Insurance and Financial Hedging of Oil Pollution Risks[1]

André SCHMITT[2] Sandrine SPAETER[3]

July, 2003

First Draft

[1]The IFE (Institut Français de l'Energie) is aknowledged for financial support. We are also grateful to members of the IOPC Fund and of ITOPF in London for useful discussions and for providing documents.

[2]LARGE, Université Louis Pasteur, 61, Avenue de la Forêt Noire, F-67 085 Strasbourg Cedex, Phone: +33 (0)390 242 158. Fax: +33 (0)390 242 151. E-mail: aschmitt@cournot.u-strasbg.fr

[3]Corresponding author. BETA, Université Louis Pasteur, 61, Avenue de la Forêt Noire, F-67 085 Strasbourg Cedex, Phone: +33 (0)390 242 076. Fax: +33 (0)390 242 071. E-mail: spaeter@cournot.u-strasbg.fr

Abstract

The current international regime that regulates the maritime oil transport calls for financial contributions of oil firms once an oil spill has occurred. Their percentage of contribution to the International Oil Pollution Compensation Fund does only depend on their level of activity. In this paper, we show that such a compensation regime may be improved by introducing financial hedging mechanisms. Standard insurance is limited for the coverage of large risks and capital markets have the capability to widely diversify risks. We show that standard insurance increases when it is bundled with a financing hedging strategy. Such a joint contract mitigates also the transaction costs of the insurer. Still we show that the opportunity of sending positive signals to capital markets about their prevention policies increases the incentives of firms to invest in risk-reducing activities.

Key-Words: oil spill, legislation, insurance, capital markets, prevention, catastrophe.

JEL Classification: D80, G22, Q25.

1 Introduction

The maritime transport of oil is regulated by the 1992 Civil Liability Convention in most countries of the world[1], except mainly for the United States, which have their own Convention[2]. In this paper, we focus on the compensation system implemented when an oil spill is registered in the territorial sea of any member of the 1992 Civil Liability Convention. Since oil spills can create severe damages to the environment but also to the human activities near the coast, they may induce huge claims, which cannot be covered without a compensation system adapted to those catastrophic losses. Hence, we will show that the current International regime would benefit from a reorganization involving both standard insurance and financial hedging.

The 1992 International Oil Pollution Compensation Fund (1992 IOPC Fund) participates in the compensation of victims of an oil spill if the payment already done by the insurer of the owner of the tanker[3] is not sufficient. The contributions of oil firms to the Fund are proportional to the quantity of oil received in a year and they are due each time an oil spill occurs in the territorial waters of a member, whatever the flag of the tanker and whatever the citizenship of the oil firm. Hence the IOPC Fund allows it to compensate victims even if the owner of the tanker is not a citizen of a member state and empirical facts show that the IOPC Fund seems to be rather efficient in minimizing the time between the oil spill event and the effective compensation of victims. However, funds are levied at random dates and expenses are not smoothed through time. Hence the 1992 IOPC Fund does not work as an insurance system, despite the fact that it is often presented as a way to improve the compensation of victims.

[1] 81 states ratified the 1992 Civil Liability Convention at 20 November 2002.

[2] The 1990 Oil Pollution Act. See Ketkar (1995) and Kim (2002) for details on this legislation.

[3] Under the 1992 Civil Liability Convention, only the owner of the tanker is held financially liable for the catastrophe. The convention obliges him to buy pollution insurance, provided by P&I Clubs which are non-profit making mutual insurance associations. These mutual groups offer insurance depending on the size of the boat and not directly on the damages that may be induced by a wreck. Hence, insurance may be limited, as it was the case for the Erika's wreck on the French coast in December 1999 (7% of the total available funds).

In this paper, we show that the oil industry has several interests in reorganizing the compensation regime towards a system closer to hedging mechanisms. Without adequate risk management, oil firms loose some efficiency in their activities and the cost induced by this inefficiency is lost for the victims' compensation. In particular, the 1992 IOPC Fund, as it works, does not rest on the risk transfer principle. By defining contributions on the basis of the aggregate risk of the pool, the mutuality principle (Borch (1962), Wilson (1968)) seems to be applied. Nevertheless, the aggregate risk is still variable because of the possible huge consequences of an incident and because of the limited number of members in the Fund. Consequently, the mutuality principle is no longer sufficient to spread all the risk on the oil firms. We show that capital markets seem to be able to solve the issue of diversification and also to mitigate transaction costs. Indeed Doherty (2000) gives several arguments that first, make insurance profitable for firms, and second, enhance the fact that insurance mechanisms have to be completed by some investment in capital markets when dealing with large risks. Froot (2001) provides also different reasons why markets are more efficient than insurers in global risk reductions. One important point is that securitization may reduce transaction costs such as adminsitrative fees or costs related to agency issues. In the same spirit as in Doherty and Dionne (1993), Schlesinger (1999), Doherty and Schlesinger (2002) and in Mahul (2002), we show that insurance bundled with a financial hedging strategy dominates a situation with only standard insurance. However, our economic context is rather different from these studies. In our framework, each individual bears a purcentage of the aggregate risk of the pool (here, the IOPC Fund) and an individual risk of bad reputation that is positively correlated to the aggregate risk and non insurable. Up to now, the litterature focused essentially on risks that can be split into idiosyncratic risk, specific to the individual and easily insurable, and a systematic risk, independent from the idiosyncratic one. Another important point of our analysis deals with prevention, which is not considered in the previous models. We show that financial hedging may give additionnal incentives to oil firms to invest in prevention. This result is important when focusing on the current discussions that are held at the European Commission about the evolution of the financing of the IOPC Fund. Especially, it is argued that an increase in the percentage of individual contribution may improve the safetyness of boats chartered by oil firms. Following our results, another alternative is to radically modify the structure of the financing and to introduce some hedging mechanisms obtained through insurance and investment on capital markets.

The paper is organized as follows. The second section focuses with the current regime of the IOPC Fund. In this basis model, we introduce standard insurance mechanisms and we define the optimal insurance contract an oil firm (or the Fund) can buy to an insurer. It entails a deductible with coinsurance for all losses higher than the deductible. In the third section, we show that financial hedging may be a good way to cover the residual risk still retained by oil firms (or by the pool) after insurance. When incorporating this point in the insurance contract, the risk premium asked by the insurer decreases and more standard insurance becomes available for small and medium oil spills, while capital markets are useful for hedging huge oil spills. Another important point is that financial markets may provide incentives to invest in prevention by allowing firms to give positive signals to potential investors. Section four concludes the paper and discusses the implications of our results. All proofs are given in Appendix.

