

THE NEGLIGENCE RULE SPECIFICITY UNDER RADICAL UNCERTAINTY

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The Negligence Rule Specificity under Radical Uncertainty

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Summary:

This article is an attempt to reassess the relationships between the strict liability regime and the negligence rule under radical uncertainty (ambiguity theory). In an accident model two representative agents (potential injurer and victim) form divergent beliefs about the probability distribution of an accident and the potential damage scale. It issues on the following results:

- *When the injurer's wealth cover the damage cost, then the socially first-best level of care is established by the injurer under strict liability only. When, the injurer's wealth is insufficient, this level is not reach (capped strict liability regime for instance)*
- *Under negligence, the authorities (Regulator or Court) can choose as first best level of care either the level that favors the injurer's interests or the victim ones of. No rational rule can justify a choice rather than the other.*
- *The efficiency of both regimes cannot be compared because they obey to different logics.*

JEL codes: D62, K13, K23, K32, Q52, Q58.

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0. Introduction

Nowadays, public opinion plays an increasing role in the establishment of safety standards that protect human and animal health and the environment. Numerous health scandals, environmental disasters and, furthermore, worrying scientific information rally consumers, users and the vicinity of potentially hazardous facilities or processes. The public disposes of many tools to be heard: protest votes in local or regional elections or referendum, legal proceedings against actual or potential polluters, public demonstrations or boycotts. These factors have prompted the governments to introduce public consultation procedures¹ where concerned people can express their doubts and wishes facing hazardous projects. Then, more or less, the public participates in the forming of emission standards, health and environmental regulations to restrain their potential dangerous consequences. Obviously, this participation depends on multiple factors as the development stage of the country, the population's level of education, etc.

These standards help to establish criminal, civil or administrative liability against the polluters' infringement. Then, this article studies the importance of the public expression in the determination of the socially efficient care level under different civil liability regimes, mainly, the strict liability regime and the rule of negligence. In this aim, I develop a model of unilateral accident inspired by the works of Brown (1973) and Shavell (1987) although in a situation of radical uncertainty such as recently developed by Bogus (2006), Teitelbaum (2007), Franzoni (2012), Langlais (2012). Indeed, uncertainty creates beliefs among the various categories of agents as mentioned by Franzoni (2013 p.6): *"ambiguity aversion is taken as a rational response to scientific uncertainty. In other words, I do not consider ambiguity aversion as a "cognitive bias" but a genuine component of welfare, to be factored into the efficiency quest"*. The introduction of the victims' beliefs about the damage scale in the accident model under radical uncertainty not only changes the issues in a risky world, but also the recent ones considered as intangible in uncertainty.

¹ The USA enacted the Emergency Planning and Community Right-to-Know Act (EPCRA) in 1986. This act establishes requirements for federal, state and local governments, tribes, and industry regarding emergency planning and "community right-to-know" reporting on hazardous and toxic chemicals. This law helps increase the public's knowledge and access to information on chemicals at individual facilities, their uses, and releases into the environment. In the European Union, the Aarhus Convention adopted in 1998 induces the parties *"guarantee the rights of access to information, public participation in decision-making, and access to justice in environmental matters in accordance with the provisions of this Convention"* art.1.

Indeed, the first noticeable result is that, under strict liability, uncertainty does not constitute a hurdle to enforce the socially optimal care level. We know that this is true under the standard model with neutral to risk agents, but not with adverse to risk injurers (Shavell 1982) or risk averse to ambiguity agents, Bigus (2006), Teitelbaum (2007), Franzoni (2015) among others. The second result is that, under negligence, when polluters and victims, independently one of the other, express their preferences and do not blend into each other, then, the regulator (and/or the court) faces a dilemma and should choose between two polar cases without rational and decisive choice criterion. Indeed, the regulator chooses either the injurer's level of care, or, in the opposite, the one that makes secure the victims. This point fundamentally differentiates strict liability from negligence rule. This subjectivity applies also to the Court that is the effective decision maker under the rule of negligence because it assigns liability in case of an accident. Consequently, alike the regulator, the judge defines a first-best level of care with the same elements than the regulator and, as expected, this issues on the same paradoxical result. Therefore, under the negligence rule, the regulator and the court are not neutral players. Furthermore, this duality may explain differences in interpretation between the regulator and the court in setting the socially first best care level. The first one (regulator) may choose to set the level in a way that favors polluters while the judge could prefer the level sought by victims.

Then, a first section exposes the set of the divergence of beliefs among the potential victims and tortfeasors. Indeed, in the literature this point is seldom considered. This section, then, presents each category of agents' program considering the beliefs about the damage scale and the accident probability distribution. A second section develops the model under the strict liability regime which here constitutes a benchmark. The third section shows how the agents' different opinions influence the socially efficient care level formation. The rule of negligence and the strict liability regime may coincide but only under particular conditions. In general, we cannot compare them. It studies the case of a limited liability case (capped strict liability). A fourth section examines the related literature. A fifth part concludes.

1. Divergent beliefs and the agents' program

In this section, I analyze the causes of diverging views between the polluter and the victim about the extent of damage and the probability of an accident. Both categories of agents (injurer and victim) are representative agents.

1.1 Notations and assumptions

- x represents the level of care (or prevention), it is a cost corresponding to an effort.
- $\Psi(x)$ is the injurer's Expected Choquet Utility (ECU) for an effort corresponding to x (see appendix 1 for the definition of ECU).
- u is the injurer's wealth, $u > 0$, and l is the maximum damage value with ($u > l$). This means that the injurer is never judgment-proof and can always compensate or repair the damage after harm he is responsible.
- $\Phi(x)$ is the victim's ECU for the injurer's care effort of x .
- v is the victim's wealth, $v > 0$.
- By assumption, the level of damage corresponds to the repairs level due to the injurer.
- $p(x)$ is the probability of an accident for a care level x , with $p'(x) < 0$ and $p''(x) > 0$.

These last assumptions are standard. It is necessary to notice that these probabilities are “official” probabilities that the regulator provides to the economy as a whole. The agents may agree about them or can mistrust them. It is the point that I am studying now.

1.2 Divergence of view on the damage scale

Each catastrophic event is specific and never reproducible as such. This factual situation explains why injurers and victims may legitimately form different beliefs about the effective scale of damage. Indeed, it is challenging assessing, for instance, the effects and consequences of any accidental discharge of a given quantity of toxic effluents in rivers, soil, air, etc. Given a technology, the extent of the damage mainly depends on climatic and meteorological conditions, on contingent events (night, day, holidays of people, etc.). Generally, the standard accident model summarizes the damage costs using a given expected value, or, it considers that this one varies deterministically according to the activity level². It implicitly admits that this value is common knowledge. However, as an expected value, it depends from a given probability distribution. Therefore, in an uncertain world, agents can put into question the expectation likelihood. To understand the difficulty in evaluating a priori the cost of an accident, it is sufficient mentioning the uncertainties associated to assess ex-post the costs of such event. Shavell in “Economic Analysis of Accident Law”, emphasizes the point: « *Once it has been established that an injurer is liable, the amount he is to pay the victim must be determined* », Shavell (1987, p. 127). He also mentions that courts face with large uncertainty when they must determine the victims' financial losses: « *By contrast,*

² See for instance Dari-Mattiacci and Parisi, (2003).

because non pecuniary losses cannot be observed directly, they are difficult for courts to estimate. » (Shavell, (1987), op. cit. p.134). For instance, for Rogers, Bichaka and Balch (1991) it is always a hard task evaluating damage to individuals because this one depends on the economic nature of the destroyed goods. More precisely, if referring to market values can help estimating private goods or property losses; this is scarcely the case of semi-public and public goods. Furthermore, the intensity of the sinister also affects the value of goods (Maes (2005)). Therefore, assessing the potential damage before an accident occurrence is a hard task and, consequently, it is legitimate thinking that agents form divergent estimates about it. Consequently, if evaluating ex-post damage is complex, the challenge is much higher to do it ex-ante. Then, it seems reasonable considering that polluters and victims assess the costs of a major damage inside an interval and form beliefs once given "official" data. In the present context, these factors form the ambiguity theory basis.

