Environmental Risks, the Judgment-Proof Problem and Financial Responsibility*

Bidénam Kambia-Chopin†

This version April 2007

Abstract

This paper examines a setting in which a firm is liable to pay environmental damages caused by its activity but may not have sufficient wealth for repair of damages. In order to induce the full internalization of the environmental cost, the firm is required to demonstrate a financial guarantee from a solvent party that covers this cost. Since the firm and the guarantor are joint liable for the harm caused by the firm, it is in the interest of the guarantor to design the guarantee contract in order to induce the firm to take an adequate level of prevention. First, I show that financial responsibility regime may achieve the social optimum. Secondly, I identify a particular form of contract in the set of contracts which induce the socially optimal level of prevention. This contract is closed to an alternative risk transfer product referred to as the spread loss treaty.

*I am very grateful to Jean-Marc Bourgeon, Georges Dionne, Marie-Cécile Fagart, Mouhamadou Fall, Claude Fluet, Bruno Jullien, Anne Lavigne, Rémi Moreau, Pierre Picard, Sandrine Spaeter, Jean-Marc Tallon and Daniel Zajdenweber. The paper also benefited from the comments of session participants of the 2005 SCSE congress in Charlevoix, 2005 AFSE congress in Paris and seminar participants at HEC Montréal, Université d'Orléans, Université de Sherbrooke and Université du Québec à Montréal.

†Canada Research Chair in Risk Management, CREF and HEC Montréal, 3000 chemin de la Côte-Sainte-Catherine, Montréal (QC), H3T 2A7, Canada. Tel: 1 5143406613. Email: bidenam.kambia@hec.ca

JEL Classification: D21, D82, K13, K32.

Keywords: alternative risk transfer, environmental risk, financial responsibility, judgment-proof problem, moral hazard.

Résumé

Nous considérons une entreprise dont l'activité peut causer des dommages environnementaux dont le montant peut excéder la valeur de ses actifs. Afin de permettre une réparation totale des dommages quelle que soit leur ampleur, l'entreprise est assujettie à la justification de garanties financières émanant d'une institution financière. Le garant doit répondre des obligations financières de l'entreprise lorsque la responsabilité de celle-ci est mise en jeu. Par conséquent, il offre à l'entreprise un contrat qui l'incite à adopter un niveau de prévention adéquat. Dans un premier temps, nous montrons que l'objectif de réparation totale des dommages n'est pas toujours incompatible avec la mise en oeuvre du niveau de prévention socialement optimal. Deuxièmement, nous caractérisons une forme particulière de contrat induisant le niveau de prévention socialement optimal. Ce contrat peut être rapproché d'un traité d'étalement de la sinistralité.

Classification JEL : D21, D82, K13, K32.

Mots clés : transfert alternatif des risques, risques environnementaux, garantie financière, responsabilité limitée, aléa moral.

1 Introduction

Liability rules are an important tool of environmental risks management in Canada, United States and Europe. The major legislations are CERCLA (Comprehensive Environmental Response, Compensation and Liability Act) adopted by the American Congress in 1980 and the Directive of the European Parliament and the Council on Environmental Liability with regard to the Prevention and Remedying of Environmental Damages which came into force in April 2004. A liability rule induces correct incentive for risk prevention only if information is symmetric and the potential injurer has sufficient wealth to cover his liability. Indeed, it is well known from the previous literature that when the injurer's wealth is not sufficient to pay liability judgments ex post (the injurer is said to be judgment-proof) this leads to underprovision of care ex ante (see Summers (1983) and Shavell (1986)). In the case of environmental risks, on the one hand, perfect control of firms' actions in prevention is not possible, and on the other hand, the wealth of the polluter may be small relative to the clean-up costs and victims' compensation[1].

There are many policies to alleviate the judgment-proof problem. The first one is to extend liability to the parties who have a contractual relationship with the risky firm, the case under CERCLA which imposes extended liability to lenders. The economic analysis of the extended lender liability has given raise to mitigated results. Pitchford (1995) considers a one-period moral hazard model with two states of nature (accident or not). Since the loan fee fixed by the lender included his expected liability costs, the more the lender is liable, the more he charges the firm in the no-accident state. Then, the state of nature "no-accident" becomes unfavourable for the firm and the full liability of the lender[2] leads to a suboptimal level of effort whereas partial lender's liability allows to achieve the optimal

[1] Ringleb and Wiggins (1990) show that after the enactment of CERCLA, large companies strategically subcontracted their dangerous activities to small ones in order to shield assets from liability in the case of environmental accident.

[2] The lender pays for the full amount of the damages and recovers a part of this amount from the borrower.

level of prevention. In a two-period model, Boyer and Laffont (1997) show that partial liability of lender is optimal. Consequently, these authors conclude that the society has to make a trade-off between prevention and compensation. In an alternative setting in which environmental damages are stochastic and prevention cost is a monetary investment that needs external funding, Dionne and Spaeter (2003) show that lender extended liability has a positive effect on the firm's prevention level if and only if an increase in the face value of the debt implies an increase in preventive investment. Moreover, Balkenborg (2001) and Lewis and Sappington (2001) show that the benefits of the extension of liability to lenders depend on the observability of the firm's prevention level by the lender, the bargaining power of each party and the nature of environmental damages. Finally, Hutchison and Van't Veld (2005) consider a model with both observable damage-reducing activities and non-observable probability-reducing measures and show that introducing extended liability to lender induces judgment-proof firms with high gross profits to take socially optimal levels of care, those with intermediate gross profits to take a suboptimal level of care and drives those with low gross profits out of business.

