Liability law and uncertainty spreading

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Abstract

This paper investigates the ability of liability rules to allocate uncertainty. Using local approximations, a convenient mean-variance liability model is derived, able to capture the disposition of the parties towards both standard risk and ambiguity. Ambiguity arises when the causal link between conduct and harm is not conclusive, as is frequently the case with toxic torts. Strict liability proves superior to negligence when harms are uncorrelated and victims are at least as uncertainty-averse as the injurer. Negligence is preferable when harms are correlated and victims are numerous. Thus, negligence proves particularly apt to address systematic harms, such as those arising from design defects and warning failures. The main results also apply when accidents are bilateral and when parties can purchase insurance from an uncertainty-averse insurer.

Keywords: *negligence vs. strict liability, products liability, scientific uncertainty, ambiguity, toxic torts.*

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From an economic perspective, liability law serves two broad goals: to provide parties with incentives to invest in precaution and, at the same time, to spread the risk of accidents. This article investigates the performance of strict liability and negligence rules against these two goals, and tries to determine under what conditions one rule is preferable to the other.

The risk-spreading function of the liability system has long been a source of controversy. For product defects, strict liability has been forcefully defended on the grounds that manufacturers are in the best position to bear the risks inherent to mass production. As Justice Traynor argued in a famous concurring opinion: "[t]he cost of an injury and the loss of time or health may be an overwhelming misfortune to the person injured, and a needless one, for the risk of injury can be insured by the manufacturer and distributed among the public as a cost of doing business."[1] Whether manufacturers are indeed in the best position to provide insurance to consumers against risk, is at the center of the current debate on liability reform.[2]

In modern society, the importance of risk allocation is magnified by technological innovation. The degree of safety of newly developed products and technologies cannot always be ascertained because of long latency periods and lack of epidemiological data. In this case, the risk allocated by the liability system is of a different kind, for it originates from scientific uncertainty (not knowing with certainty the probability of harm), rather than factual uncertainty (not knowing with certainty whether harm will occur). Optimal uncertainty sharing is thus of the utmost importance for harms generated by new substances and technologies, like engineered nanomaterials and GMOs, whose degree of hazardousness remains partially unknown.[3] Liability law should also address the issue whether scientific uncertainty calls for a cautionary approach to standard set-

[1] *Escola v. Coca-Cola Bottling Co.*, 24 Cal.2d 453, 150 P.2d 436 (1944). This view is still shared by many courts and commentators (see Owen (2008), §5.4). Priest (1985) attributes the development of the theory of strict liability for products and, eventually, the liability crises of the 1980s to the "enterprise liability" theory popular in the 1950s. See also Abraham (2008).

[2] See, for instance, Polinsky and Shavell (2010), Goldberg and Zipursky (2010), Hylton (2013), Hersch and Viscusi (2013), and Daughety and Reinganum (2014).

[3] While the applications of nanotechnology grow at an exponential rate (more than 1,300 nano-influenced consumer products are present in the marketplace), so do the highly unknown risks from exposure to nano fibers (see David (2011)). With uncertainty are fraught also a very large number of chemical compounds (Cranor (2011)) and GMOs (Strauss (2012)).

ting.[4] Independently of whether losses are borne by victims or injurers, both standard risk and scientific uncertainty (ambiguity) add to the cost of accidents.[5]

An additional factor that might impinge on the cost of accidents is the interdependence of harms. Contrary to most contributions to the literature, in which the injurer faces one victim, in my basic model the injurer can harm n victims, and harms can be correlated. Correlation across harms is of special concern to liable injurers (and their insurance companies), because it inflates the variance of their total liability burden. Admittedly, the extent of this correlation depends on the harm's type. Some product-related harms tend to be highly correlated, like those arising from flaws affecting the entire product line. Design defects, for example, lead to the distribution of products that are all inadequately safe (as in the well know case of the Pinto cars susceptible to explode in rear-end collisions) or unreasonably harmful (as in the case of insulation containing row asbestos).[6] In other cases, the defect affects individual items, as when foreign matter enters food and drink or when the product happens to be improperly assembled or finished.[7] In these cases, typically associated to manufacturing defects, harms tend to be uncorrelated. I show that correlation, together with the disposition of the parties towards risk and ambiguity, is the driving factor in the choice between liability rules.