The difficulty of a priori knowing the distribution probability for the extent of damage explains that polluter and the victim may experience different views about them. The regulator has given an estimate of the probability distribution of a potential damage, but both categories of agents may modify it depending on their beliefs, i.e. their degree of optimism and level of aversion to ambiguity. In the following, as described in appendix 1, the damage expectation corresponds to the Choquet integral of a neo-additive capacity:

$$(1) \theta_I = \alpha \delta \bar{d} + (1 - \alpha) \delta l + (1 - \delta) \bar{l}$$

(Where, respectively, α corresponds to the agent's level of optimism and, naturally $(1 - \alpha)$ the pessimism level, δ is the degree of ambiguity preference and $(1 - \delta)$, the reverse. then $\alpha, \delta \leq 0$. I stands for "injurer" and $\bar{l} = E_p(a)$) (see appendix 1 for details).

Hence, the Choquet integral of a neo-additive capacity consists of the following elements, i) The maximum value of the costs associated with a major accident (l), ii) Their minimum ($\bar{d}$), iii) Their expected value $\bar{l}$.

Optimism and pessimism are associated with the accident scale. Optimism implies a high value of α , because it is associated with the lowest damage ($\bar{d}$), while pessimism $(1 - \alpha)$ is linked to the highest one (l). Damage spans the entire A spectrum. For instance, when $\alpha = 0$, the injurer is fully pessimistic, then:

$$V(A/p, \delta, 0) = \delta l + (1 - \delta) \bar{l}$$

Then, this expression only depends on his attitude to ambiguity δ . When $\delta = 0$, (full aversion for ambiguity) then the capacity comes to $\bar{l}$. Conversely, the higher δ , the lesser the

tortfeasor will be confident in the expected value of the damage costs, $\delta = 1$ means a complete distrust in it:

$$V_p(A / p, 1, \alpha) = \alpha \bar{d} + (1 - \alpha)l$$

This expression is the Hurwitz criterion that the injurer's level of optimism and pessimism weight.

1.3 Divergence of view on the distribution of probability of accidents

I extend the above argument to the accident probability distribution. In this area, the accidents have not yet occurred and the probabilities are a priori probabilities. Indeed, accident statistics are few available. The human factor plays an important role as, for example, how the press reports information related to risk activities. As previously, diverging in opinion between injurer and victim is not uncommon.

1.3.1 The injurer's program

Consequently, to deal with the probability distribution of an accident my processing is fully consistent with Teitelbaum (2007). Thus, the injurer's payoff function is:

$$(2) \quad \begin{cases} \text{Sup}\{f\} = (u - x), \text{ without accident} \\ \text{Inf}\{f\} = (u - x - \theta_I) \text{ after an accident} \end{cases}$$

(where $\theta_I > 0$ is the level of repairs that the injurer will have to pay when induced in liability). Consequently, the injurer's payoff function writes as:

$$(3) \quad \Psi(x) = \beta \theta \text{Sup}\{f\} + (1 - \beta) \theta_I \text{Inf}\{f\} + (1 - \theta) \{(1 - p(x)) \text{Sup}\{f\} + p(x) \text{Inf}\{f\}\}$$

(where, respectively, β and $1 - \beta$ represent the level of optimism and pessimism and θ the degree of preference of ambiguity). Replacing the maximum and minimum values, we get:

$$(4) \quad \Psi(x) = u - x - \beta(1 - \theta)\theta_I - (1 - \theta)\theta_I p(x).$$

After simplification, the injurer's program consists in choosing the care level that minimizes the accident probability and maintains the lowest prevention cost:

$$(5) \quad \underset{x \geq 0}{\text{Max}} \{u - x - (1 - \beta)(1 - \theta)\theta_I - (1 - \theta)\theta_I p(x)\}$$

As the wealth u is given, when the injurer's liability may be engaged, the program comes at minimizing:

$$(6) \quad \underset{x \geq 0}{\text{Min}} \{x + (1 - \beta)(1 - \theta)\theta_I + (1 - \theta)p(x)\theta_I\},$$

And let x^* the injurer's equilibrium care level.

1.3.2 The victim's assessment

The benevolent regulator considers the victim's perception of damage in the social utility function. This factor influences the first-best care level and the current liability regime and it impacts the repairs level by the compensation that the victims receive. Thus, the victims' damage ECU becomes:

$$(7) \quad \theta_v = \varepsilon \eta \bar{d} + (1 - \varepsilon) \eta l + (1 - \eta) \bar{l},$$

Where η is the victim's ambiguity preference (and $(1 - \eta)$ his ambiguity aversion), while ε and $(1 - \varepsilon)$ express (respectively) his optimism and pessimism level. This one is integrated in their global ECU:

$$(8) \quad \phi(x) = \{ \sigma \omega v + (1 - \sigma) \omega (v - \theta_v) + (1 - \omega) \{ p(x)(v - \theta_v) + (1 - p(x))(v) \} \} = v - (1 - \omega) \sigma \theta_v - (1 - \omega) \theta_v p(x)$$

This expression corresponds to the damage that the victim suffers when the injurer is free from any liability. This value is a maximum value, indeed, in case of limitation of the injurer's liability; the amount charged to victims will be less than this amount. In fact, the amount of compensation or damages payable by the victims is closely subject to the current liability system. The specification of the model can be achieved independently therefrom.

2. The strict liability regime

In the model, the regulator is benevolent and collects the preferences of both categories of agents. It sets the level of care that maximizes the agents' welfare. Besides the uncertainty question, the only difference with the standard model comes from the divergent estimate between victim and polluter concerning the damages amount. With strict liability, the party who causes the damage is held responsible even without proof of misconduct. The existence of damage and the proximity of the activity or still the activity itself are sufficient to deduce its liability.

a) The injurer

Here, the polluters are fully responsible when occurs an accident linked to their activity whatever the level of care they took. Then the payoff function is the following Choquet integral:

$$(9) \quad \Psi^{SL}(x) = u - x - (1 - \beta) \theta \theta_I - (1 - \theta) \theta_I p(x)$$

The solution of the program that maximizes $\Psi^{SL}(x)$ is x^{SL} which is deduced from the first order conditions calculation.