Financial responsibility is another remedy for the jugment-proof problem. Under a regime of financial responsibility, the firm is required to demonstrate that the cost of the harm she can cause is covered. The most common instrument of financial responsibility is the insurance contract. But as it is well known, the compulsory liability insurance induces the efficient level of prevention only when the insurer is able to observe the prevention level performed by the firm (see Shavell (1986), Jost (1996), Polborn (1998)). Following the analysis of Jost (1996), Feess and Hege (2000, 2003) consider a model with monitoring and monitoring-based incentives and show that the mandatory liability coverage for total harm leads to an allocation that is closed to the first-best.

In this paper, we investigate how the socially optimal allocation can be implemented through ex ante financial responsibility and ex post strict liability rule. We do not restrict our analysis to insurance contract but on contrary analyze financial guarantee contract.

Indeed, in the Directive of the European Parliament and the Council on environmental liability there is a special focus on a future legislation that imposes financial responsibility on the polluting firms. Then we analyze the consequences of financial responsibility on the incitation to prevention in a context of asymmetric information and show that the first-best allocation may be attainable. This follows from the fact that the level of damages provides a signal of the firm's prevention level (see Lewis and Sappington (1999)) and can be used to design an optimal contract. But contrary to Lewis and Sappington (1999), in our setting, prevention measures do not only involve a desutility for the firm but also reduce the funds available for compensation and clean-up (see Beard (1990), Lipowsky-Posey (1993) and Dionne and Spaeter (2003)).

We consider a firm which activity yields a non-random gross profit and generates random environmental damages. The firm can improve the distribution of damages by an investment in prevention at the beginning of the period and safety measures during the production process. At the end of the period, only the damages and the resources of the firm net of the prevention cost are observable. Moreover, it is assumed that the firm's wealth is lower than the highest amount of damages its activity can generate. We establish a necessary and sufficient condition for the implementation of the socially optimal allocation in spite of moral hazard when the firm is mandated to cover the highest amount of damages its activity can generate. We also demonstrate that the set of contracts which implement the socially optimal level of prevention includes a particular contract of the form "reward or maximal penalty" which is closed to a finite risk product referred to as spread loss treaty. The rest of the paper is organized as follows. The following section presents the optimal choice of the firm in the absence of the financial responsibility regime. Section 3 investigates the impact of financial responsibility on the firm's prevention level. Finally, section 4 concludes.

2 The optimal choice of the firm without financial responsibility

Consider a risk-neutral firm which activity generates a fixed profit P and creates a possibility of environmental damages $\ell \in [0, L]$. The firm can improve the distribution of damages by an investment in prevention at the beginning of the period and safety measures during the production process; these two measures are represented by a single prevention variable denoted e. However, the reduction of risk generates a cost $c(e)$ when the firm chooses a level of prevention e. Moreover we assume that before engaging in its activity, the firm has initial wealth (equity) R which can be partially used to cover the cost induced by prevention measures. Let $f(\ell/e)$ and $F(\ell/e)$ be respectively the density and the distribution function of the damages; the following is assumed:

Assumption 1 : $\forall e$, $f(\ell/e) > 0$, $\dfrac{f_e(\ell/e)}{f(\ell/e)}$ decreases with ℓ[3]. This means that the observation of a lower level of damage is relatively more likely if a higher level of prevention has been adopted. This assumption implies the first order stochastic dominance: $\forall \ell \in]0, L[$, $F_e(\ell/e) > 0$. Moreover, $F_e(0/e) = F_e(L/e) = 0$.

Assumption 2 : $\forall \ell \in]0, L[$, $F_{ee}(\ell/e) < 0$. The distribution function is strictly concave in e[4].

Assumption 3: $c_e(e) > 0$ and $c_{ee}(e) > 0$. The prevention cost is strictly convex in e.

Assumption 4: If the amount of damages is very high, the firm' assets may be insufficient for compensation; then the firm will be pushed into bankruptcy. Assume that the discount rate is null so that the firm's net value without investment in prevention noted π equals $R + P$. Formally, this limited liability assumption can be written as:

$$L > \pi \tag{1}$$

What about the optimal level of prevention from the firm's point of view? The intuition

[3] Monotone Likehood Ratio Property (MLRP).

[4] Concavity of Distribution Function Condition (CDFC).

suggests that a firm faced with limited liability will underinvest in prevention. But, as we will see below, this is not always true.