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[4]In commenting toxic torts (Comment c "Toxic substances and disease", *Restatement (Third) of Torts,* § 28), the ALI drafters elucidate that: "There are instances in which although one scientist or group of scientists comes to one conclusion about factual causation, they recognize that another group that comes to a contrary conclusion might still be "reasonable." Judgments about causation may also be affected by the comparative costs of errors, as when caution counsels in favor of declaring an uncertain agent toxic because the potential harm it may cause if toxic is so much greater than the benefit foregone if it were permitted to be introduced." Scientific uncertainty has been a distinguishing trait of leading toxic torts, including asbestos, Agent Orange, Dalkon Shield, DES, and Bendectin.

[5]The literature (both theoretical and empirical) on ambiguity is extensive. Ambiguity aversion was at the core of Ellsberg (1961)'s criticism of expected utility. Good surveys are provided by Wakker (2010), Etner et al. (2012) and Gilboa and Marinacci (2013).

[6]*Grimshaw v. Ford Motor Company*, 119 CA3d 757 (1981); *Arena v. Owens-Corning Fiberglas Corp.,* 74 Cal. Rptr. 2d 580 (Cal. Ct. App. 1998).

[7]See, for example, *Shoshone Coca-Cola Bottling Co. v. Dolinski,* 420 P.2d 855 (Nev. 1966) (a decomposed mouse found in a soda bottle), *Furline v. Michigan Turkey Producers Co-op*, 2010 WL 3273126 (W.D. Mich. 2010) (needle lodged in hotdog); *Cooper Tire & Rubber v. Mendez*, 204 S.W.3d 797 (Tex., 2006) (tread lost by radial tire), *Ford Motor Co. v. Zahn*, 265 F.2d 729 (8rg Cir. 1959) (jagged edge on car's ashtray), *Jenkins. v. General. Motors. Corp.* 446 F.2d 377 (5th Cir. 1971) (inadequately torqued nut on a bolt).

In the model, parties formulate beliefs about the probability of harm given the prevention measures adopted. I first assume that these beliefs are correct on average, so as to reflect the foreseeability of harm.[8] The opposite case is studied in the Appendix. If parties have no doubt about the probability of harm (each party formulates the same belief), the model comports with the standard expected utility approach. If parties formulate multiple beliefs about the probability of harm (as a result of scientific uncertainty), the decision environment includes ambiguity. Ambiguity aversion is modelled according to the smooth model of Klibanoff et al. (2005), which posits that parties are averse to mean preserving spreads of the beliefs.[9]

To obtain simple results, I rely on local approximations of the willingness of the parties to bear uncertainty. These approximations allow for an analysis of liability policy independent of income levels, a convention that comports with current practice and standard cost-benefit analysis.[10] Under this income-independence assumption, the decision problem assumes a simple mean-variance shape, in which the premium that an individual is willing to pay to avoid uncertainty is the sum of a risk premium and an ambiguity premium. The risk premium depends on the variance of the mean probability of accident, while the ambiguity premium depends on the variance of the beliefs around their mean, as in Maccheroni et al. (2013). On the basis of this convenient simplification, I am able to characterize the optimal features of the negligence and strict liability rules, and to clearly identify the conditions under which either rule allows for better uncertainty spreading.

How uncertainty is allocated across the parties ultimately depends on two factors:

[8] Foreseeability of risks is a common requisite for liability to apply (at least after *Feldman v. Lederle Laboratories*, 479 A.2d 374, N.J. 1984). This paper does not address scientifically unknowable risks. Additionally, because the information set does not chance with time, it does not consider hindsight liability. On the latter, see Ben-Shahar (1998).