b) The Victims

Under strict liability, the injurer fully compensates the victims' losses. Hence, whatever the situation (accident or not), the victims' damage function is always: $\Theta_V^{SL} = 0$. This view may appear as quite restrictive because it is not sure that a monetary repair, for instance, could compensate the whole set of moral, physical and psychological losses and the level of repair could always be below the damage value. In fact, the case corresponds to a limited liability and this point is analyzed in section 3. Then, when the victim knows he incurs no losses, and his payoff stays at his initial wealth:

$$(10) \quad \phi^{SL}(x) = v$$

Consequently, when the injurer's wealth is large enough ($u > l$), whatever the future events, the victim does not suffer any structural loss. Indeed, the injurers' assets fully compensate the damage. This fact is common knowledge.

c) The regulator

As we know that the regulator is benevolent, his actions consist in maximizing the agents' welfare. This is a function built from the aggregation of the agents' utility functions. Then, his program is:

$$(11) \quad EWS^{SL}(x) = \max_{x \geq 0} \{ \Psi^{SL}(x) + \phi^{SL}(x) \} = \max_{x \geq 0} \{ u + v - x - (1 - \beta)\theta\theta_I - p(x)((1 - \theta)\theta_I) \}$$

The above program turns back at minimizing: $x + p(x)((1 - \theta)\theta_I)$. Here, the regulator requires a level of care equivalent to x^{*SL} , where x^{*SL} is this value for which $EWS'(x^{*SL}) = 0$, or still:

$$(12)$$

$$p'(x^{*SL}) = -\frac{1}{(1 - \theta)\theta_I}$$

x^{*SL} is the socially optimal care effort. However, the injurer maximizes his payoff at x^{SL} that maximizes $\max_{x \geq 0} \{ u - x - \beta\theta\theta_I - (1 - \theta)\theta_I p(x) \}$, or (the same), minimizes the accident costs $x + p(x)((1 - \theta)\theta_I)$. Here, it is obvious that the regulator and the injurer minimize the same function and $x^{SL} = x^{*SL}$. We deduce the following proposition:

Proposition 1: *Under radical uncertainty and strict liability, when the injurer's wealth can cover the damage ($u > l$), then, a social optimum will be achieved: The victims are fully reimbursed for their losses and the level of prevention effort is the socially first best level.*

Proof: The proof is obvious, it is sufficient to compare the first order conditions from both the regulator's and the injurer's programs.

Remark : This result is similar to the one reached with the basic unilateral accident model when both regulator and injurer are risk neutral (see Shavell 1987). Here, the agents' ambiguity aversion (polluters and victims) is not a hurdle to the implementation of the first-best. This results from the fact that the regulator aggregates the agents' preferences.

3. The specific feature of the negligence rule under radical uncertainty

In this section, the paper analyzes the negligence rule's specific feature compared to strict liability. It puts into evidence the fact that the authority is not neutral when defining the social prevention standard. "Authority" refers both to the regulator and the court. At the moment, in order to simplify the model, by assumption, the court and the regulator share the same assessment concerning the socially first-best care level.

3.1 Negligence and the regulator's dilemma

Conversely to the strict liability regime, when the injurer is free from any liability, negligence involves that the victim bear the repairs burden. Consequently, the victim makes the following damage assessment:

$$(13) \quad \theta_V = \varepsilon \eta \bar{d} + (1 - \varepsilon) \eta l + (1 - \eta) \bar{l}$$

If the injurer does not conform to the socially first best care level ($x < x_k^{NR*}$), his expected loss equals θ_I , but it is null if the care level x is higher than x_k^{NR*} , ($x \geq x_k^{NR*}$) ($k = I, V$). Given these factors, the Choquet integrals of the expected payoff become:

- For the victims:

$$(14) \quad \phi^{NR}(x) = \begin{cases} v & \text{if } x < x_k^{NR*} \\ v - (1 - \omega) \sigma \theta_V - (1 - \omega) \theta_V p(x) & \text{if } x \geq x_k^{NR*} \end{cases}$$

- And the injurers,

$$(15) \quad \psi^{NR}(x) = \begin{cases} u - x - (1 - \beta) \theta \theta_I - (1 - \theta) \theta_I p(x) & \text{if } x < x_k^{NR*} \\ u & \text{if } x \geq x_k^{NR*} \end{cases}$$

Equations (14) and (15) show the asymmetric situation between the victim and the injurer. Indeed, if the latter does not conform to the socially first best prevention level x_k^{NR*} , then he expects to repair up to: $(1 - \beta)\theta\theta_I + (1 - \theta)\theta_I$. However, when the court does not hold the polluter as liable (when $x \geq x_k^{NR*}$), the victim's forecast about the cost of damage is $(1 - \omega)\sigma\theta_V + (1 - \omega)\theta_V$. The social utility function deduces from the aggregation of the $\phi^{NR}(x)$ and $\Psi^{NR}(x)$ functions:

- If $x < x_k^{NR*}$, the injurer bears the repairs burden and the social utility function writes as :

$$(16) \quad EWS^{NR}(x)_{x < x_k^{NR*}} = \phi^{NR}(x)_{x < x_k^{NR*}} + \Psi^{NR}(x)_{x < x_k^{NR*}} = \left((u - x - (1 - \beta)\theta\theta_I - (1 - \theta)\theta_I p(x)) \right) + v$$

- And, when $x \geq x_k^{NR*}$:

$$(17) \quad EWS^{NR}(x)_{x \geq x_k^{NR*}} = \phi^{NR}(x)_{x \geq x_k^{NR*}} + \Psi^{NR}(x)_{x \geq x_k^{NR*}} = u + v - x - (1 - \omega)\sigma\theta_V - (1 - \omega)\theta_V p(x)$$

The above two expressions show that, compared to the standard model, the social cost value is no longer unequivocal. Among other, it depends on the injurer's compliance with the socially efficient care level. Consequently, the expected social cost of an accident becomes:

$$(a) \quad x + (1 - \beta)\theta\theta_I + (1 - \theta)\theta_I p(x) \text{ for } x < x_k^{NR*} \text{ and,} \\ (b) \quad x + (1 - \omega)\sigma\theta_V + (1 - \omega)\theta_V p(x) \text{ for } x \geq x_k^{NR*}$$

Then, the question is now: how to determine the socially efficient care level? The regulator calculates it either from the expression (a) or the expression (b). If this one chooses (a), he determines $x_I^{NR*} \geq 0$, where :

$$\frac{\partial EWS^{NR}(x_I^{NR*})}{\partial x_I^{NR*}} = 0 \Rightarrow p'(x_I^{NR*}) = -\frac{1}{(1 - \theta)\theta_I}$$

Index I means that the socially first-best care level is calculated from the injurer's accident cost expressed in (a). Then if the tortfeasor complies with it, i.e. if $x \geq x_I^{NR*}$ then, the victims bear the repairs full burden. These last ones conceive the accident cost at $x + (1 - \omega)\sigma\theta_V + (1 - \omega)\theta_V p(x)$ if $x \geq x_I^{NR*}$.

Note that the perception is the same when the socially efficient care level is calculated from (b). The regulator determines x_V^{NR*} such that :

(18)

$$\frac{\partial EWS^{NR}(x_V^{NR*})}{\partial x_V^{NR*}} = 0 \Rightarrow p'(x_V^{NR*}) = -\frac{1}{(1 - \omega)\theta_V}$$

And obviously if $x \geq x_V^{NR*}$ then, the victims' perceived expected accident cost is also $(1 - \omega)\sigma\theta_V + (1 - \omega)\theta_V$.

