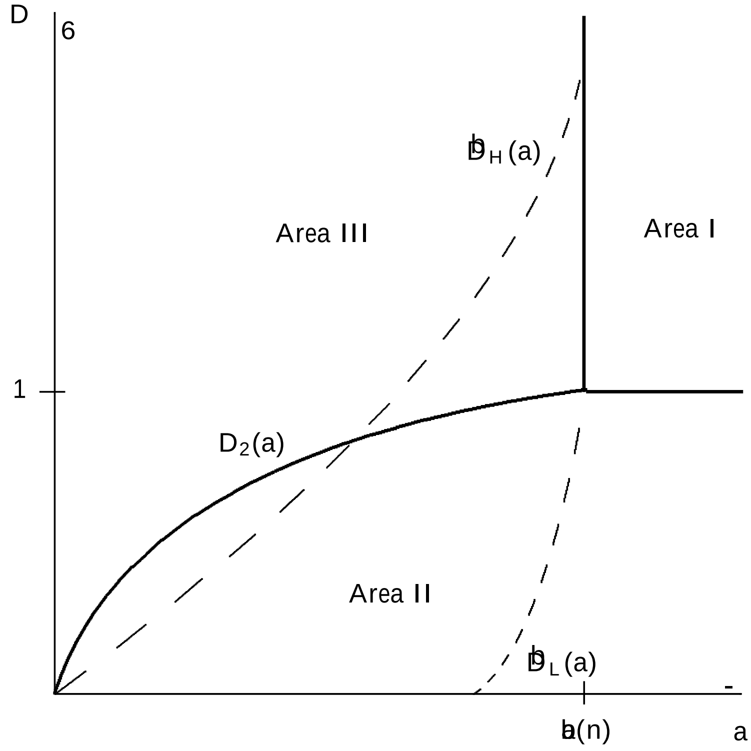

Figure 2: Private choice of e¤ort under a negligence rule

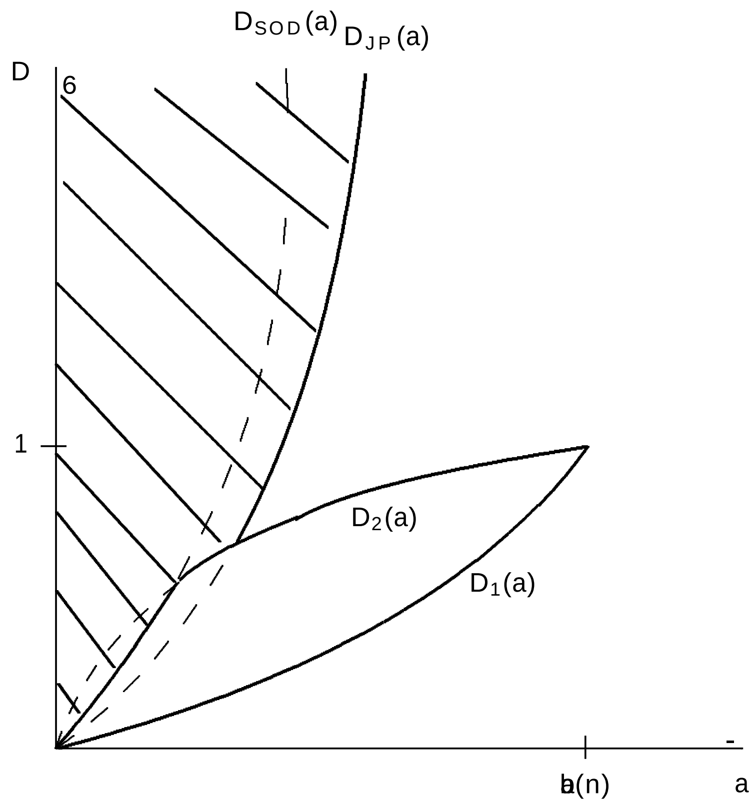

Figure 3: Optimal action for the regulator

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