[9] If parties are certain of the probability of accident, but they do not agree on it, we obtain the "diverging expectations" model, which has been used with success in the litigation literature (see, for example, Waldfogel (1998)). If parties are not certain of the probability of an accident, and their beliefs are not correct on average, we obtain (an extended version of) the accident model developed by Teitelbaum (2007). The relationship between these models and my own is explored in the Appendix.

[10] Compensation may depend on income if lost earnings are included in the damages awarded. In this case, income is used to assess harm but not the party's ability to bear risk.

i) whether strict liability or negligence applies; and ii) if negligence applies, whether the injurer has met the standard of care set by the courts. If the injurer is found liable, damages are awarded to the victims.[11]

Under the strict liability rule, the injurer decides the level of care to take, whereas the courts set the damages awarded. Damages can fall short of full compensation for victims because of statutory caps or explicit exclusion of certain harms; however, victims are actually overcompensated in cases in which the court awards punitive damages. Damages are thus the determining factor in the allocation of uncertainty and the amount of precaution taken by the injurer. As in Shavell (1982), I prove that optimal damages are less than fully compensatory. They increase with the degree of risk aversion of the victims, and, if care does indeed reduce ambiguity, with victims' degree of ambiguity aversion.

Under the negligence rule, the injurer bears the loss only if she does not meet the standard of care (at equilibrium, she will meet the standard.) The standard of care is set by the courts, which balance the costs and benefits of precaution. The optimal standard of care increases with the degree of risk aversion of the victims, while it increases with their degree of ambiguity aversion if, and only if, care reduces the variance of their beliefs. Hence, uncertainty about factual causation does not necessarily command a precautionary approach to standard setting.

Because both negligence and strict liability are capable of providing the injurer with incentives to take care (under very weak conditions), the contrast between the two rules is found in the ability of each to optimally allocate uncertainty. Note that under strict liability, the loss can be shared (by means of under-compensatory damages), while under negligence, all uncertainty is borne by the victims.

As a first step, it is useful to compare negligence to strict liability with fully compensatory damages (even where compensatory damages are not optimal). These two rules are symmetric in that they allocate the full loss to one side. Because of the interdependence of harms, however, the uncertainty cost borne by the injurer under strict liability

[11] This paper studies the impact of uncertainty on the allocation of the loss in the traditional strict liability vs. negligence set-up. An alternative interpretation is to assume strict liability, and to consider the impact of uncertainty on the causation standard. If the causation standard is not met, the loss falls on the victims.

can be substantially greater than the uncertainty cost borne by the victims under negligence. Particularly when harms are correlated and victims are numerous, negligence is better at spreading uncertainty, and it clearly dominates over strict liability. However, where harms are not correlated, the number of potential victims is irrelevant. If the injurer and the victims are equally averse to uncertainty, negligence and strict liability with compensatory damages are equally good. Neither of these rules' allocation of uncertainty is optimal, however, for risk is placed solely on one party. Here, the additional leverage that strict liability places in the hands of the courts comes into play: damages can be set below the compensatory level, and some uncertainty can be efficiently shifted onto victims. For this reason, strict liability is marginally superior to negligence in the case of uncorrelated harms. The main conclusion of this paper can thus be summarized as follows: **strict liability is preferable to negligence when harms are uncorrelated and the victims are at least as averse to uncertainty as the injurer. Negligence is preferable when harms are correlated and victims are numerous**.[12]

In the basic model, I assume that victims cannot prevent harm, that neither party is insured, and that victims are strangers to the injurer. These hypotheses prove nonessential. In Section 3, I extend the analysis to bilateral accidents, in which victims can take precautions that reduce the likelihood of harm. In this case, the comparison is carried out between negligence and strict liability with the added condition of the affirmative defense of contributory negligence. The main result holds true.

When parties can purchase insurance from an uncertainty-averse insurance company, a similar logic applies (see Section 4). Indeed, if care levels can be included in the insurance contract (e.g., in the form of loss control provisions) the result remains unchanged. Given that the optimal insurance contract includes a deductible, some uncertainty falls on the insured party. Hence, the ability of the parties to bear the risk of uncertainty remains central to liability design. If insurers cannot observe levels of care, the negligence rule is preferable when harms are correlated. Strict liability is preferable

[12]With minor qualifications, this insight extends beyond the mean-variance approach (see Appendix A5).

only under stronger, sufficient conditions (see Appendix A4).