Hence, each solution is exclusive one from the other one. Indeed, we can easily check that if the regulator chooses x_I^{NR*} as the socially efficient care level, then the expected social cost of an accident is:

$$x_I^{NR*} + \begin{cases} (1 - \beta)\theta\theta_I + (1 - \theta)\theta_I p(x) & \text{for } x < x_I^{NR*} \\ (1 - \omega)\sigma\theta_V + (1 - \omega)\theta_V p(x) & \text{for } x \geq x_I^{NR*} \end{cases}$$

And, if the regulator chooses x_V^{NR*} , this value becomes:

$$x_V^{NR*} + \begin{cases} (1 - \beta)\theta\theta_I + (1 - \theta)\theta_I p(x) & \text{for } x < x_V^{NR*} \\ (1 - \omega)\sigma\theta_V + (1 - \omega)\theta_V p(x) & \text{for } x \geq x_V^{NR*} \end{cases}$$

Then, which prevention level should hold up the planner: x_V^{NR*} or x_I^{NR*} ? Is it the one of the potential victim or, in the opposite, the injurers' one? In the standard accident model, this dilemma does not exist because the victims agree about the regulator's damage scale. Here, however, a dilemma arises because both situations are not only exclusive one from the other but the "right" socially first-best of care depends on the regulator's choice and this last one disposes of no rational criterion to enforce x_V^{NR*} rather than x_I^{NR*} . We can see, that if the regulator chooses x_I^{NR*} , (i.e. the injurer's one), then, this agent will « naturally » adopt the socially efficient care level. To see this, it is sufficient to calculate the first order conditions from his accident cost function $\Psi^{NR}(x)$, where, if x_I^{NR} is the level that minimizes his cost:

$$\frac{\partial E\Psi^{NR}(x)}{\partial x} = 0 \Rightarrow \exists x_I^{NR} > 0: p'(x_I^{NR}) = -\frac{1}{(1 - \theta)\theta_I}$$

It is then obvious that this level coincides with the socially first-best level of care, $x_I^{NR*} = x_I^{NR}$ (as in the strict liability case (proposition 1)). If, however, the regulator establishes the level of prevention at x_V^{NR*} , the injurer faces the choice to comply or not to this level because $x_V^{NR*} \neq x_I^{NR}$. Accordingly, the regulator is placed in a position of arbiter. This leads him to establish the care level defined by the polluter, or, conversely, the level that the potential victim wishes. However, the criteria that entail choosing x_I^{NR*} rather than x_V^{NR*} are lacking.

As a conclusion, under negligence, when both injurer and victim form beliefs about the damage level scale, the first-best level of care depends on the regulator's choice. Indeed, this last one may either favor the injurer's perception or the victims' ones. Naturally, this

involves different levels of socially optimal care. And then, the question is to know which level the regulator will adopt and why.

3.2 Studying the relationships between x_I^{NR*} and x_V^{NR*} .

At first glance, nothing says that neither x_I^{NR*} or x_V^{NR*} is always superior to the other. For example, we can have: $x_I^{NR} > x_V^{NR}$ or the reverse: $x_I^{NR} < x_V^{NR}$ the writing x_I^{NR} and x_V^{NR} means that these values are the parties' optimal level of care and the "star" appears when the regulator chooses one of them. The above inequalities may hold several meanings. For instance, $x_I^{NR} < x_V^{NR}$ reflects that the tortfeasor tends either to undervalue the accident cost or that the potential victim overestimates it, or, simultaneously, that, both party under and overestimate them. Considering $x_I^{NR} > x_V^{NR}$, on may reverse the interpretation: the victim underestimates the risk while the injurer, who better knows his technology, can take more significant prevention measures than required by the victim. These situations deserve a specific analysis because they hold at the victim's information level, their beliefs about the dangerousness of the process or the facility. Considering each situation, the regulator may choose either the prevention level that the victims require (x_V^{NR}) or the tortfeasor's one (x_I^{NR}). The following table summarizes these situations;

	$x_I^{NR*} < x_V^{NR*}$		$x_I^{NR*} > x_V^{NR*}$	
Social care level	x_I^{NR*}	x_V^{NR*}	x_I^{NR*}	x_V^{NR*}
Situations	(a)	(b)	(c)	(d)

Table 1: Consequences of the regulator's choice concerning the socially efficient care level.

1) Case (a) or $(x_I^{NR*} < x_V^{NR*}, x_I^{NR*})$: Here, the potential victim requires a prevention level higher than the injurer's one. Thus, in case of accident, if $x > x_P^{NR*}$, the victim suffers both the damage consequences and, possibly, the recover costs. This ends up in the usual position of the standard model under the fault liability. The only difference comes from the victims' perception of the damage cost which is different from the standard model:

$$(1 - \omega)(\varepsilon\eta\bar{d} + (1 - \varepsilon)\eta l + (1 - \eta)\bar{l}) \neq \bar{l}$$

Note that the higher the ambiguity preference concerning the probability distribution (ω near 1), the higher the belief that $(1 - \omega)(\varepsilon\eta\bar{d} + (1 - \varepsilon)\eta l + (1 - \eta)\bar{l})$ is lesser than $\bar{l}$.

2) Case (b) or $(x_I^{NR*} < x_V^{NR*}, x_V^{NR*})$: Here, the regulator considers that the injurer's effort level is higher than the one the latter plans to implement. If the injurer wants to escape liability, he must accept the standard the regulator sets. Consequently, he should invest more in security. However, if his prevention effort is too large compared to the expected benefit, then, he can renounce producing. Indeed, enforcing a norm which is not the firms' first best could lead these last one to withdraw if the supplementary care entails too high cost that lowers the firms' payoff, for instance if $\Psi^{NR}(x_I^{NR*}) \geq 0 > \Psi^{NR}(x_V^{NR*})$.

3) Case (c) or $(x_I^{NR*} > x_V^{NR*}, x_I^{NR*})$: This case is paradoxical because the polluter offers a higher level of security than requires the potential victim. This corresponds to two configurations of information failure from the victims' side. The first one concerns the establishment of a risky activity in a Third World country with an under-educated population. In the opposite, the second one relates to the implementation of an innovative activity in a developed country. Then, the firm benefits from private information on the actual dangerousness of its business while the public knows very few about it. Note that the equilibrium solution is similar to the strict liability regime and it provides a better risk cover to victims.

4) Case (d) or $(x_I^{NR*} > x_V^{NR*}, x_V^{NR*})$: Here, the regulator establishes a lower prevention level than the one that the polluter chooses. A priori this is unreal, but can correspond to the regulator's sub- information level. Taking this as granted, then the injurer could lower the prevention level from x_I^{NR*} to x_V^{NR*} , the difference could be considered as an informational rent $(x_I^{NR*} - x_V^{NR*})$ that he could allocate to productive activities this could increase the firm's profit.

3.3 Is the benevolent regulator neutral ?

The situations (a) to (d) have been developed as possible choices for the regulator according that $x_I^{NR*} < x_V^{NR*}$ or the reverse. For a given state, for instance $x_I^{NR*} < x_V^{NR*}$, there is no criterium for inducing it to choose x_I^{NR*} rather than x_V^{NR*} . Here, if the regulator/court gives preference to x_I^{NR*} one may consider that he prefers not to compel the injurer. In the opposite, choosing x_V^{NR*} comes to favor the potential victim's safety against the injurer. Qualifying the regulator as benevolent could involve that this one systematically favors the highest level of prevention, x^* such that $x^* = \text{Max}\{x_I^{NR*}, x_V^{NR*}\}$.