The social welfare criterion is assumed to be the minimization of the total social cost which is the sum of the expected damages and the prevention cost. Assume that the regulator observes the level of prevention. We denote by e^* the socially optimal level of prevention. Formally, it is the level of prevention that minimizes the total social cost, in other words it is the solution of the following problem:

$$\underset{e}{Min} \int_0^L \ell f(\ell/e) d\ell + c(e)$$

The first-order condition (FOC) is given by:

$$c_e(e^*) = -\int_0^L \ell f_e(\ell/e^*) d\ell$$

Integration by part of the right-hand-side term with respect to ℓ and the fact that $F_e(0/e) = F_e(L/e) = 0$ lead to:

$$c_e(e^*) = \int_0^L F_e(\ell/e^*) d\ell \qquad (2)$$

The left-hand-side term represents the social expected marginal cost of prevention and the right-hand-side represents the social expected marginal benefit in terms of improvement of the distribution of damages. At the social optimum e^*, the expected marginal cost of prevention equals the expected marginal benefit of prevention[5].

The objective of the firm is to maximize its net revenue which equals to the sum of its profit and equity minus the expected liability payments (compensation and clean-up costs). The firm can only pay up to her assets. Hence she chooses the prevention level which solves

[5] The second order condition is also satisfied. Differentiation of the FOC and taking into account that $F_{ee}(\ell/e) < 0$ and $c_{ee}(e) > 0$ lead to:

$$c_{ee}(e^*) - \int_0^L F_{ee}(\ell/e^*) d\ell > 0$$

the following problem:

$$\begin{aligned} & \underset{e}{Max}\ \pi - c(e) - \int_0^{\pi - c(e)} \ell f(\ell/e) d\ell - [1 - F(\pi - c(e))] [\pi - c(e)] \\ \Leftrightarrow\ & \underset{e}{Max}\ F(\pi - c(e)) [\pi - c(e)] - \int_0^{\pi - c(e)} \ell f(\ell/e) d\ell \end{aligned}$$

If we denoted by e^P the interior solution of the above problem, it solves the following FOC:

$$\begin{aligned} & - c_e(e^P) F\left[\pi - c(e^P)\right] + F_e\left[\pi - c(e^P)\right]\left[\pi - c(e^P)\right] - \int_0^{\pi - c(e^P)} \ell f_e(\ell/e^P) d\ell = 0 \\ & \Leftrightarrow c_e(e^P) F\left[\pi - c(e^P)\right] = - \int_0^{\pi - c(e^P)} \ell f_e(\ell/e^P) d\ell + F_e\left[\pi - c(e^P)\right]\left[\pi - c(e^P)\right] \end{aligned}$$

Integration by part of the first term of the right-hand-side term with respect to ℓ and the fact that $F_e(0/e) = F_e(L/e) = 0$ yield:[6]

$$c_e(e^P) F\left[\pi - c(e^P)\right] = \int_0^{\pi - c(e^P)} F_e(\ell/e^P) d\ell \tag{3}$$

Then, we can establish the following result:

Lemma 1 *A judgment-proof firm does not always choose a suboptimal level of prevention.*

Proof. From the comparison of conditions (2) and (3). ■

At the optimal private level of prevention, the private expected marginal benefit of prevention equals the private expected marginal cost. The private expected marginal benefit of prevention is lower than the social one because of the partial internalization of environmental damages by the firm. Moreover, the private expected marginal cost of prevention is lower than the social one because the funds invested in the prevention are not available for compensation and clean-up. Consequently, the optimal private level of prevention may be lower

[6] This condition is sufficient if the second order condition is satisfied. Differentiation of (3) with respect to e leads to: $c_{ee}(e^P)F(\pi - c(e^P)) + 2c_e(e^P)F_e(\pi - c(e^P)) - \int_0^{\pi - c(e^P)} F_{ee}(\ell/e^P)d\ell - \left[c_e(e^P)\right]^2 f(\pi - c(e^P))$. The first three terms are positive and the last term is negative. So we have to assume that their sum is negative.

or higher than the socially optimal one, depending on which effect dominates. However, the judgment-proofness of the firm will result in a partial remediation of damages. One can think about compulsory liability insurance which covers the highest amount of damages as a solution to this problem. But, it is well known from insurance economics literature that the combination of full insurance and non observability of prevention level leads to under-provision of care by the insured. Then, which kind of contract can provide the full coverage of damages and induce the firm to choose an optimal level of prevention?

3 Financial Responsibility

This section is devoted to the economic analysis of a hybrid regime of ex ante regulation through financial responsibility requirement and ex post strict liability. More precisely, in our setting the financial responsibility takes the form of a guarantee provided by another party that has "deep-pockets". Then the hybrid regime can be viewed as a regime of vicarious liability in which the guarantor and the firm are joint liable. As we know, in this setting, the victims generally choose to collect from the guarantor because the later has deep-pockets. Then, in what follows, we will assume that the risk-neutral firm (the agent) and his risk-neutral guarantor (the principal) are jointly liable and that it is the guarantor who has to compensate for the damages generated by the firm[7,8].

The prevention level performed by the agent and consequently the cost of such a measure are not observable by the principal. Moreover, the amount of damages and the *net* resources of the firm at the end of the period are observable. The timing of the model is as follows. First, the guarantor and the firm sign a contract which stipulates the state-contingent-payments that the firm has to make to its guarantor. Secondly, the firm performs a level of

[7] Apart from the deep-pockets reason, this rule ensures the financial participation of the principal even if he argues that his agent does not respect a clause in the contract.