Finally, Section 5 shows how the results translate, with few changes, to the situation in which injurer and victims come into contact through the market, as with products liability. Here, improvements in the uncertainty allocation affect the quantity of product sold. This variation, however, can only be for the better, for if the uncertainty allocation improves, the quantity sold will increase, to the benefit of both the manufacturers and the consumers. Thus, the main result applies yet again: negligence is preferable when harms are correlated and the number of products sold is high. If consumers have widely ranging beliefs about the safety of the product (while the manufacturer does not) and harms are not correlated, strict liability is likely to be preferable. The insurance provided by the producer allows the consumers to overcome their reluctance to purchase the good.

It is remarkable how current products liability law resonates with the optimal features outlined above. Manufacturing defects, arising when the product departs from its intended design due to a random failure in the production or distribution line, tend to generate uncorrelated harms. They are generally subject to strict liability. Design defects, occurring when the intended design of the product line is itself unreasonably dangerous, and warning failures, occurring when a product becomes unreasonably dangerous because adequate instructions and warnings are not provided, tend to generate highly correlated harms.[13] Both in the US and the EU (as well as Japan), they are subject to a de-facto negligence regime (see Owen (2008), Howells and Owen (2010)).

Literature. The relative performance of strict liability vis-a-vis negligence has long been debated. Under uncertainty-neutrality, both rules can provide parties with an incentive to adopt an efficient level of care. The comparison between strict liability and negligence must then account for additional factors, such as activity levels, judicial errors, judgment-proofness, and litigation expenditure.[14] If the assumption of uncertainty neutrality is dropped, the disposition of the parties towards uncertainty becomes

[13]This point is noted by Viscusi (2000), who underlines the difficulties encountered by insurance companies in dealing with correlated risks.

[14]See Shavell (2007), Schaefer and Mueller-Langer (2009), and references therein.

paramount and the two liability rules are no longer equivalent.

In his classic analysis of liability design under risk aversion, Shavell (1982) demonstrates that when parties are risk-averse neither liability rule is efficient. Strict liability is preferable when the injurer is risk-neutral and the victim risk-averse; negligence is preferable in the opposite case.[15] Beyond these polar cases, no further conclusion can be reached because attitudes towards risk themselves depend on the liability rule adopted. Another important result, found in Shavell (1982), is that optimal damages under strict liability are under-compensatory. This result derives from the basic insight of Mossin (1968) that a minimal amount of self-insurance is optimal when insurance premia include a loading factor (i.e., when they are not actuarially fair). This result holds in my (smooth) uncertainty model, but it does not hold when the beliefs of the parties are biased (see Appendix A6). To my knowledge, I am the first to formally include a measure of correlation in liability design.

Criticism of EU theory has become prominent over the last 30 years. Large amounts of evidence have been collected to identify its major drawbacks (see Wakker (2010)). Among the many non-Expected Utility theories, two main strands have emerged. The first builds on the concept of ambiguity aversion, thus addressing the classic Ellsberg paradox; the other (Rank Dependent Expected Utility and Prospect theory) assumes that preferences are not linear in probabilities, thus addressing the Allais paradox. The liability model of Teitelbaum (2007), discussed in the Appendix, is formally equivalent to RDEU theory, and as such, it provides an important insight on non-EU approaches.[16] The present analysis departs from Teitelbaum (2007) in several important respects. First, I allow for both risk and ambiguity aversion. Second, and more importantly, ambiguity aversion is taken as a *rational* response to probabilistic uncertainty, rather

[15]Other investigations of optimal liability design under risk aversion include Greenwood and Ingene (1978), deriving optimal risk sharing rules using a local approach, and Graff Zivin and Small (2003), dealing with bilateral accidents with side payments under CRRA utilities. Nell and Richter (2003) address the case of perfectly correlated risks under CARA utilities. They prove that negligence is approximately efficient when the number of victims goes to infinity, if care is constrained above. Without restricting care, I identify the condition for the superiority of negligence both for unilateral and bilateral accidents, also for the case in which the number of victims and total harm are finite. Langlais (2010) investigates optimal risk allocation for perfectly correlated harms under RDEU.