For the polluter, choosing x_V^{NR*} when $x_V^{NR*} < x_I^{NR*}$ makes few questions. Indeed, as case (b) shows it, x_V^{NR*} is a social optimum. In the opposite (when $x_V^{NR*} > x_I^{NR*}$) the reverse

case may induce him to stop producing if the regulator enforces x_V^{NR*} , this is particularly true when:

$$\psi^{NR}(x_I^{NR*}) \geq 0 > \psi^{NR}(x_V^{NR*})$$

If the injurer's activity is of strategic interest for the economy as a whole, this choice may socially be harmful. In this section, the object is to study how to overcome this difficulty if possible by building a program that minimizes the accident costs for victims. However, to guaranty the activity continuousness, the regulator has to choose a prevention level that insures a positive payoff to the potential injurer. Let this level be U , ($U > 0$). Then, let u_a and v_a correspond respectively to the injurer's wealth and victims without accident occurrence and, respectively, u_n and v_n their wealth after an accident. The regulator's program becomes:

$$(19) \quad \max_{x, v_a, v_n, u_a, u_n} [(\sigma\omega + (1 - \omega)(1 - p(x)))\phi^{NR}(v_a) + ((1 - \sigma)\omega + (1 - \omega)(p(x)))\phi^{NR}(v_n)]$$

Under the constraints:

$$(20) \quad (\beta\theta + (1 - \theta)(1 - p(x)))\psi^{NR}(u_a) + ((1 - \beta)\theta + (1 - \theta)(p(x)))\psi^s(u_n) = U$$

$$(21) \quad (\sigma\omega + (1 - \omega)(1 - p(x)))v_a + ((1 - \sigma)\omega + (1 - \omega)(p(x)))v_n + (\beta\theta + (1 - \theta)(1 - p(x)))u_a + ((1 - \beta)\theta + (1 - \theta)(p(x)))u_n + (1 - \omega)\sigma\theta_V + \beta\theta x + x + [(1 - \omega)\theta_V + (1 - \theta)x]p(x) = u + v$$

This system assumes that the resources available for potential repairs remain constant, that is to say equal to the present as in Shavell (1982). We use the Khun-Tucker method to solve it. Then, for a given x and differentiating the program to v_a and v_n , and u_a , u_n , it appears that $\phi^{NR}(v_a) = \phi^{NR}(v_n)$ (by eliminating multipliers) for $v_a = v_n = \mu$ and $u_a = u_n = h$, this condition is sufficient and necessary to satisfy (20) and (21). Replacing theses values in the program by μ and h , this one becomes:

$$(22) \quad \max_{x, \mu, h} [\phi^{NR}(\mu)]$$

Under the constraints:

$$(23) \quad \psi^{NR}(h) = U$$

$$(24) \quad \mu + h + (1 - \omega)\sigma\theta_V^{NR} + \beta\theta\theta_I + x + [(1 - \omega)\theta_V^{NR} + (1 - \theta)\theta_I]p(x) = u + v$$

v

By (23), $\bar{h}$ is determined and it is substituted in (24). Then:

$$(25) \quad \mu = \begin{cases} u + v - \bar{h} - (1 - \beta)(1 - \theta) \theta_I - (x + (1 - \theta) \theta_I p(x)) \\ \text{if } x \geq x_I^{NR*} \\ u + v - \bar{h} - (1 - \omega) \sigma \theta_V - (x + [(1 - \omega) \theta_V] p(x)) \\ \text{if } x \geq x_V^{NR*} \end{cases}$$

As the components of $u + v - \bar{h} - ((1 - \omega) \sigma \theta_V, (1 - \beta)(1 - \theta) \theta_I)$ are given, the program amounts at minimizing either $(x + (1 - \theta) x_I^{NR} p(x))$ or $(x + (1 - \omega) \theta_V p(x))$. This one is contingent to the regulator's choice concerning its own purposes and this does not solve the dilemma. In fact, potentially the regulator has to choose between two solutions, either x_I^{NR*} that corresponds to the optimal level of care from the injurer viewpoint, or x_V^{NR} the one wished by the victims. In conclusion, the regulator does not dispose of an indisputable criterion that allows him to choose between the two possible socially efficient levels.

3.4 Negligence: A rationale for Divergent views between judge and regulator

The existence of two potential levels of prevention gives rational motives to understand the possible divergent opinions between the regulator and the court. Indeed, the two entities may vary concerning the interest to preserve under the negligence regime. The Court has to assign liability following its own criteria, as Faure (2010) mentions it:

“Under negligence, it is the judge who will determine the efficient care standard. Therefore, the judge will need further information on the costs of preventive measures and will have to weigh these against the probability that additional investments would reduce the expected damage. This will hence be translated in a due care standard to be followed by the potential injurer. Under negligence the injurer only needs information about the due care required but the court on the basis of case law”. Faure (2010, p.20)

So, even if both the Court and the regulator dispose of equivalent calculation means and, furthermore, share the same rationality, they may diverge in defining the socially first-best care level³. As Faure mentions it, the judge will always be preminent.

This discrepancy may generate uncertainty about the level of care that the injurer intends to set up. When both regulator and judge share the same evaluation, for instance, respectively, $(x_V^{NR*}$ and $x_V^{NR*})$ or $(x_I^{NR*}$ and $x_I^{NR*})$, this could mean that the regulator influences the judges by the setting of legal technical standards to which must comply the company. However, in all cases, to avoid being blamed, a tortfeasor will choose to bring its

³ However, the court may feel difficulty in assessing the adequacy of the level of prevention and the level of activity (Shavell (1987)).

care level to the level that courts recommend. But, as it this knowledge is always afterwards, this raises the question of how the injurer could implement this value.

This does not mean that courts define a more severe design for polluters than the regulator does. It is important to note that, unlike strict liability, here, radical uncertainty is a key factor in explaining differences in resources allocated to prevention following that the authorities (regulator / court) prefer to focus on companies or victims. The negligence rule shows that even if the authorities are benevolent, they cannot be totally neutral.

If, for example ($x_V^{NR*} > x_I^{NR*}$), then, they can choose either x_V^{NR*} or x_I^{NR*} . We saw that if the expectations of the victims are more important than the optimal safety offered by companies x_I^{NR*} , and if the authorities prefer x_V^{NR*} , if the injurer faces a too high cost level to increase safety from x_I^{NR*} to x_V^{NR*} , he could resign and stop producing.

However, he also could adopt several strategic behaviors. First, he may accept running the liability risk. Indeed, an injurer may consider that if the expected damages are not too high in such a way that he remains solvent, then, if x_V^{NR*} is the first best level of care and $x_V^{NR*} > x_I^{NR*}$, then he could supply a care level equal to x_I^{NR*} . Thus, he incurs the risk to lose: $u - x_p^{NR*} - (1 - \beta)\theta\theta_I - (1 - \theta)\theta_I p(x_I^{NR*})$ (where x_I^{NR*} is the level that maximizes the injurer's payoff). This choice means that the injurer accepts to run a risk equivalent to the strict liability case.