2 The 1992 IOPC Fund Regime

We start this section by presenting the main points of the current legislation. A formalization of the current risk management system is provided in a second paragraph.

2.1 Oil Firms and Risk Mutualization

Since 24 May 2002, International maritime transport (except for the United States) is exclusively regulated by the 1992 Civil Liability Convention (CLC in the course) and by the 1992 International Oil Pollution Compensation Fund Convention (IOPC Fund)[4].

[4] Actually, the first Civil Liability Convention is dated from 1969 and the Fund was created in 1971. Both were amended in 1992. For details, see the companion paper Schmitt and Spaeter (2003).

The Fund is financed by contributions of the oil industry of member states receiving more than 150,000 tons of oil per year after sea transport. The contribution of each company is proportional to the annual tonnage received and is directly payable to the Fund. One important point is that contributions, decided each year by the Assembly of the Fund, cover administrative costs and estimated compensation payments for passed pollutions. More precisely, for a given oil spill each oil firm pays an ex post indemnity equal to a percentage of the loss. Hence the oil spill can be considered as an aggregate loss of the pool, which is shared across its members.

This International compensation regime seems to be rather efficient: It has improved the protection of sea environment against oil pollution by inducing a decrease of the number of huge oil spills in the last two decades[5]. Also, it facilitates claims settlement for victims of pollution and it has increased compensation available for them. Although claims for damage to the ecosystem are not admissible, compensation is granted to a wide range of costs (clean-up operations, property damages, economic losses, ...). Besides, contributions borne by the oil industry are really fair compared to the revenues induced by oil activities[6].

Nevertheless this regime also shows its limits regarding the total compensation available for victims[7] and the incentives to enhance environmental prevention through the chartering of safety boats. Indeed, while the shipowner is solely held liable through the Civil Liability Convention, the whole oil industry participates in compensations through the IOPC Fund Convention: no direct compensation between the owner of the oil escaped from the boat and victims can be established. From a theoretical point of view, Ringleb and Wiggins (1990) show that such considerations may lead firms to subcon-

[5] However, while the number of spills has decreased, the average level of damages has increased.

[6] From 1996 to 2001, the annual contributions represented at most 0,05% of the price per ton of crude oil received.

[7] Only partial compensation was available to victims after the wrecks of Nakhodka (1997), Erika (1999) and Prestige (2002). In the case of Erika, the purcentage of compensation was the highest one among these three catastrophes: About 80% of the aggregate loss estimated by the experts of the IOPC Fund.

tract risky activities (here the maritime transport of oil) and that those firms have no sufficient incentives to charter boats with high levels of quality.

Besides, even if the shipowner is held liable by the Convention, he is often protected by the corporate limited liability rule which benefits mostly the low market value firms as shown by Schmitt and Spaeter (2002). Consequently, risk-reducing activities may still be worsened.

2.2 The Model

Here, we consider the current situation of the IOPC Fund, where no insurance is available.

Consider n oil firms the states of which are members of the Fund. We denote $\widetilde{x_i}$ the risk that a given boat chartered by Firm i for the transport of its oil has an accident. The random variable $\widetilde{x_i}$ takes the value zero with probability p_i and the positive value x_i with probability $(1-p_i)$. Probability p_i of incident is affected by the level of prevention e_i decided by the oil firm that means, here, by the safetyness of the chartered boat: $p_i = p(e_i)$ with $p'(e_i) < 0$. The cost of prevention is defined as $c(e_i) = e_i$: e_i increases as the safetyness of the ship chartered by the oil firm increases. Finally the aggregate risk of the Fund is $\widetilde{X} = \sum_{i=1}^{n} \widetilde{x_i}$ with values[8] in $[0, T]$ and with distribution function $F(X/e)$, where e is the vector of all individual investments in prevention. An increase in the level of individual prevention improves the distribution in the sense of the first order stochastic dominance, but at a decreasing rate: $F_{e_i} > 0$, $F_{e_ie_i} \leq 0, \forall X \in \left]0, T\right[$ and $F_{e_i}(0/e) = F_{e_i}(T/e) = 0$.

As it works currently, each time an accident is registered in the territorial waters, the Fund calls for contributions that are, for each oil firm, proportional to their level of activity. We denote α_i this purcentage. In this system, which is close to the mutuality principle, the firm does not bear all the risk directly linked to the boats she charters since it is spread across all members of the Fund. But, if the firm is the owner of the oil spilled on the coasts of a given state, she will suffer from an effect of bad reputation. Hence

[8] Here, T is simply equal to the sum of the positive values of all oil spill risks: $T = \sum_{i=1}^{n} x_i$.

we assume that each incident will have a negative reputational effect on all members of the Fund and also an additionnal individual negative effect on the firm owner of the oil spilled. Formally, the random variable describing the total effect is denoted $-g(\widetilde{X}, \widetilde{x_i})$ with $0 < g_X < g_{x_i}$. The preferences of the firm are represented by a Von Neumann Morgenstern utility function $u(.)$ and she owns an initial non random wealth w_i.