[16]Chakravarty and Kelsey (2012) extend Teitelbaum (2007) to bilateral accidents, and focuses on the case in which care reduces the level of harm (rather than its probability).

than a cognitive bias. As originally noted by Ellsberg (1961), ambiguity aversion is not a mistake that agents would be willing to correct once noted. Instead, ambiguity aversion is the manifestation of rational doubt about the reliability of subjective beliefs (the probability estimates).[17] If one takes this approach and includes ambiguity costs in welfare evaluations, then the relevant question becomes not how to force people to behave *as if* they were ambiguity-neutral but rather how to allocate the loss when people have to bear the cost of uncertainty.[18]

1 Uncertainty aversion

Let us consider the case in which an injurer (I) can cause an accident affecting n identical victims (V). Assume first that the probability of accident is $\pi(x)$, where x is the level of care taken by the injurer, and where $\pi(x)$ is common knowledge. In case of accident, each victim bears a monetary loss ℓ.

The expected utility of the victim, given the probability of accident $\pi(x)$, is

$$EU_{\pi(x)} = (1-\pi(x))\,u(i_V) + \pi(x)\,u(i_V - \ell),$$

where i_V is the income of the victim.[19]

For small losses, the certainty equivalent $c_{\pi(x)}$ of the accident prospect (such that $u\left(c_{\pi(x)}\right) = EU_{\pi(x)}$) can be written as:

$$c_{\pi(x)} \simeq i - \pi(x)\,\ell - \tfrac{1}{2}\rho_V\ \sigma^2_{\pi(x)}\ell^2, \tag{1}$$

where $\pi(x)\,\ell$ is the expected loss, $\sigma^2_{\pi(x)} = \pi(x)(1-\pi(x))$ the variance of the unit loss, and ρ_V the Arrow-Pratt degree of absolute risk aversion of the victim.

[17]See the convincing arguments of Gilboa and Marinacci (2013), and references therein.

[18]My approach to efficiency has two important positive collateral advantages. First, it is immune to Coasian bargaining: agents are not interested in modifying the efficient outcome by direct negotiations or other market arrangements. Second, the enforcement of efficient rules does not depend on unbiased, technocratic courts. This non-paternalistic approach is also taken by the theoretical literature on efficient ambiguity sharing. See, for instance, Strzalecki and Werner (2011) and literature cited therein.

[19]The loss reduces the victim's wealth. In theory, it can be perfectly compensated.

Suppose now that the probability of accident is uncertain: the victim formulates beliefs about $\pi(x)$. Let μ_V be the probability distribution over beliefs $\pi(x)$. The variance of the beliefs, $\sigma^2_{\mu_V}(\pi(x))$, captures the degree of ambiguity of the risk environment: the more dispersed the beliefs, and the higher the ambiguity.[20]

Under Expected Utility theory, the distribution of the beliefs is irrelevant: the only thing that matters is the mean probability of accident: $p(x) = E_\mu(\pi(x))$. This corresponds to the case of an ambiguity-neutral agent. Ambiguity-averse agents, instead, tends to dislike choice environments where probabilities are not known for sure (they are averse to mean preserving spreads of the beliefs). Instead of maximizing the simple mean of the Expected Utilities associated to the different beliefs, they maximize the mean of a concave transformation of the expected utilities.