Second, he may try improving the victim's information level. Indeed, the injurer may devote information means towards the potential victims in order to improve their knowledge and make convergent x_V^{NR*} and x_I^{NR*} . The term "information" is generic and refers to different ways to inform the public about the effective dangers and protection means taken by the injurer. This could take the form of advertising, training, lobbying, etc. This effort from the injurer's side could involve a convergence of views with the victim's perception. However, this deserves more attention and pushing further this point goes beyond this paper's scope.

3.5 The injurer's limited liability

The injurer's wealth limitation (compared to the damage scale) means that he can become "judgment-proof" and, there, proposition 1 cannot apply. In this sub-section, the study focuses on a particular case of limited liability where the regulator puts bounds (or cap) on the level of repairs. Then, capped strict liability is this strict liability that blames an injurer's hazardous activity without the need of demonstrating the existence of misconduct but, the bound on the repair level limits the level of injurers' debt. Consequently, both victims

and polluters bear the repairs burden. This liability governs sensitive sectors as the maritime transportation of oil or the nuclear industry. Concerning this last one, international conventions⁴ establish strict liability exclusively channeled to the operators of the nuclear installations. If this liability is absolute, it is limited in time and amount which is now set to €1.500M. In the USA, the Price-Anderson Act limits insurance to \$300 million and caps the operators' liability of \$10.5 billion. The maritime transport depends on the International Convention on Civil Liability for Oil Pollution (CLC) and the Oil Pollution Compensation Fund (Fund Convention) establishes a two-tier liability system. It is built upon both a bounded strict liability for the ship owners and a collectively financed fund, which provides supplementary compensation to victims of oil pollution damage who have not obtained full compensation. This last notion applies only to people privately concerned with personal losses. Hence, concerning injurers, the damage scale is limited till a given ceiling c (cap) $c < l$ less than the maximum level of damage. The victims bears the difference $l - c$. Hence, the respective payoff functions of injurers and victims write as the following.

a) The Injurer

Limiting the amount of the damage affects the injurer's Choquet integral. Indeed, now, c is the maximum repair amount that the injurer must pay in case of an accident, this, whatever the care he took. His expected damage function writes as:

$$(26) \quad \theta_l^{SLC} = \alpha \gamma \bar{d} + (1 - \alpha) \gamma c + (1 - \gamma) \bar{l} \text{ where } c > \bar{l},$$

(where SLC stands for (capped strict liability). Then, his program becomes:

$$(27) \quad \psi^{SLC}(x) = \underset{x \geq 0}{\text{Max}} \{ u - x - (1 - \beta) \theta \theta_l^{SLC} - (1 - \theta) \theta_l^{SLC} p(x) \}$$

b) The Victims

Compared to the previous situation where the polluters were liability free, the repairs borne by victims decrease and they will have to support the expected following loss:

$$(28) \quad \theta_v^{SLC} = (1 - \varepsilon) \eta (l - c)$$

This means that they bear the damage charge comprised between l and $(l - c)$. The amount below this level is paid by the injurer. Then, after having introduced this expression in the victims' CEU, we get:

$$(29) \quad \phi^{SLC}(x) = v - (1 - \omega) \sigma \theta_v^{SLC} - (1 - \omega) \theta_v^{SLC} p(x)$$

c) The Regulator

⁴ For instance, the OECD's Paris Convention of 1960, the IAEA's Vienna Convention of 1963, the Convention on Supplementary Compensation for Nuclear Damage (CSC) of 1997 and 2003, the OECD Paris (and Brussels) that amended it in 2004.

As previously, by summing (23) and (25), we get the social utility function:

$$(30) \quad EWS(x) = \Psi^{SLC}(x) + \phi^{SLC}(x) = u + v - x - (1 - \beta)\theta\Theta_I^{SLC} - \omega\sigma\Theta_V^{SLC} - p(x)\left((1 - \theta)\Theta_I^{SLC} + (1 - \omega)\Theta_V^{SLC}\right)$$

According to this scenario, the regulator requires a level of protection equal to x^{*SLC} , where x^{*SLC} is this value for which $EWS'(x^{*SLC}) = 0$, and,

(31)

$$p'(x^{*SLC}) = -\frac{1}{(1 - \theta)\Theta_I^{SLC} + (1 - \omega)\Theta_V^{SLC}}$$

The injurer maximizes his payoff for, x^{SLC} his program is:

$$(32) \quad \underset{x \geq 0}{Max}\{u - x - (1 - \beta)\theta\Theta_I^{SLC} - (1 - \theta)\Theta_I^{SLC}p(x)\}$$

We can see that this program goes back at minimizing $\{x + (1 - \theta)\Theta_I^{SLC}p(x)\}$.

And, as shows appendix 2, $x^{SLC} < x^{*SLC}$. It follows that the regulator must find the economic tools that induce the tortfeasor to achieve the prevention level x^{*SLC} rather than x^{SLC} . Here, enforcing negligence is not possible since ceiling the repairs is intended to encourage the producers to invest when the expected level of repairs is too high and may deter the investment in risky activities. This situation may be extended to all cases of the injurer's limited liability: limitation due to the scarcity of this wealth compared to the damage (judgment proof case), bounds put on the repairs level by the court. This result joins Franzoni (2012)'s analysis, this point is detailed below.

4. Links to the literature

Comparing the effectiveness of two liability systems needs the formulation of a prior model. Until recently the standard accident model served as a benchmark. However, Mingus (2006) and Teitelbaum (2007) contributions opened the door to critical approaches and mark a rupture with the standard (basic) model. However, alternative theoretical models may vary considerably from one author to another. Indeed, each model assumes different basic functions grounded on the agents' specific ambiguity or risk aversion functions. Teitelbaum (2007)' model assumes that the regulator owns a specific utility function that expresses its own preferences and not the ones of the agents as in the standard model. Indeed, implicitly, the standard model assumes that all categories of agents are risk neutral and the regulator aggregates the agents' preferences and defines the first best level of care (Shavell (1987). However, in the Shavell (1982)'s paper, things become different when he assumes that the injurer's becomes risk averse while the regulator stays neutral to risk. This corresponds to the

Teitelbaum's case, except that ambiguity replaces risk aversion. Consequently, the impossibility for the regulator to enforce the socially first best level of care comes from the discrepancy between this level and the injurer's optimal care level⁵.

In a somewhat different view, Chakravarty and Kelsey (2016) analyze the welfare implications of tort rules. For this purpose, they model a bilateral accident model where injurer and victim both invest in care and the parties are gifted with Neo-capacity utility functions. Both agents derive utility from an unobservable action, which may lead to the accident. When the agents only choose the level of care, under negligence, ambiguity-averse agents are more likely to choose the optimal amount of care. Second, when agents choose care and the unobservable action, they propose a system of negligence, plus punitive damages which give optimal level of both care and unobserved action by injurers and victims.