The oil firm has to choose the level of quality e_i of the boat to be chartered that maximizes her expected net welfare:

$$\max_{e_i} R = \int_0^T \left(u(w_i - \alpha_i X - g(X, \widetilde{x_i})) - e_i\right) f(X/e) dX, \tag{1}$$

where $g(X, \widetilde{x_i})$ is the expected value of the reputational effect evaluated with respect to $\widetilde{x_i}$:

$$g(X, \widetilde{x_i}) = p(e_i) g(X, x_i) + (1 - p(e_i)) g(X, 0) \tag{2}$$

Lemma 1 *With the notation* $w_f = w_i - \alpha_i X - g(X, \widetilde{x_i})$, $g_{e_i} = g_{e_i}(X, \widetilde{x_i})$, $g_X = g_X(X, \widetilde{x_i})$ *and for given prevention levels of the other oil firms, the optimal level of prevention* e_i^* *satisfies the following first order condition:*

$$-\int_0^T g_{e_i}.u'(w_f) f(X/e) dX + \int_0^T (\alpha_i + g_X).u'(w_f) F_{e_i}(X/e) dX = 1 \tag{3}$$

The right term of Equality (3) is the expected marginal cost of prevention. From our assumptions, this amount is certain and equal to one. The left-hand-side term is the expected marginal benefit of prevention. First, chartering safetier boats will reduce the risk of bad reputation because the probability for Firm i to be directly involved in a wreck (probability p_i) declines when e_i increases. Second, prevention has also a positive impact on the aggregate risk of the Fund since it improves its distribution. Firm i will benefit from an aditionnal reduction in the bad reputation due, this time, to the reduction of the aggregate risk of the pool. Lastly, the presence of α_i in the second member of the left-hand-side term represents the direct benefit of prevention: increasing prevention reduces the risk $\alpha_i \widetilde{X}$ borne by Firm i.

This first order condition will be useful in the course for comparing the different levels of prevention obtained when the firm has successively access to standard insurance and to a joint contract that displays standard insurance and financial hedging.

From a practical point of view, it is interesting to notice that, following the wreck of Erika in 1999 near the French coast, the French government asked for an increase in the funds available for compensation through the IOPC Fund. In ou model, such a decision fits with an increase of the purcentage α_i of contribution to the Fund. Proposition 1 hereafter informs us on the effect of such a decision on the level of prevention decided by the oil firms.

Proposition 1 *(i) The effect on prevention of a variation in the individual contribution level to the Fund is given by*

$$\frac{de_i}{d\alpha_i} = \frac{\int_0^T g_{e_i}.X.u''(w_f)f(X/e)dX + \int_0^T u'(w_f)F_{e_i}(X/e)dX - \int_0^T (\alpha_i + g_X).X.u''(w_f)F_{e_i}(X/e)dX}{-R_{e_ie_i}}, \tag{4}$$

with $R_{e_ie_i}$ the derivative of R_{e_i} given by (3) with respect to e_i.

(ii) An increase in the percentage of contribution induces an increase in the level of prevention.

Having to pay more in case of an accident is similar for the firm to bearing more risk. Thus the marginal benefit of prevention increases, while the monetary marginal cost of prevention remains unchanged: The price of chartering safety boats is not affected. Finally, the oil firm has incentives to increase the level of preventive investment e_i.

From a theoretical point of view, increasing the level of contribution of oil firms to the Fund may be a good way to improve prevention. However, an increase in all α_i reduces the risk mutuality effect since more aggregate loss is borne by each individual firm. Furthermore, small firms may have some difficulties to fulfill their commitments if their contributions become too high. In what follows, we focus on standard insurance as an alternative to an increase of individual contributions and we look at the optimal contract between an insurer and an oil firm, knowing that the risk to be dealt with is a catastrophe risk. Standard insurance can be bought by each individual firm or by the pool. Here we choose the first alternative.

Now, assume that the oil firm can transfer part of her risk $\alpha_i X$ to an insurer. The compensation function is denoted $C(\alpha_i X)$ and the insurance premium is $Q = (1+\lambda)E\left[C(\alpha_i X)\right]$ where λ represents the administrative costs of the insurer plus the risk premium per unit of transferred risk and E the expectation operator over X.. The Von Neumann Morgenstern utility function of the insurer is denoted $v(.)$ with $v'(.) > 0$ and $v''(.) \leq 0$ and W is his initial wealth.

The maximization program of the oil firm subject to the participation constraint of the insurer becomes:

$$\max_C R^C = \int_0^T \left(u(w_i - \alpha_i X + C(\alpha_i X) - Q - g(X, \widetilde{x_i})) - e_i\right) f(X/e)dX \tag{5}$$

$$\text{subject to } \int_0^T v(W + Q - (1+\lambda)C(\alpha_i X)) f(X/e)dX \geq v(W)$$

We use optimal control to solve this maximization program. The random variable X plays the role of time, $C(\alpha_i X)$ is the control variable while the state variable is $z(X) = \int_0^X v(W + Q - (1+\lambda)C(\alpha_i t))f(t/e)dt$. Its evolution is described by the system:

$$\begin{cases} \dot{z}(X) = v(W + Q - (1+\lambda)C(\alpha_i X))f(X/e) \\ z(0) = 0 \\ z(T) = v(W) \end{cases}$$

The Hamiltonien of Program (5) is

$$H = (u(w_f) - e_i + \mu(X)v(W + Q - (1+\lambda)C(\alpha_i X)).f(X/e), \tag{6}$$

with μ the Lagrange function. The contract C^* that maximizes H is presented in Proposition 2 hereafter.

Proposition 2

(i) The optimal insurance contract displays a positive deductible when administrative costs are increasing in the level of indemnities. Marginal compensations for damages beyond the level of deductible are given by the equation

$$C^{*\prime}(\alpha_i X) = \frac{\left(1 + \frac{g_X}{\alpha_i}\right) R_u}{R_u + (1+\lambda) R_v}, \tag{7}$$

with R_u and R_v the absolute risk aversion ratios of, respectively, the insured and the insurer.

(ii) The optimal contract presents a disappearing deductible if the insurer is risk-neutral. If the insurer is risk averse and asks for a high risk premium in order to insure the large risk, the coverage displays coinsurance between both parties for all damages beyond the deductible.

Equation (7) is close to the one of Raviv (1979) obtained in a model with one insurable risk and to that obtained by Gollier (1996) with background risk. Actually, in our model, the risk of bad reputation is uninsurable and positively correlated to the insurable risk (we have $g_X > 0$). Thus we should expect that the insured firm accepts to pay for a higher coverage of the first risk in order to protect herself against her background risk if she is prudent in the sense of Kimball (1990). This result is obtained if we assume that the insurer is risk neutral, but prudence is not necessary. Indeed both risks are perfectly correlated and it is such as the insured firm bears an individual "aggregate" risk, $\alpha_i X + g(X, \widetilde{x}_i)$, which cannot be completely insured whatever the positive cost of insurance. Hence, the risk neutrality of the insurer is sufficient to obtain the optimality of a disappearing deductible: $C^{*\prime}(\alpha_i X) > 1$.