[8] This assumption is similar to the one of Pitchford (1995) who considers that in the case of accident, the lender pays for compensation.

prevention and bears the associated cost which is unobservable by the guarantor. Then the profit is realized and the damages occur and finally the transfer is made to the guarantor. Moreover, it is assumed that the guarantor has all the bargaining power and his objective is to design a scheme of transfers that maximizes his profit.

If we denote by $t(\ell)$ the payment made by the firm when the amount of damages equals ℓ, the guarantor's problem $(P1)$ can be written as[9]:

$$\underset{t(\ell);e}{Max} \int_0^L (t(\ell) - \ell) f(\ell/e) d\ell$$

$$st\ \pi - c(e) - \int_0^L t(\ell) f(\ell/e) d\ell \geq \underline{u} \text{ with } \underline{u} \geq 0 \tag{4}$$

$$t(\ell) \leq \pi - c(e) \quad \forall \ell \tag{5}$$

$$t(\ell) \geq B \quad \forall \ell \quad \text{with } B < 0 \tag{6}$$

$$-c_e(e) - \int_0^L t(\ell) f_e(\ell/e) d\ell = 0 \tag{7}$$

The condition (4) represents the participation constraint of the firm and reflects the fact that the financial guarantee must yield an expected revenue at least equal to what the firm would have obtained without contracting. The firm's limited liability constraint is given by (5). Condition (6) reflects the fact that the transfer is bounded below and the possibility of rewarding the firm[10]. The last condition is the incentive compatibility constraint which reflects the optimal behavior of the firm in choosing the prevention level[11].

Every level of the firm's utility u is given by the following expression:

$$u = \pi - c(e) - \int_0^L t(\ell) f(\ell/e) d\ell \tag{8}$$

Taking into account this expression, the objective function of the guarantor becomes:

$$\pi - c(e) - u - \int_0^L \ell f(\ell/e) d\ell$$

[9] We assume that the guarantor's profit is positive at the solution to (P1).

[10] In agency literature, when the agent faces bounded penalty, the principal can use rewards to incite him.

[11] It is the so-called first-order approach that consists to take into account just the FOC of the optimization problem of the firm. Rogerson (1985) has shown that this approach is valid under assumptions 1 and 2.

Moreover, (5) and (6) imply:

$$\pi - c(e) \geq \int_0^L t(\ell) f(\ell/e) d\ell \geq B$$

$$\text{thus} \quad 0 \leq u \leq \pi - c(e) - B$$

Consequently, the existence of a transfers scheme verifying (4), (5) and (6) implies that the utility of the firm is bounded: $u \in [\underline{u}, \pi - c(e) - B]$. Note that the principal's objective function depends only on the expected transfer (by u). Therefore, all solutions that verify the agent's incentive constraint and that have the same expectation are equivalent from the principal's point of view. However, the existence of such solutions is not guaranteed. Indeed, if the problem admits no solution, then it is not possible to implement a given level of prevention e for a given level of utility u. Then it is essential to characterize the conditions under which the problem $(P1)$ admits a solution **for a given** u **and a given** e.

Let us assume that $u \in [\underline{u}, \pi - c(e) - B]$, then the first step of the analysis consist to establish conditions under which the incentive constraint (7) is satisfied.

Let $\Im = \{t(\ell) \text{ such that } B \leq t(\ell) \leq \pi - c(e) \quad \forall \ell\}$, be the set of admissible transfers. Let us define:

$$G\left[t(.)\right] = \int_0^L t(\ell) f_e(\ell/e) d\ell$$

$$m = \min_{t(\ell) \in \Im} \int_0^L t(\ell) f_e(\ell/e) d\ell$$

$$M = \max_{t(\ell) \in \Im} \int_0^L t(\ell) f_e(\ell/e) d\ell$$

We can establish the following result:

Lemma 2 *The minimum,* m*, of the function* $G\left[t(.)\right] = \int_0^L t(\ell) f_e(\ell/e) d\ell$ *is strictly negative and the maximum,* M*, is strictly positive.*

Proof. From assumption 1, $\forall e$, $f(\ell/e) > 0$ and $\dfrac{f_e(\ell/e)}{f(\ell/e)}$ decreases with ℓ. Since $F_e(L/e) = 0$, $\dfrac{f_e(\ell/e)}{f(\ell/e)}$ can not be positive (or negative) everywhere. Then there exists a level of damages ℓ^* such that $\forall \ell \leq \ell^*$, $\dfrac{f_e(\ell/e)}{f(\ell/e)} \geq 0$ and $\forall \ell > \ell^*$, $\dfrac{f_e(\ell/e)}{f(\ell/e)} < 0$.