Another category of models assumes that the benevolent regulator aggregates the gain functions (or accident costs) of both parties. They differ in their assumptions about the attitude to risk and / or uncertainty agents. Thus, for example Franzoni (2013) the agents' utility functions is inspiring from Klibanof and al. (2005)'s model (smooth ambiguity). He does not consider ambiguity aversion as a cognitive bias, but a genuine component of welfare. Indeed, originally, for Ellsberg (1961), ambiguity aversion is not a mistake that agents would be willing to correct once they note it, consequently, the agents (victims and injurer) form (prior) beliefs about the probability of harm. Then, each belief comes with a degree of plausibility (a probability measure) and, in the decision environment, the ambiguity degree is captured by the variance of the prior beliefs of the agents. The parties may feel different degrees of ambiguity (i.e. their prior distributions for the probability of harm differ). Consequently, the model consists in minimizing the social accident loss that includes the expenditure in prevention, expected harm, and the uncertainty premium of the parties. Then, ambiguity induces an injurer subject to strict liability to take greater precautions if, and only if, such precautions reduce the spreading of prior beliefs (together with the mean probability of harm). Negligence leads to raise the standard of care, but only in situations where investing in care has the power to reduce the perceived ambiguity. Moreover, strict liability dominates negligence, but only under very restrictive conditions: the injurer feels both a lower degree of risk aversion and a lower degree of ambiguity aversion, than the victim, and the injurer's assessment of the likelihood of harm is less ambiguous.

⁵ See also Mondello (2012) and Lampach and Spaeter (2016).

Langlais (2012) also keeps the aggregation of agents' preferences. In a somewhat different model, he also shows that Knight's uncertainty leads to a socially inefficient level of care and he considers a global non-insurable risk where the polluters invest in reducing risk technologies. Compared to victims, the polluter feels a little degree of aversion to risk and ambiguity. Then, his estimate of the prejudice likelihood also corresponds to a lower ambiguity degree. Langlais' model is based on supposed pessimistic and risk-averse agents. Agents are maximizers Rank Dependent Expected Utility, he is closed with Bigus (2005) work. He shows that the required security level is higher than in a neutral to risk economy and that no liability regime is significantly efficient.

5. Conclusion

Simple in its basic formulation, the unilateral accident model is far from having revealed all its potential. In the standard accident model, equivalence between strict liability regime and negligence rule is essentially associated with the fundamental assumptions of risk-neutral regulator and injurers. This model is not robust to a risk adverse agent without insurance or to radical uncertainty. In all cases, under radical uncertainty, whatever the chosen methodology, the relationship between the two polar liability regimes, strict liability and the rule of negligence, is not anymore insured and most of the authors consider this point as granted. Then, the remaining question is to know which liability regime insures better social safety coverage. Taking the stance opposite to the common view, this paper stands that comparing liability regimes has little meaning. Indeed, radical uncertainty is not an obstacle to induce the agents to naturally choose the socially efficient level of care, conversely to the well-accepted idea. The main conditions are, first, that the injurer disposes of a sufficient wealth compared to the damage scale and, second, the regulator enforces a strict liability regime. The difficulties to compare both regimes come from the negligence rule side. In its basement the above model allows the expression of doubts (beliefs) of the potential victim and injurer. This issues on the fact that under this regime, the authorities (either the regulator or the court) face a dilemma. Indeed, two socially efficient care levels can be enforced: either the injurer's efficient one, or the victim's one and no rational criterion leads to rationally choose among them. Consequently, even benevolent, the authority (judge or regulator) may favor one party against the other one. Indeed, it is the judge that, in fine, assigns the liability burden and his view is then fundamental this may explain the difference between the judge and the regulator's view on the level of the socially efficient care level.

As a conclusion, the main result of this study is that both regimes cannot be accurately compared and it is difficult inferring that strict liability gives better results than the negligence rule, even if, under the assumption of no judgment-proof situation, the strict liability regime ensures that the injurer establishes the socially first-best level of care. This level corresponds to the injurer's efficient care level, without possibly considering the victim's beliefs. This is not the case under the rule of negligence where both agents can express them. One further difference between these liability regimes is that the negligence rule allows different behaviors between the agents. For instance, under a negligence regime, in order to increase the level of optimism or decrease the ambiguity preference of the victims and lead them on their view, the injurers may develop information strategies to improve the victims' knowledge for instance. Under strict liability, this is true only with a capped strict liability regime.

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Appendix 1

The concept of neo-additive capacity

More generally, the criticism of the expected utility foundations began in the midst of last century, when, first, Allais (1953) criticized the Savage's independence axiom. Furthermore, Ellsberg in 1961 showed that the Savage's preference preorder leads to the paradoxical situation in which the sum of probability on uncertain events differs from one⁶.

Schmeidler (1989) systematizes Ellsberg's approach by using Choquet's integrals as a substitute to the Savage Expected Utility theory (SEU). For modern ambiguity theory, a non-additive probability or "capacity" represents the agents' beliefs about the likelihood of events. The agents maximize a utility function, based not on the sum of weighted utility indices, with weights that sum to 1 as in the theory of Savage, but for a sum greater than 1 which represents a Choquet integral. It is admitted that according the integral shape (concave or convex) the agent expresses optimism (concavity due to super-additivity) or pessimism (sub-additivity). Schmeidler's approach hardly lends itself to manageable extensions. However, Chateauneuf, Eichenberger and Grant (2007) (CEG) performed this task by developing the concept of neo-additive capacity. Due to its characteristics, this concept allows integrating the contributions of experimental economics in the decision field⁷. Indeed, this capacity is additive on non-extreme values, but non-additive for maximum and minimum values. This means that, for example, in bets situations, the "real" persons do not behave as predicted by the expected utility theory. Indeed, they tend to overestimate the probability of higher earnings while generally this one is close to 0 (the case of national lotteries) and tend to underestimate the probabilities of losses for low earnings (see Camerer and Weber (1992) Gonzales and Wu (1999) or Abdellaoui (2000)). These results are illustrated by the well-known inverted S-shaped curve. Appendix 1 of this article briefly presents the mathematical foundations of this approach (see CEG (2007) for a full formal mathematical presentation).

A capacity is an extension of a probability. It is a function $\tau(p)$ that assigns real numbers to events $\mathcal{E}$, where $\mathcal{E}$ is the set built from the set $\mathcal{S}$ of the states of nature. A capacity fulfills two conditions. First, for all $E, F \in \mathcal{E}$, and $E \subseteq F$, then $\tau(E) \subseteq \tau(F)$ as monotonicity condition and, second, as normalization conditions, $\tau(\emptyset) = 0$ and $\tau(\mathcal{S}) = 1$.

⁶ See Teitelbaum (2007) for a complete review.

The best way to integrate capacities is the Choquet integral. To do that, it is assumed that exists a simple function of finite range f that takes values $\mu_1 \geq \mu_2 \dots \geq \mu_n$. A Choquet integral of a simple function f with respect to a capacity $\mu(\cdot)$ is defined as:

$$V(f/\tau) = \sum_{\mu \in f(\mathbb{S})} \mu[\tau(\{s/f \geq \mu\}) - \tau(\{s/f > \mu\})] \quad (1A)$$

Through the concept of neo-additive capacity the Choquet integral overweight high outcomes if the capacity is concave or overweigh low income if the capacity is convex. Convexity of a capacity is verified by the following relationships:

$$\tau(E \cup F) \geq \tau(E) + \tau(F) - \tau(E \cap F) \text{ (and concave in the opposite situation).}$$

Applying this to our model, we consider that the polluter and the society cannot assess with certainty the exact value of a maximum damage. Let be $\mathcal{E}$ the finite set of states to which correspond the catastrophic events $\mathcal{A}$ (σ -algebra of $\mathcal{E}$). We consider a finite set of outcomes ($A \subset \mathbb{R}$) and let $\Phi = \{f: \mathcal{E} \rightarrow A\}$ be a set of simple functions from states to outcomes which correspond to simple acts and takes on values $a_1 \geq a_2 \dots \geq a_n$.