Actually, here we are dealing with catastrophe risks and an insurer whose portfolio contains the aggregate risk of the Fund bears an additional risk of insolvency following a catastrophe that he has accepted to cover. Besides, it is important to notice that due to the strengthening of environmental legislations in the eighties in the United States and at the beginning of the nineties in Europe, insurers decided to exclude pollution risks from their policies and specific reinsurance groups have had to offer such contracts. Thus, it is not reasonable to assume that the insurer is risk-neutral if we wish to give some practical consistency to our modelization. In the same spirit, empirical facts show that reinsurance groups who accept to cover pollution damages are asking for high insurance premia, which entail high risk premia. It is often argued that the management of large risks often entails additional transaction costs, due to risks of insolvency or to the complexity of audits and of claims settlements. This may justify the significant increase in the price of classical insurance. Consequently, it is reasonable to assume that the insurer we are dealing with is risk averse and that administrative costs related to the management of catastrophe risks are sufficiently high to obtain that, in many cases, the optimal insurance contract displays coinsurance between the insurer and the insured firm beyond a deductible level.

A contract with coinsurance beyond a deductible may also be the best risk sharing when the insurer bears convex administrative costs, as shown by Raviv (1979). If the convexity assumption is not the most plausible when dealing with classical risks such as car- or house-insurance risks, it is much more closer to reality when we are focusing on large risks. Consequently, convex costs may also explain the optimality of coinsurance in the management of large risks[9]. Another result of this section is given by Proposition 3.

Proposition 3 *Denote* $w_f^C = w_i - \alpha_i X + C(\alpha_i X) - Q - g(X, \widetilde{x_i})$.

(i) The optimal level of prevention e_i^C *satisfies the following first order condition:*

$$-\int_0^T (g_{e_i} + Q_{e_i}).u'(w_f^C) f(X/e^C) dX + \alpha_i \int_0^T (1 + \frac{g_X}{\alpha_i} - C'(\alpha_i X)).u'(w_f^C) F_{e_i}(X/e^C) dX = 1 \tag{8}$$

(ii) When standard insurance is available and when the insurer can obtain information on prevention, the optimal level of prevention decided by the firm increases.

[9] This assumption is not retained here. With a cost function more general than the one we use, the parameter λ would be replaced by the first derivative of the cost function and the second derivative would appear at the denominator of Equation (7).

This last result is not surprising. Here, the insurer can obtain information about the level of prevention decided by the firm. When a given boat is chartered, its capacity and its safetyness are common knowledge. Hence the insurance premium is evaluated with respect to the distribution of the agregate risk, which depends on the level of prevention. If insurance is available, an increase in the level of prevention decreases the level of the premium. In our model, an increase in prevention has also an effect on the marginal indemnities through its impact on the non insurable rik. Indeed, the marginal level of the bad reputation risk g is present in $C'(\alpha_i X)$. Finally, as in standard models with complete information on prevention, the level of prevention increases when the revenue of the insured is hedged. In the next section, we will show that a mixed strategy classical insurance/financial hedging still improves this level of prevention when informations on the risk-reducing policy of the oil firm are also available on capital markets.

Finally, when only standard insurance is available, insurers may ask for high risk premia for accepting to manage a catastrophe risk and the optimal contract displays some coinsurance: as the damage increases, oil firms are less covered and have to bear more and more residual risk. In the next section, the issue is to find complementary mechanisms that are able to diversify risks over a wider range of individuals and to transfer risk to agents such as financial investors. In such a manner, it will be possible to reduce the residual risk borne by the firm after (standard) insurance and to increase available funds for victims in case of an accident.

3 Providing a better hedging strategy through capital markets

A more complete hedging strategy would consist in combining several coverage instruments. Doherty and Dionne (1993) and Mahul (2002) provide such an approach by dividing the risk into two components: an idiosyncratic risk, which can be related to the specific activities of a given firm, and a systematic risk, related to the risk of the industry as a whole. While the individual risk can be insured by a standard insurance policy, the systematic risk is managed through a participating contract. A participating contract is a policy with a variable premium based on the realized systematic loss. In a second stage, the variability of the insurance premium is hedged either through standard insurance or thanks to adequate financial instruments.

Our problematic is different from the ones of Doherty and Dionne (1993) and Mahul (2002) because 1) the oil industry does not bear an insurable idiosyncratic risk since the effect of bad reputation, which plays this role, is non insurable, 2) The individual risk of the oil firm is correlated to the risk of the Fund, while in the previous analyses both are independent. These differences will have an impact on the link we will obtain between standard insurance and financial hedging. Finally, we also focus on the level of prevention decided by the oil firm.

Now, assume that the oil firm transfers part of her risk to an insurer, but that the maximum damage that will be covered by the contract is equal to $\overline{X}$ with $\overline{X} \in]0, T[$. The idea is to limit the implication of the insurer in the coverage of large risks in order to mitigate his bankruptcy risk. We denote $I(.)$ the indemnity schedule. When an oil spill occurs and after having contributed to the Fund, the oil firm obtains an indemnity $I(\alpha_i X)$ if her contribution is less than $\alpha_i \overline{X}$ and the fixed amount $\overline{I} = I(\alpha_i \overline{X})$ for any larger contribution. Still assume that the firm can sell a part β of her residual risk[10] $\alpha_i X - \overline{I}$ to an external investor. The price of this transfer depends on β and also on the level of prevention e_i adopted by the firm: in this model, financial markets can obtain some information about environmental policies adopted by the firms[11]. The risk premium asked by the external investor is noted $\pi = \pi(\beta, e_i)$ and it satisfies the properties $\pi_\beta > 0$ and $\pi_{e_i} < 0$. Lastly, the insurer's unit cost of insurance is δ and it depends on β: if the insured commits to cover the worst states of nature on financial markets, the insurer takes into account this information when evaluating the insurance premium. It is such like a sharing of catastrophes between the insurer and the financial markets. Consequently,

[10] By buying and selling puts and calls of appropriate underlying securities.

[11] See Lanoie et al. (1998) for details about how those informations circulated on financial markets.

we can assume that the costs of risk management are lower than in the previous case because of a decrease in the risk premium. Formally, we have: $\delta(\beta) > 0, \delta(0) = \lambda$ and $\delta_\beta < 0$.