A second order approximation of this transformation function yields a mean-variance model (see Appendix A1), in which the certainty equivalent for the victim can be written as

$$C_V(x) = i_V - p(x)\ell - UP_V(x), \tag{2}$$

where i_V is the income of the victim, $p(x)\ell$ the expected loss, and $UP_V(x)$ the uncertainty premium, where

$$\underbrace{UP_V(x)}_{\text{uncertainty premium}} = \underbrace{\tfrac{1}{2}\rho_V\ \sigma^2_{p(x)}\ \ell^2}_{\text{risk premium}} + \underbrace{\tfrac{1}{2}\theta_V\ \sigma^2_{\mu_V}(\pi(x))\ \ell^2}_{\text{ambiguity premium}} \equiv \tfrac{1}{2}\Psi_V(x)\ell^2. \tag{3}$$

The uncertainty premium is equal to the sum of the risk and ambiguity premia. The **risk premium** is one half of the degree of risk aversion ρ_V times the variance generated by the mean probability of accident times the square of the loss. The **ambiguity premium** is one half of the agent's degree of ambiguity aversion θ_V times the variance of the prior beliefs times the square of the loss. The uncertainty index: $\Psi_V(x) = \rho_V\ \sigma^2_{p(x)} + \theta_V\ \sigma^2_{\mu_V}(\pi(x))$ is thus a local measure of the costs of risk and ambiguity for the victim. Note that the uncertainty premium smoothly converges to zero as the loss

[20]Beliefs can be interpreted as "expert opinions," to which parties assign some level of plausibility. Conflicting opinions create costly uncertainty, as documented, among others, by Viscusi (1997), Viscusi (1999) and Cabantous et al. (2011).

goes to zero (henceforth the name "smooth model").

In the following, I will assume that victims (and injurer) are neither risk nor ambiguity lovers: $\rho_V \geq 0$, $\theta_V \geq 0$.[21] Results can be easily adapted to the opposite case.

Before turning to the calculation of the uncertainty index of the injurer, I need to make some assumptions on the structure of the beliefs. The injurer and the victims can have different priors about the (marginal) probability of accidents $\pi_j(x)$ affecting victim j . I assume, however, that these priors share the same mean $p(x)$. In this sense, the accident is a "foreseeable" risk.

Assumption 1 *Foreseeability. For all levels of care $x \geq 0$ and all victims $j \in \{1, 2, ..., n\}$, the beliefs of the injurer and the victims are correct on average: $E_{\mu_I}(\pi_j(x)) = E_{\mu_V}(\pi_j(x)) \equiv p(x)$.*

When parties consider a precautionary measure, they agree on the impact of this measure on the mean probability of accident (for any victim j). Beliefs, however, can be characterized by different levels of ambiguity (measured by the variance of the prior). As the ambiguity drops to zero, the model converges to the standard EU model, in which $p(x)$ is regarded as the "true" accident probability.[22]

Care is assumed to reduce the mean probability of harm at a decreasing rate. To better disentangle the effect of risk aversion, I further assume that the mean probability of harm is not too large.

Assumption 2 *For any level of care: $p(x) \leq 1/2$, $p'(x) < 0$, and $p''(x) > 0$.*

For any victim j, the variance of the unit loss generated by the mean probability of harm is $\sigma^2_{p(x)} = p(x)(1 - p(x))$. This variance decreases with x if Assumption 2 is

[21] From auto collision insurance choices of households, the following baseline estimates of the absolute risk aversion index have been optained: $\rho \in [0.002, 0.008]$ (Barseghyan et al. (2013)), $\rho \simeq 0.0067$ (Cohen and Einav (2007)), and $\rho \in [0.002, 0.0053]$ (Sydnor (2010)). Conte and Hey (2013) and Attanasi et al. (2014) provide experimental estimates of the smooth model.

[22] To rationalize: when the evidence on harm is scarce or is conflicting, beliefs will be characterized by ambiguity. Here, $p(x)$ is just the mean belief. As the evidence accumulates, ambiguity disappears and $p(x)$ emerges as the "objective" probability of harm, known to all parties.

met.[23]

The certainty equivalent for the injurer, assuming that she bears a loss ℓ for any victim affected, is more complex, since losses can be correlated. For simplicity, the correlation across harms is assumed to be fixed and to be independent of the level of care x. For any belief and any couple of victims j and k, the correlation between accidents is equal to $\varrho \in [0,1]$. If $\varrho = 0$, harms are uncorrelated, as in the case of harms caused by non-systematic manufacturing defects (due to incorrect assembly, damage or contamination in the production process). If $\varrho = 1$, harms are perfectly correlated, as in the case of design defects and warning failures affecting the entire product line.[24]