Let us consider an interval $I = \left[\underline{\ell}\ ,\overline{\ell}\right]$ strictly included in $[0, L]$ and the following scheme of transfers:

$$t(\ell) = \begin{cases} \pi - c(e) & \forall \ell \notin I \\ \pi - c(e) - k,\ with\ k > 0 & \forall \ell \in I \end{cases}$$

With a I strictly included in $[0, \ell^*]$ we have:

$$\int_0^L t(\ell) f_e(\ell/e) d\ell = \int_0^L [\pi - c(e)]\, f_e(\ell/e) d\ell - k \int_{\underline{\ell}}^{\overline{\ell}} f_e(\ell/e) d\ell$$

$$= -k \int_{\underline{\ell}}^{\overline{\ell}} f_e(\ell/e) d\ell < 0$$

With a I strictly included in $[\ell^*, L]$ we have:

$$\int_0^L t(\ell) f_e(\ell/e) d\ell = \int_0^L [\pi - c(e)]\, f_e(\ell/e) d\ell - k \int_{\underline{\ell}}^{\overline{\ell}} f_e(\ell/e) d\ell$$

$$= -k \int_{\underline{\ell}}^{\overline{\ell}} f_e(\ell/e) d\ell > 0$$

Since by definition, $\forall\ t(\ell)$, $m \leq \int_0^L t(\ell) f_e(\ell/e) d\ell \leq M$. Then $m < 0$ and $M > 0$. ■

The function $G\left[t(.)\right] = \int_0^L t(\ell) f_e(\ell/e) d\ell$ is bounded in the set of admissible transfers. Then the validity of the incentive constraint depends on the value taken by the minimum of the function $G\left[t(.)\right]$ as follows.

Lemma 3 *The incentive constraint is satisfied for a given* e *and* u *if and only if* $m \leq -c_e(e)$.

Proof. Necessary condition: Let us assume that $m > -c_e(e)$. Then, all transfers schemes are such that $\int_0^L t(\ell) f_e(\ell/e) d\ell > -c_e(e)$. In this case, there is no transfers scheme which satisfies the incentive constraint (7). Consequently, the set of solutions of the problem $(P1)$ is empty.

Sufficient condition: As $M > 0 > -c_e(e)$ and $m \leq -c_e(e)$, there exists a scheme of transfers $t(\ell)$ such that $\int_0^L t(\ell) f_e(\ell/e) d\ell = -c_e(e)$. ■

The second step of the analysis is devoted to the characterization of the transfers scheme which minimizes the function $G\left[t(.)\right]$.

Lemma 4 *The scheme of transfers $\widehat{t}(\ell)$ which minimizes the function $G[t(.)]$ has the following form:*

$$\widehat{t}(\ell) = \begin{cases} B & \forall \ell < \widehat{\ell} \\ \pi - c(e) & \forall \ell > \widehat{\ell} \end{cases}$$

With $\widehat{\ell}$ defined by $\widehat{\ell} = F^{-1}\left[\dfrac{u}{\pi - c(e) - B}\right]$

Proof. Let us consider the following program:

$$\underset{B \leq t(\ell) \leq \pi - c(e)}{Min} \int_0^L t(\ell) f_e(\ell/e) d\ell$$

$$st \; t(\ell) \leq \pi - c(e) \quad \forall \ell \tag{9}$$

$$t(\ell) \geq B \quad \forall \ell \tag{10}$$

$$\int_0^L t(\ell) f(\ell/e) d\ell = \pi - c(e) - u \tag{11}$$

Denoted by $\omega(\ell)$, $\eta(\ell)$ and λ the (positive) lagrangian multipliers associated respectively to the constraints (9), (10) and (11). The lagrangian of this problem can be written as:

$$\begin{aligned} \pounds\left(t(\ell), \omega(\ell), \eta(\ell), \lambda\right) &= -\int_0^L t(\ell) f_e(\ell/e) dl + \omega(\ell)\left[\pi - c(e) - t(\ell)\right] + \eta(\ell)\left[t(\ell) - B\right] \\ &\quad -\lambda\left[\pi - c(e) - u - \int_0^L t(\ell) f(\ell/e) d\ell\right] \end{aligned}$$

At the optimum we have:

$$\omega(l)\frac{\partial \pounds}{\partial \omega(\ell)} = \omega(\ell)\left[\pi - c(e) - t(\ell)\right] = 0$$

$$\eta(\ell)\frac{\partial \pounds}{\partial \eta(\ell)} = \eta(\ell)\left[t(\ell) - B\right] = 0$$

$$\lambda\frac{\partial \pounds}{\partial \lambda} = -\lambda\left[\pi - c(e) - u - \int_0^L t(\ell) f(\ell/e) d\ell\right] = 0$$

$$\frac{\partial \pounds}{\partial t(\ell)} = -f_e(\ell/e) - \omega(\ell) + \eta(\ell) + \lambda f(\ell/e) = 0$$

The last optimality condition can be rewritten as:

$$\frac{-f_e(\ell/e)}{f(\ell/e)} + \lambda - \frac{1}{f(\ell/e)}\omega(\ell) + \frac{1}{f(\ell/e)}\eta(\ell) = 0 \tag{12}$$

In the proof of lemma 2, we have shown that there is a level of damages ℓ^* such that $\frac{f_e(\ell^*/e)}{f(\ell^*/e)} \geq 0$ for $\ell \leq \ell^*$ and $\frac{f_e(\ell^*/e)}{f(\ell^*/e)} < 0$ for $\ell > \ell^*$. Consequently, $\forall \ell > \ell^*$ we have $\frac{-f_e(\ell/e)}{f(\ell/e)} + \lambda > 0$.