The maximization program of the oil firm becomes

$$
\begin{aligned}
\max_{I,\beta} R^\beta \quad = \quad & \int_0^{\overline{X}} u(w_i - \alpha_i X - Q^\beta + I(\alpha_i X) - g(X, \widetilde{x}_i) - \pi(\beta, e_i)) f(X/e) dX \qquad (9) \\
& + \int_{\overline{X}}^{T} u(w_i - \alpha_i X - Q^\beta + \overline{I} + \beta \left[\alpha_i X - \overline{I}\right] \\
& - g(X, \widetilde{x}_i) - \pi(\beta, e_i)) f(X/e) dX - e_i \\
& \text{subject to} \\
& \int_0^{\overline{X}} v(W + Q^\beta - (1 + \delta(\beta)) I(\alpha_i X)) f(X/e) dX \\
& + v(W + Q^\beta - (1 + \delta(\beta)).\overline{I})(1 - F(\overline{X}/e)) \geq v(W),
\end{aligned}
$$

with $Q^\beta = (1 + \delta(\beta)) E\left[I(\alpha_i X)\right]$ the insurance premium. Now, we have to define the optimal evolution of I for any damage lower than the bound $\overline{X}$ and the optimal level of β.

Proposition 4

(i) The optimal indemnity function displays a positive deductible. Marginal indemnities for losses between the deductible level and the bound $\alpha_i \overline{X}$ are given by:

$$I^{*\prime}(\alpha_i X) = \frac{\left(1 + \frac{g_X}{\alpha_i}\right) R_u}{R_u + (1 + \delta(\beta)).R_v}, \qquad (10)$$

with R_u and R_v the absolute risk aversion ratios of, respectively, the insured and the insurer.

(ii) For given risk attitudes of the agents and positive hedging from the financial market, the optimal coverage is higher than the one obtained when only standard insurance is available: $I^{*\prime} > C^{*\prime}$ for any loss partially covered and less than $\overline{X}$.

(iii) An increase in the financing of large losses by capital markets, increases standard insurance of small and medium losses.

Point iii) enhances the fact that firms should use the wide diversification capability of financial markets to manage the potential large consequences driven by catastrophe risks and should call for standard insurance for small and medium losses. In the specific framework of the oil industry, this would mean that the general Fund[12], which manages small oil spills, should negociate some coverage conditions offered by standard insurers, while the main claims Fund should rather be managed through interventions on capital markets.

Lemma 2 *Partial financial hedging is optimal if and only if*

$$\begin{aligned}\pi_\beta.\int_0^T u'(w_f^\beta)f(X/e)dX &= \int_0^{\overline{X}} I_\beta^*(\alpha_i X).u'(w_f^1)f(X/e)dX + \int_{\overline{X}}^T (\alpha_i X-\overline{I}).u'(w_f^2)f(X/e)dX \\ &\quad -Q_\beta^\beta.\int_0^T u'(w_f^\beta)f(X/e)dX, \qquad (11)\end{aligned}$$

$$\text{with}\begin{cases} w_f^\beta = w_i-\alpha_i X-Q^\beta+I(\alpha_i X).\mathbf{1}_{\{X\leq\overline{X}\}}+\left[\overline{I}+\beta\left(\alpha_i X-\overline{I}\right)\right].\mathbf{1}_{\{X>\overline{X}\}}-g(X,\widetilde{x}_i)-\pi(\beta,e_i) \\ w_f^1 = w_i-\alpha_i X-Q^\beta+I(\alpha_i X)-g(X,\widetilde{x}_i)-\pi(\beta,e_i) \\ w_f^2 = w_i-\alpha_i X-Q^\beta+\overline{I}+\beta\left[\alpha_i X-\overline{I}\right]-g(X,\widetilde{x}_i)-\pi(\beta,e_i). \end{cases}$$

Function $\mathbf{1}_{\{.\}}$ is the indicator function, which takes value one if the condition into brackets is satisfied, zero otherwise.

Equation (11) is obtained by differentiating (9) with respect to β. It is a good strategy for the oil firm to seek external financing if the expected marginal cost of an increase in β (left-hand-side-term) equals the expected marginal benefit, obtained thanks to an increase in the coverage of the small and medium losses (first member in the righ-hand-side-term), to the direct increase of the coverage of large losses (second member) and to the decrease of the price of standard insurance (third member).

[12] Actually, what we commonly call the 1992 IOPC Fund is composed of two distinct funds. The first one, the general Fund, is dedicated to the payment of the current administrative costs and to the compensation of small oil spills (less than 4 millions SDRs with one Special Drawing Right = US$ 1.40489 on 14 May 2003), while the main claims Fund is dedicated to large oil spills.

Lastly, we have to discuss the level of prevention adopted by the firm in the case of a joint hedging contract. A differentiation of (9) with respect to e^{β}, the level of prevention in this model, and integrations by part lead to the following first order condition:

$$\begin{aligned} 1 &= -\int_{0}^{T} (g_{e_i} + \pi_{e_i} + Q^{\beta}_{e_i}).u'(w^{\beta}_f) f(X/e) dX \\ &\quad + \alpha_i \int_{0}^{T} (1 + \frac{g_X}{\alpha_i} - I^{*\prime}(\alpha_i X).\mathbf{1}_{\{X \leq \overline{X}\}} - \beta.\mathbf{1}_{\{X > \overline{X}\}}).u'(w^{\beta}_f) F_{e_i}(X/e) dX \end{aligned} \tag{12}$$

Proposition 5 *The level of prevention adopted by the firm is higher than the one obtained in the model with standard insurance when the opportunity of announcing her prevention policy to markets induces easier access to external financing ($\pi_{e_i} < 0$).*

4 Discussion

[to be completed] The new firms' management of risks tries to encompass all types of risks. Firms have to cope with numerous sources of uncertainties, linked to the production processes, to unanticipated market evolutions, non expected internal organization issues and also with uncertainties related to the existence of large risks. Large risks are often catastrophe risks, with random events the frequence of which is very low, but that induce very large economic consequences, irreversible ecological damages and sometimes loss of human lifes. This is the case for the maritime transport of oil. To manage oil spills, the 1992 IOPC Fund calls for ex post contributions to each oil firm the state of which is member of the Fund. However, no insurance mechanism is designed and only the mutuality principle is applied: The individual contribution corresponds to a percentage of the aggregate risk of the Fund. Because of the limited number of members and also of the huge financial consequences induced by some oil spills, the aggregate risk cannot be fully spread across the oil firms. Hence it is useful to think about other diversification and/or coverage instruments that would help to smooth the payments of firms through time and also to increase the funds available for compensation. In this

paper, we have shown that transferring part of the aggregate risk, namely the part related to catastrophic losses, to investors that have access to capital markets makes standard insurance of small and medium oil spills less costly. The mixed strategy, which consists in using the properties of standard insurance for risks that are reasonably insurable and the wide capability of financial markets to diversify risk across many people in the world for catastrophic losses, seems to be a good compromise. Moreover if firms can send to the markets signals on their environmental policies, financing hedging creates additionnal incentives to invest in risk-reducing activities.