The injurer is gifted with a Choquet objective function which corresponds here to an expected cost function. His beliefs on the level of damage correspond to a neo-additive capacity (μ) based on (p). Hence, the operator will form beliefs about the level of the damage. This is a supplementary uncertainty. We can define now the neo-additive capacity. To do that, let us consider that the σ -algebra $\mathcal{A}$ is partitioned in three subsets that we present and characterize (for a more complete information see CFG (2002, 3).

- The set of null events $\mathcal{N}$, where $\emptyset \in \mathcal{N}$ and for $G \subset H$, and $G \in \mathcal{N}$ if $H \in \mathcal{N}$.
- The set of “universal events” $\mathcal{W}$, in which an event is certain to occur, (complement of each member of the set $\mathcal{N}$).
- The set of essential events, $\mathcal{A}^*$, in which events are neither impossible nor certain. This set is composed of the following:

$$\mathcal{A}^* = \mathcal{A} - (\mathcal{N} \cup \mathcal{W})$$

Before going further, we define the following capacities ν (see appendix):

$$\nu_0(A) = 1 \text{ if } A \in \mathcal{W} \text{ and } 0 \text{ otherwise and } \nu_1(A) = 0 \text{ for } A \in \mathcal{N} \text{ and } \nu_1(A) = 1 \text{ otherwise.}$$

Furthermore, we define a finite additive probability $p(\cdot)$ such that $p(A) = 0$, if $A \in \mathcal{N}$ and 1 otherwise.

Definition 1: Let λ, γ that belong to a simplex Δ in $\mathbb{R}^2$, ($\Delta := \{(\lambda, \gamma) / \lambda \geq 0, \gamma \geq 0, \lambda + \gamma \leq 1\}$), a neo-additive capacity μ based on the distribution of probability $p(\cdot)$ is defined as:

$$\mu(A / p, \lambda, \gamma) = \begin{cases} 0 & \text{for } A = \emptyset \\ \lambda v_0(A) + \gamma v_1(A) + (1 - \gamma - \lambda)p(A) & \text{for } \emptyset \subsetneq A \subsetneq \mathcal{E} \\ 1 & \text{for } A = \mathcal{E} \end{cases} \quad (2A)$$

A neo-additive capacity is additive on non-extreme outcomes. Here p corresponds to the probability of a major accident of a given scale. This is a common belief and $(1 - \gamma - \lambda)$ represents the degree of confidence of the agent in this belief. We will give below, after the presentation of the Choquet integral of the neo-additive capacity, a more complete explanation on the concept of optimism. Then, we can define the Choquet integral which is a weighted sum of the minimum, the maximum and the expectation of a simple function $f: \mathcal{E} \rightarrow \mathbb{R}$ as it is expressed in the following relationship:

$$V(f / p, \lambda, \gamma) = \lambda \cdot \inf(f) + \gamma \cdot \sup(f) + (1 - \gamma - \lambda)E_p(f) \quad (3A)$$

Where $E_p(f)$ is the expected value of the expected costs of a major accident, and from the linearity of the Choquet integral with respect to the capacity, we define $V(f / v_0(\cdot)) = \inf(f)$ and $V(f / v_1(\cdot)) = \sup(f)$, (proof see CFG(2002, 3) and CFG(2006, 3)).

Then for $e \in \mathcal{E}, f(e) = a$, we put, $f(e_1) = \sup(f) = a_1 = l$ and $f(e_n) = \inf(f) = a_n = \bar{d}$. As, $p(\cdot)$ is a finitely additive probability distribution on $\mathcal{A}$, we define $E_p(f)$ as:

$$E_p(f) = E_p(a) = \int_{\bar{d}}^l a p(a) da \quad (4A)$$

Taking into account these factors, the Choquet integral writes now:

$$V_p = \lambda \cdot \bar{d} + \gamma l + (1 - \gamma - \lambda)E_p(a) \quad (5A)$$

Hence, if $\gamma = \lambda = 0$, we find the usual expected utility. With $1 \geq \gamma > 0, \lambda = 0$, the subject is waiving between the lowest value and the expected value of the function. That corresponds to pessimism because the operator cannot consider that l occurs with sufficiently high probability. Then, optimism is induced by $\gamma = 0, 1 \geq \lambda > 0$.

Keeping order in a correspondence with the Teitelbaum (2007)'s analysis, we make the following change of variable that corresponds to the treatment of CEG (2007):

$$\lambda = \delta\alpha, \gamma = \delta(1 - \alpha), \text{ then we can check that } 1 - \gamma - \lambda = 1 - \delta \text{ with } \delta, \alpha \in (0, 1)$$

The neo-additive capacity is then:

$$\mu(A / p, \delta, \alpha) = \begin{cases} 0 & \text{for } A = \emptyset \\ \delta\alpha v_0(A) + \delta(1 - \alpha)v_1(A) + (1 - \delta)p(A) & \text{for } \emptyset \subsetneq A \subsetneq \mathcal{E} \\ 1 & \text{for } A = \mathcal{E} \end{cases} \quad (6A)$$

Or, still, for $\emptyset \subsetneq A \subsetneq \mathcal{E}$

$$\mu(\cdot) = \delta\alpha\bar{d} + \delta(1 - \alpha)l + (1 - \delta)p(A) \quad (7A)$$

we get then the neo-capacity's Choquet Integral:

$$V_p = \delta\alpha\bar{d} + \delta(1 - \alpha)l + (1 - \delta)E_p(a) \quad (8A)$$

The precise meaning of the weight δ (aversion for ambiguity) and α (degree of optimism) is made in the paper.

Appendix 2

Proof that : $x^{SLC} < x^{*SLC}$.

This proof is classical. If x^{SLC} verifies $\Psi'^{SLC}(x^{SLC}) = 0$, and $p'(x^{SLC}) = -\frac{1}{(1-\theta)\Theta_p^{SLC}}$

For $(1 - \omega)\Theta_V^{SLC} \geq 0$, $(1 - \theta)\Theta_p^{SLC} + (1 - \omega)\Theta_V^{SLC} \geq (1 - \theta)\Theta_p^{SLC}$, and,

$$\frac{1}{(1-\theta)\Theta_p^{SLC} + (1-\omega)\Theta_V^{SLC}} < \frac{1}{(1-\theta)\Theta_p^{SLC}}, \text{ for } \theta \neq 0$$

Consequently :

$$p'(x^{*SLC}) = -\frac{1}{(1-\theta)\Theta_p^{SLC} + (1-\omega)\Theta_V^{SLC}} > p'(x^{SLC}) = -\frac{1}{(1-\theta)\Theta_p^{SLC}}, p'(x) < 0$$

However, as $p''(x) > 0$, $p'(x)$ is an increasing function, $p'(x^{*SLC}) > p'(x^{SLC})$ involves that $x^{*SLC} > x^{SLC}$.

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