Is it possible that $\frac{-f_e(\ell/e)}{f(\ell/e)} + \lambda > 0$ in all the interval $[0, L]$? Assume that it is the case. From (12), we obtain $\eta(\ell) - \omega(\ell) < 0 \; \forall \ell$, i.e., $\omega(\ell) > \eta(\ell) \geq 0 \; \forall \ell$. Knowing that at the optimum, $\omega(\ell)\,[\pi - c(e) - t(\ell)] = 0 \; \forall \ell$, this implies $t(\ell) = \pi - c(e) \; \forall \ell$, i.e., $\int_0^L t(\ell) f_e(\ell/e) d\ell = 0$. So, it is not possible that $\frac{-f_e(\ell/e)}{f(\ell/e)} + \lambda > 0$ in all the interval $[0, L]$.

Moreover, the function $\frac{-f_e(\ell/e)}{f(\ell/e)} + \lambda$ increases with respect to ℓ because assumption 1 states that the function $\frac{f_e(\ell/e)}{f(\ell/e)}$ decreases with ℓ. Consequently, there is a level of damages $\widehat{\ell}$ such that $\frac{-f_e(\ell/e)}{f(\ell/e)} + \lambda \leq 0$ for $l \leq \widehat{\ell}$ and such that $\frac{-f_e(\ell/e)}{f(\ell/e)} + \lambda > 0$ for $\ell > \widehat{\ell}$.

From (12) and the fact that $\forall \ell \leq \widehat{\ell}$, $\frac{-f_e(\ell/e)}{f(\ell/e)} + \lambda < 0$ we obtain $\eta(\ell) - \omega(\ell) > 0$, i.e., $\eta(\ell) > \omega(\ell) \geq 0$. Knowing that at the optimum, $\eta(\ell)\,[-B + t(\ell)] = 0$, this implies $t(\ell) = B$ for $\ell < \widehat{\ell}$.

Using (12) and the fact that for $\ell > \widehat{\ell}$, we have $\frac{-f_e(\ell/e)}{f(\ell/e)} + \lambda > 0$, we obtain $\eta(\ell) - \omega(\ell) < 0$, i.e., $\omega(\ell) > \eta(\ell) \geq 0$. Knowing that at the optimum, $\omega(\ell)\,[\pi - c(e) - t(l)] = 0$, this implies $t(\ell) = \pi - c(e)$ for $\ell > \widehat{\ell}$.

Finally, from (11), the level of utility of the agent can be written as:

$$u = \pi - c(e) - B \int_0^{\widehat{\ell}} f(\ell/e) d\ell - [\pi - c(e)] \int_{\widehat{\ell}}^{L} f(\ell/e) d\ell$$

$$\Longleftrightarrow u = [\pi - c(e) - B]\, F(\widehat{\ell}/e)$$

$$\Longleftrightarrow \widehat{\ell} = F^{-1}\left[\frac{u}{\pi - c(e) - B}\right]$$

■

Now, from the lemma above, we can derive the following proposition.

Proposition 5 *The program (P1) admits a solution, i.e., the levels of utility u and prevention e can be implemented if and only if :*

$$\begin{cases} u \in [\underline{u}, \pi - c(e) - B] \\ [\pi - c(e) - B]\, F_e(\widehat{\ell}/e) \geq c_e(e) \quad \textit{with } \widehat{\ell} = F^{-1}\left[\dfrac{u}{\pi - c(e) - B}\right] \end{cases}$$

Proof. The first line is implied by the constraints (4), (5) and (6). The second line follows from lemmas 3 and 4. ∎

The intuition underlying Proposition 5 is the following. For a given level of prevention e, it is not possible to find a scheme of transfers which gives a level of utility u to the firm if the marginal cost of providing the prevention level e is higher than the marginal benefit. Let us remark that the marginal benefit of prevention is reflected by the reduction of the expected transfers that the firm has to pay to her guarantor and is given by $-\int_0^L t(\ell) f_e(\ell/e) d\ell$. From lemma 4, we know that it is the scheme $\widehat{t}(\ell)$ which gives the maximal marginal benefit of prevention: $[\pi - c(e) - B]\, F_e(\widehat{\ell}/e)$. If this upper limit of the marginal benefit of prevention is lower than the marginal cost of prevention for a given e; then there is not any scheme of transfers which implements the level of prevention e.