APPENDIX

Proof of Lemma 1

A differentiation of (1) with respect to e_i leads to:

$$R_{e_i} = -\int_0^T g_{e_i}(X, \widetilde{x}_i).u'(w_f)f(X/e)dX + \int_0^T u(w_f)f_{e_i}(X/e)dX - 1$$

With $F_{e_i}(0, e) = F_{e_i}(T/e) = 0$, an integration by part of the second term induces that:

$$R_{e_i} = -\int_0^T g_{e_i}(X, \widetilde{x}_i).u'(w_f)f(X/e)dX + \int_0^T (\alpha_i + g_X(X, \widetilde{x}_i)).u'(w_f)F_{e_i}(X/e)dX - 1$$

If an interior solution exists, then it satisfies $R_{e_i} = 0$. Lemma 1 is demonstrated.

Proof of Proposition 1

Point i) is obtained thanks to a total differentiation of Equation (3) with respect to (w.r.t.) e_i and α_i.

For Point ii), notice that the higher the prevention, the less the bad reputation risk: $g_{e_i} < 0$. Besides, an increase in the aggregate loss X of the Fund deteriorates the reputation of all firms, so that $g_X > 0$. By assumption we also have that F_{e_i} is positive. Finally, the numerator of (4) is strictly positive for a risk-averse, or risk-neutral, oil firm. The denominator is obtained thanks to a differentiation of (3) w.r.t. e_i. With $g = g(X, \widetilde{x_i})$ we have:

$$
\begin{aligned}
R_{e_ie_i} \quad = \quad & -\int_0^T g_{e_ie_i}.u'(w_f)f(X/e)dX + \int_0^T g_{e_i}^2.u''(w_f)f(X/e)dX - \int_0^T g_{e_i}.u'(w_f)f_{e_i}(X/e)dX \\
& + \int_0^T g_{Xe_i}.u'(w_f)F_{e_i}(X/e)dX - \int_0^T (\alpha_i + g_X).g_{e_i}.u''(w_f)F_{e_i}(X/e)dX \\
& + \int_0^T (\alpha_i + g_X).u'(w_f)F_{e_ie_i}(X/e)dX
\end{aligned}
\tag{13}
$$

The third term is equal to $\int_0^T \left[g_{e_iX}.u'(w_f) - (\alpha_i + g_X).g_{e_i}.u''(w_f)\right].F_{e_i}(X/e)dX$. From the definition (2) of $g(X, \widetilde{x_i})$, we have that $g_{e_iX} = g_{Xe_i} = 0$, so that (13) reduces to:

$$
\begin{aligned}
R_{e_ie_i} \quad = \quad & -\int_0^T g_{e_ie_i}.u'(w_f)f(X/e)dX + \int_0^T g_{e_i}^2.u''(w_f)f(X/e)dX \\
& -2\int_0^T (\alpha_i + g_X).g_{e_i}.u''(w_f)F_{e_i}(X/e)dX + \int_0^T (\alpha_i + g_X).u'(w_f)F_{e_ie_i}(X/e)dX
\end{aligned}
$$

If the second order conditions are satisfied, then $R_{e_ie_i}$ is negative. By assumption, we have $F_{e_ie_i} \leq 0$, $g_X > 0$ and $u'' < 0$. Besides, $g_{e_ie_i}$ is equal to $p_{e_ie_i}.(g(X, x_i) - g(X, 0))$ (see Equation (2)). Function $g(X, .)$ is increasing in x_i and $p_{e_ie_i}$ is positive or equal to zero, so that $g_{e_ie_i}$ is positivė. Finalement $R_{e_ie_i}$ is negative and Point ii) of Proposition 1 is demonstrated.

Proof of Proposition 2

The optimality conditions related to optimal control that must be satisfied are

$$
\begin{cases}
(i)\ H_z = -\mu'(X) \\
(ii)\ H_\mu = \dot{z}(X) \\
(iii)\ z(0) = 0 \\
(iv)\ z(T) = v(W)
\end{cases}
$$

and $H_C = 0, \forall X$ such that $0 < C(\alpha_i X) < X$. From (6) we have $H_z = 0$ so that μ is constant. Conditions (ii), (iii) and (iv) are also satisfied. Besides $f(X/e)$ is, by definition, always positive. Hence it is possible to work with the simplified Hamiltonien $H^* = H/f(X/e)$. We have for any X such that $0 < C(\alpha_i X) < X$:

$$H_C^* = 0$$

$$\iff u'(w_f^C) - \mu(1+\lambda)v'(W_f^C) = 0 \tag{14}$$

with $w_f^C = w_i - \alpha_i X + C(\alpha_i X) - Q - g(X, \widetilde{x}_i)$ and $W_f^C = W + Q - (1+\lambda)C(\alpha_i X)$.

First, we have to show that the optimal contract displays a positive deductible. Let us define as $J(X)$ the function given by (14) and evaluated at $C(\alpha_i X) = 0$ and $K(X)$ the same function but evaluated at $C(\alpha_i X) = \alpha_i X$. By differentiationg them w.r.t. X it is easy to show that $J(X)$ is increasing in X and $K(X)$ is decreasing. Moreover, both functions are equal at point $X = 0$. Denote them L: $L = u'(w_i - Q) - \mu(1+\lambda)v'(W+Q)$. Two cases must be considered : either L is negative or L is positive (the trivial case for which $L = 0$ is not analyzed).

♦ $L > 0$

Since J is increasing in X, L is the smallest value it can take. Thus J is always positive and $C(\alpha_i X) = 0$ is never optimal[13]. Besides, K is decreasing in X. Then it exists a positive level of damage $\widehat{X}$ such that K is positive on $\left[0, \widehat{X}\right]$ and $C(\alpha_i X) = \alpha_i X$ is optimal on this interval. For damages higher than $\widehat{X}$, K becomes negative: from this point, coverage must be constant and an upper limit of insurance is optimal.

♦ $L < 0$

In this case, K is always negative and full coverage is never optimal. Besides, it exists a level of damage D such that J is negative on $[0, D]$ and presents partial coverage for any damage higher than D. A positive deductible is optimal.

Following Raviv (1979), we can show that, at fixed insurance premium, an upper limit is always stochastically dominated by pure coinsurance when insurance is costly.

[13] We have $H_{CC}^* = u''(w_f^C) + \mu(1+\lambda)^2 v''(W_f^C) < 0$. The second order conditions are satisfied and the result holds.

The intuition is that the risk averse insured prefers a transfer of indemnities of small damages to higher ones when insurance is costly. In the same spirit, a deductible contract dominates a pure coinsurance contract in the sense of second order stochastic dominance (Gollier and Schlesinger (1996)). Hence, the optimal contract displays a strictly positive deductible as long as the marginal cost of insurance λ is positive.

Second, we have to define the optimal marginal indemnities beyond the deductible level. By differentiating Equality (14) w.r.t. X and using it to define μ we must have:

$$(-\alpha_i + \alpha_i.C^{*\prime}(\alpha_i X) - g_X).u''(w_f^C) + (1+\lambda)^2.\alpha_i.C^{*\prime}(\alpha_i X).\mu.v''(W_f^C) = 0$$

$$\iff C^{*\prime}(\alpha_i X) = \frac{(1+\frac{g_X}{\alpha_i}).u''(w_f^C)}{u''(w_f) + (1+\lambda).\frac{v''(W_f^C).u'(w_f^C)}{v'(W_f^C)}}$$

$$\iff C^{*\prime}(\alpha_i X) = \frac{(1+\frac{g_X}{\alpha_i}).R_u}{R_u + (1+\lambda).R_v}$$

Equation (7) of point i) is demonstrated. If the insurer is risk neutral we have R_v equal to zero and $C^{*\prime} = 1 + \frac{g_X}{\alpha_i}$. Since all terms are positive, the slope of the compensation fucntion for any damage partially covered is larger than one. Hence the deductible disappears progressively as the damage increases.

If the insurer is risk averse and asks for a large risk premium, which means that λ is large, the value of $C^{*\prime}(\alpha_i X)$ may be less than one so that coinsurance for any partially indemnified loss is optimal. Point (ii) of Proposition 2 is demonstrated.

Proof of Proposition 3

Point i) is obtained thanks to a differentiation of (5) w.r.t. e_i. We denote e_i^C the solution of the first order condition

$$
\begin{aligned}
R^C_{e_i} &= 0 \\
&\Leftrightarrow \; 1 = -\int\limits_0^T (g_{e_i} + Q_{e_i}).u'(w^C_f)f(X/e^C)dX + \int\limits_0^T u(w^C_f)f_{e_i}(X/e^C)dX \\
&\Leftrightarrow \; 1 = -\int\limits_0^T (g_{e_i} + Q_{e_i}).u'(w^C_f)f(X/e^C)dX \\
&\quad + \left[u(w^C_f).F_{e_i}(X/e^C)\right]_0^T - \int\limits_0^T (-\alpha_i - g_X + \alpha_i.C'(\alpha_i X))u'(w^C_f)F_{e_i}(X/e^C)dX \\
&\Leftrightarrow \; 1 = -\int\limits_0^T (g_{e_i} + Q_{e_i}).u'(w^C_f)f(X/e^C)dX \\
&\quad + \alpha_i \int\limits_0^T (1 + \frac{g_X}{\alpha_i} - C'(\alpha_i X))u'(w^C_f)F_{e_i}(X/e^C)dX \qquad (15)
\end{aligned}
$$

Point i) is demonstrated. Point ii) is obtained thanks to a diffrentiation of (15) w.r.t. e_i and C:

$$
\begin{aligned}
\frac{de_i}{dC} &= \frac{1}{-R^C_{e_i e_i}}.\left[-\int\limits_0^T (g_{e_i} + Q_{e_i}).(1 - Q_C).u''(w^C_f)f(X/e^C)dX - \int\limits_0^T Q_{e_i C}.u'(w^C_f)f(X/e^C)dX \right. \\
&\quad \left. + \alpha_i \int\limits_0^T (1 + \frac{g_X}{\alpha_i} - C'(\alpha_i X))(1 - Q_C).u''(w^C_f)F_{e_i}(X/e^C)dX \right] \qquad (16)
\end{aligned}
$$

Marginal compensations $C'(\alpha_i X)$ are always lower than or equal to $1+\frac{g_X}{\alpha_i}$ at optimum (see Equation 7)). The premium Q is equal to $\int\limits_0^T (1+\lambda)C(\alpha_i X)f(X/e^C)dX$, so that $Q_{e_i} = \int\limits_0^T (1+\lambda)C(\alpha_i X)f_{e_i}(X/e^C)dX = -\alpha_i \int\limits_0^T (1+\lambda)C'(\alpha_i X)F_{e_i}(X/e^C)dX$, which is positive, $Q_C = (1+\lambda)$ and $Q_{e_i C}$ equals zero. Equation (16) becomes:

$$
\begin{aligned}
\frac{de_i}{dC} &= \frac{\lambda}{-R^C_{e_i e_i}}.\left[\int\limits_0^T (g_{e_i} + Q_{e_i}).u''(w^C_f)f(X/e^C)dX \right. \\
&\quad \left. - \alpha_i \int\limits_0^T (1 + \frac{g_X}{\alpha_i} - C'(\alpha_i X)).u''(w^C_f)F_{e_i}(X/e^C)dX \right]
\end{aligned}
$$

The second order conditions of this problem are satisfied (the computation is similar to the one presented in the proof of Proposition 1), so that $R^C_{e_ie_i}$ is negative. Finally, $\frac{de_i}{dC}$ is positive and Point ii) of Proposition 3 is demonstrated.