From the analysis above, we can derive that when the problem $(P1)$ admits at least one solution, it is equivalent to the following problem $(P1bis)$:

$$\underset{u;e;\widehat{\ell}}{Max} \quad \pi - c(e) - u - \int_0^L \ell f(\ell/e) d\ell$$

$$st\ \underline{u} \leq u \leq \pi - c(e) - B \tag{13}$$

$$[\pi - c(e) - B]\, F(\widehat{\ell}/e) = u \tag{14}$$

$$[\pi - c(e) - B]\, F_e(\widehat{\ell}/e) \geq c_e(e) \tag{15}$$

Then, the socially optimal outcome can be implemented if $\underline{u}$ and e^* are solutions of the program (P1bis). Hence, the following proposition:

Proposition 6 *The social optimum* $(\underline{u}, e^*)$ *can be implemented with the financial responsibility if and only if:*

$$\frac{F_e(\widehat{\ell}/e^*)}{F(\widehat{\ell}/e^*)} \geq \frac{c_e(e^*)}{\underline{u}} \tag{16}$$

$$\textit{with} \quad [\pi - c(e^*) - B]\, F(\widehat{\ell}/e^*) = \underline{u} \tag{17}$$

Proof. From conditions (14) and (15). ■

The left-hand-side term of the condition (16) represents the rate of change of the marginal benefit of prevention at e^* with a transfers scheme $\widehat{t}(\ell)$, whereas the right-hand-side represents the rate of change of the marginal cost of prevention at the same point. Consequently, if there exists a level of damages $\widehat{\ell}$ such that the rate of change of the marginal benefit of prevention is at least equal to the rate of change of the marginal cost of prevention then the social optimum can be implemented.

The last step of the analysis is devoted to the characterization of a scheme of transfers which implements the first-best level of prevention. For this aim, we establish the following lemma.

Lemma 7 *The function* $\dfrac{F_e(\ell/e^*)}{F(\ell/e^*)}$ *is not increasing in* ℓ*.*

Proof. Let us define $H(\ell/e^*) = \dfrac{F_e(\ell/e^*)}{F(\ell/e^*)}$

Then, $\dfrac{dH(\ell/e^*)}{d\ell} \leq 0 \Leftrightarrow \dfrac{f_e(\ell/e^*)}{f(\ell/e^*)} \leq \dfrac{F_e(\ell/e^*)}{F(\ell/e^*)} \quad \forall \ell$

Let us assume that there is a level of damages ℓ^o such that $\dfrac{f_e(\ell/e^*)}{f(\ell/e^*)} > \dfrac{F_e(\ell/e^*)}{F(\ell/e^*)}$ in the interval $[0, \ell^o]$. Then, the function $H(\ell/e^*)$ is increasing in $[0, \ell^o]$, this implies $\dfrac{F_e(\ell^o/e^*)}{F(\ell^o/e^*)} > \dfrac{F_e(0/e^*)}{F(0/e^*)}$.

From assumption 1, we have $\dfrac{f_e(0/e^*)}{f(0/e^*)} > \dfrac{f_e(\ell^o/e^*)}{f(\ell^o/e^*)}$.

Consequently, $\dfrac{f_e(0/e^*)}{f(0/e^*)} > \dfrac{F_e(0/e^*)}{F(0/e^*)}$.

But $f_e(0/e^*) = F_e(0/e^*)$ and $f(0/e^*) = F(0/e^*)$. Hence a contradiction! ■

The two previous results permit to establish the following proposition.

Proposition 8 *The set of schemes of transfers which implement the socially optimal level of prevention contains a scheme of the following form:*

$$\widehat{\widehat{t}}(\ell) = \begin{cases} B & \forall \ell < \widehat{\widehat{\ell}} \\ \pi - c(e^*) & \forall \ell > \widehat{\widehat{\ell}} \end{cases}$$

Proof. From proposition 6, we know that the socially optimal prevention level can be achieved when the condition (16) is verified. From lemma 7, the function $\frac{F_e(\ell/e^*)}{F(\ell/e^*)}$ is not increasing in ℓ. Consequently, when the condition (16) is verified, there exists a level of damages $\widehat{\widehat{\ell}} \geq \widehat{\ell}$ such that $\frac{F_e(\widehat{\widehat{\ell}}/e^*)}{F(\widehat{\widehat{\ell}}/e^*)} = \frac{c_e(e^*)}{\underline{u}}$. ■

The scheme of transfers $\widehat{\widehat{t}}(\ell)$ is such that, if at the end of the period the amount of actual damages is lower than the target level $\widehat{\widehat{\ell}}$, then the firm is rewarded by receiving the bonus payment B, so her net revenue at the end of the period equals $\pi - c(e^*) - B$. Conversely, if the amount of actual damages is higher than the target level $\widehat{\widehat{\ell}}$, then the payment made by the firm to the guarantor equals $\pi - c(e^*)$ and the firm's net revenue at the end of the period is null[12].

This form of contract can be approached to a spread loss treaty. It is an alternative risk transfer (ART) solution, more precisely a finite risk product. By this contract, the financial responsibility of the firm is transfered to her guarantor (that can be a bank or an insurer)[13,14]. At the beginning of the contract, the firm pays either annual or single premium

[12] Note that $\widehat{\widehat{\ell}} \leq \pi - c(e^*)$. If not, the profit of the guarantor is negative.

[13] The hardening of the traditional insurance market notably concerning environmental risks has increased the demand for ART (Alternative Risk Transfer) products which cover finite risk solutions, cat bonds, captives and risk retention groups.

[14] Contrary to a traditional insurance contract, a finite risk contract spreads the risk of the same client over time.

into a so-called experience account. Furthermore, the two parties contractually agree on an investment return. The funds are used for compensation and the rest is returned to the client. But if the claims payments exceed the funds available, the client has to pay the remainder.