Proof of Proposition 4

The control variable is $I(\alpha_i X)$ and the state variable is $z(X) = \int_0^X v(W + Q^\beta - (1 + \delta(\beta))I(\alpha_i t))f(t/e)dt$.The simplified Hamiltonien of Program (9) is

$$H^{\beta *} = u(w_f^1).\mathbf{1}_{\{X \leq \overline{X}\}} + u(w_f^2).\mathbf{1}_{\{X > \overline{X}\}} - e_i + \gamma(X)v(W_f^\beta), \tag{17}$$

with $\gamma(X)$ the Lagrange function, $w_f^1 = w_i - \alpha_i X - Q^\beta + I(\alpha_i X) - g(X, \widetilde{x}_i) - \pi(\beta, e_i)$, $w_f^2 = w_i - \alpha_i X - Q^\beta + \overline{I} + \beta\left[\alpha_i X - \overline{I}\right] - g(X, \widetilde{x}_i) - \pi(\beta, e_i)$ and $W_f^\beta = W + Q^\beta - (1 + \delta(\beta))I(\alpha_i X)$. Function $\mathbf{1}_{\{X > \overline{X}\}}$ is the indicator function, which takes value 1 when the condition into brackets is satisfied, zero otherwise. Still here, the Lagrange function is a constant. We have for any X in $\left]0, \overline{X}\right[$ such that $0 < I(\alpha_i X) < X$:

$$H_I^{\beta *} = 0$$

$$\Longleftrightarrow u'(w_f^1) - \gamma(1 + \delta(\beta))v'(W_f^\beta) = 0 \tag{18}$$

First, we have to show that the optimal contract displays a positive deductible. The proof is similar to that proposed for Proposition 2.

Second, by differentiating Equality (18) w.r.t. X and using it to define γ we must have, for any X in $\left]0, \overline{X}\right[$ such that $0 < I(\alpha_i X) < X$,

$$(-\alpha_i + \alpha_i.I^{*\prime}(\alpha_i X) - g_X).u''(w_f^1) + (1 + \delta(\beta))^2.\alpha_i.I^{*\prime}(\alpha_i X).\gamma.v''(W_f^\beta) = 0,$$

$$\Longleftrightarrow I^{*\prime}(\alpha_i X) = \frac{(1 + \frac{g_X}{\alpha_i}).u''(w_f^1)}{u''(w_f^1) + (1 + \delta(\beta)).\frac{v''(W_f^\beta).u'(w_f^1)}{v'(W_f^\beta)}}$$

$$\Longleftrightarrow I^{*\prime}(\alpha_i X) = \frac{(1 + \frac{g_X}{\alpha_i}).R_u}{R_u + (1 + \delta(\beta)).R_v} \tag{19}$$

Point i) is demonstrated. For point ii), we know that δ is decreasing in β and that $\delta(0) = \lambda$. The marginal indemnities $I^{*\prime}$ and $C^{*\prime}$ (given by (7)) differ from the term δ present at the denominator of $I^{*\prime}$. Hence $I^{*\prime}$ is always higher than $C^{*\prime}$ when β is positive.

Point iii) is immediate. From (19), marginal indemnities increase as β increases.

Proof of Proposition 5

The structures of Condition (8) and (12) differ only by the term $-\pi_{e_i}.\int_0^T u'(w_f^\beta)f(X/e)dX$, which is positive. By taking this positive term into account when looking at the expected marginal benefit of prevention and by appliying the same reasoning as in the proof of Point ii) of Proposition 3, Proposition 5 is demonstrated.

References

Borch, K.: 1962, Equilibrium in a reinsurance market, *Econometrica* **30**, 424–444.

Doherty, N.: 2000, *Innovation in Corporate Risk Management: the Case of Catastrophe Risk*, In: G. Dionne (Ed.), Handbook of Insurance. Kluwer Academic Press.

Doherty, N. and Dionne, G.: 1993, Insurance with undiversifiable risk: Contract structure and organizational form of insurance firms, *Journal of Risk and Uncertainty* **6**, 187–203.

Doherty, N. and Schlesinger, H.: 2002, Insurance contracts and securitization, *Journal of Risk and Insurance* **69**, 45–62.

Froot, K.: 2001, The market for catastrophe risk: A clinical examination, *Journal of Financial Economics* **60**, 529–571.

Gollier, C.: 1996, Optimum insurance of approximate losses, *Journal of Risk and Insurance* **63**, 369–380.

Gollier, C. and Schlesinger, H.: 1996, Arrow's theorem on the optimality of deductibles: A stochastic dominance approach, *Economic Journal* **7**, 359–363.

Ketkar, K.: 1995, Protection of marine resources: The us oil pollution act of 1990 and the future of the maritime industry, *Marine Policy* **19**, 391–400.

Kim, I.: 2002, Ten years after tne enactment of the oil pollution act of 1990: A succes or a failure, *Marine Policy* **26**, 197–207.

Kimball, M.: 1990, Precautionary saving in the small and in the large, *Econometrica* **58**, 53–73.

Lanoie, P., Laplante, B. and Roy, M.: 1998, Can capital markets create incentives for pollution control?, *Ecological Economics* **26**, 31–41.

Mahul, O.: 2002, Coping with catastrophic risk: The role of (non)-participating contracts, miméo, INRA Département d'économie, Rennes.

Raviv, A.: 1979, The design of an optimal insurance policy, *American Economic Review* **69**, 84–96.

Ringleb, A. and Wiggins, S.: 1990, Liability and large-scale, long-term hazards, *Journal of Political Economy* **98**, 574–595.

Schlesinger, H.: 1999, Decomposing catastrophic risk, *Insurance: Mathematics and Economics* **24**, 95–101.

Schmitt, A. and Spaeter, S.: 2002, Improving the prevention of environmental risks with convertible bonds, Working Paper 2002-14 BETA, Université Louis Pasteur, Strasbourg.

Schmitt, A. and Spaeter, S.: 2003, Hedging strategies and the financing of the 1992 international oil pollution compensation fund, mimeo BETA, Louis Pasteur University, Strasbourg.

Wilson, R.: 1968, The theory of syndicates, *Econometrica* **36**, 119–132.