In this paper, we consider a one-period model. Consequently, the model can be viewed as if we have aggregated the periods of the spread loss treaty. Moreover, if the actual damages are low, the funds into the experience account are sufficient for compensation and clean-up whereas in the bad states of nature (high actual damages), the funds are not sufficient. Hence, because of its limited liability, the firm can not pay back the claims payments of the guarantor. Then, the guarantor takes this fact into account by penalizing the firm in the intermediate states of nature (those such that the amount of damages is between the target level $\widehat{\widehat{\ell}}$ and $\pi - c(e^*)$). Consequently, the reward is used as an incentive device.

4 Concluding remarks

A potentially judgment-proof firm may not internalize the social cost of its activity and then may have insufficient incentives to choose the socially optimal level of prevention. Whereas most of papers studied the incentive effect of the extension of liability to the lenders of the injurer-firm, this paper on contrary considers another remedy to the problems generated by the judgment-proofness. We demonstrate that a full financial responsibility (operation licence subject to the demonstration of a financial guarantee which covers the highest remediation cost) is compatible with the socially optimal level of prevention and establish a necessary and sufficient condition under which this is realized.

Furthermore, we have shown that when the socially optimal outcome is attainable, a contract of the form "reward or maximal penalty" is included in the set of first-best solutions. Such a contract rewards the firm when the actual damages are lower than a target level because the guarantor infers that the firm took an adequate level of prevention. Conversely, if the amount of the damages exceeds the target level, then the firm is maximally punished. This particular contract can be approached to an alternative risk transfer product referred to as spread loss treaty. Consequently, the alternative risk transfer solutions seem suited not only for the hedging of the environmental risks, but also for incentive purpose.

Finally, our paper demonstrates that the special focus of the Directive of the European Parliament and the Council on environmental liability on a future legislation which imposes financial responsibility on the polluting firms is justified by the fact that this legislation would improve environmental protection. But European authorities have to help insurance and banking sectors to develop the market for environmental guarantees.

References

[1] Balkenborg D.(2001), "How liable should a lender be? The case of judgment-proof firms and environmental risk: Comment", *American Economic Review,* 91, 731-738.

[2] Beard R.(1990), "Bankruptcy and care choice", *RAND Journal of Economics,* 21, 626-634.

[3] Boyd J. (2001), "Financial responsibility for environmental obligations: Are bonding and assurance rules fulfilling their promise?", Resources for the Future discussion paper 01-42.

[4] Boyer M. and Laffont J-J. (1997), "Environmental risks and bank liability", *European Economic Review,* 41, 1427-1459.

[5] Dionne G. and Spaeter S. (2003), "Environmental risk and extended liability : The case of green technologies", *Journal of Public Economics,* 87(5-6), 1025-1060.

[6] Feess E. and Hege U. (2003), "Safety monitoring, capital structure and financial responsability", *International Review of Law and Economics,* 23, 323-339.

[7] Feess E. and Hege U. (2000), "Environmental harm and financial responsibility", *Geneva Papers on Risk and Insurance, Issues and Practice,* 25(2), 220-234.

[8] Hutchison E. and Van't Veld K. (2005), "Extended liability for environmental accidents: what you see is what you get", *Journal of Environmental Economics and Management,* 49, 157-173.

[9] Innes R. (1990), "Limited liability and incentive contracting with ex-ante action choices", *Journal of Economic Theory,* 52, 45-67.

[10] Jost P. (1996), "Limited liability and the requirement to purchase", *International Review of Law and Economics,* 16, 259-276.

[11] Lewis T. and Sappington D. (2001), "How liable should a lender be? The case of judgment-proof firms and environmental risk" : Comment", *American Economic Review,* 91, 724-730.

[12] Lewis T. and Sappington D. (1999), "Using decoupling and deep pockets to mitigate judgment-proof problems", *International Review of Law and Economics*, 19, 275-293.

[13] Lipowsky-Posey L. (1993), "Limited liability and incentives when firms can inflict damages greater than worth", *International Review of Law and Economics,* 13, 325-330.

[14] Pitchford R. (2001), "How liable should a lender be? The case of judgment-proof firms and environmental risk : Reply ", *American Economic Review,* 91, 739-745.

[15] Pitchford R. (1995), "How liable should a lender be? The case of judgment-proof firms and environmental risk", *American Economic Review,* 85, 1171-1186.

[16] Polborn M. (1998), "Mandatory insurance and the judgment proof problem", *International Review of Law and Economics,* 18, 141-146.

[17] Ringleb A. H. and Wiggins S. N. (1990), "Liability and large-scale long-term hazards", *Journal of Political Economy,* 98, 574-595.

[18] Rogerson W. (1985), "The first-order approach to principal-agent problems", *Econometrica,* 53, 1357-1367.

[19] Shavell S. (1986), "The judgment proof problem", *International Review of Law and Economics,* 6, 45-58.

[20] Summers J. S. (1983), "The case of disappearing defendant : an economic analysis", *University of Pennsylvania Law Review,* 132, 145-185.

[21] Swiss Re (1999), "Le transfert alternatif des risques (ART) pour les entreprises : phénomène de mode ou formule idéale pour gérer les risques du IIIe millénaire?", Sigma 2/99.