The correlation index ϱ affects both the variance of the mean probability of loss for the injurer and the variance of her beliefs. The certainty equivalent for the injurer can be written as (see Appendix A1):

$$C_I(x) = i_I - x - p(x)\, n\ell - \tfrac{1}{2} n \left[1 + (n-1)\varrho\right] \Psi_I(x)\, \ell^2,$$

where $\Psi_I(x)$ it the uncertainty index of the injurer: $\Psi_I(x) = \rho_I\ \sigma^2_{p(x)} + \theta_I\ \sigma^2_{\mu_I}(\pi_j(x))$. Again, the uncertainty index includes a risk aversion component (index of risk aversion ρ_I times the variance of the mean probability of harm) and an ambiguity aversion component (index of ambiguity aversion θ_I times the variance of the marginal beliefs).

If harms are uncorrelated: $C_I(x) = i_I - x - n\ p(x)\,\ell - \frac{1}{2} n\ \Psi_I(x)\ \ell^2$. For each potential victim, the injurer bears an expected loss equal to $p(x)\,\ell$ and an uncertainty premium equal to $\frac{1}{2}\Psi_I(x)\,\ell^2$.

If harms are perfectly correlated: $C_I(x) = i_I - x - p(x)\ n\ell - \frac{1}{2}\Psi_I(x)\ (n\ell)^2$. When an accident occurs, all n victims are involved. The injurer is thus subject to the prospect of losing an amount equal to $n\ell$ with a mean probability $p(x)$.[25]

[23] Assumption 2 is stronger than necessary. What I really need is that the mean probability of harm is not greater than 1/2 *in equilibrium*. Conducts yielding an equilibrium probability of harm greater than 1/2 would probably qualify as reckless and wanton. They lie outside the scope of this paper.

[24] Negatively correlated accidents are not studied here. To address this case, one should consider dependency relationships of hierarchical nature (correlation across subgroups of accidents).

[25] This paper does not deal with legal development risk, i.e. the risk tied to changes in the law, like a Supreme Court's decision about eligibility of claims See Baker and Siegelman (2013) and Shavell (2014). Legal development risk would introduce correlation across claims even when harms are not

2 Optimal liability design

2.1 Strict liability

Under strict liability, the injurer pays compensation to the victims irrespective of the amount x invested in precaution. Courts can affect the injurer's behavior and the allocation of uncertainty by means of the damages awarded d. Damages can fully compensate the victims ($d = h$), they can overcompensate them, e.g., by including a punitive component, or they can under-compensate them, e.g., when caps are imposed or when some types of harm are deliberately excluded (e.g., pain and suffering).

Here and below, efficiency is achieved when total surplus - the sum of the certainty equivalents - is maximal.[26] In turn, maximization of total surplus is equivalent to the minimization of social loss:

$$L^S(d) = \quad x_0 + n\ p(x_0)\, h + \tfrac{1}{2}n\left[1 + (n-1)\varrho\right]\ \Psi_I(x_0)\ d^2 + n\tfrac{1}{2}\Psi_V(x_0)(h-d)^2, \quad (4)$$

where x_0 is chosen by the injurer so as to maximize her welfare level. In particular, the injurer will set x_0 so that

$$1 = -n\ p'(x_0)\, d - \tfrac{1}{2}n\left[1 + (n-1)\varrho\right]\Psi_I'(x_0)\, d^2 : \quad (5)$$

an additional dollar spent in precaution reduces her expected liability and her uncertainty premium by one dollar.

We have:

$$\Psi_I'(x) = \rho_I \frac{d\sigma^2_{p(x)}}{dx} + \theta_I \frac{d\sigma^2_{\mu_I}(\pi_j(x))}{dx} = \rho_I p'(x)\left(1 - 2p(x)\right) + \theta_I \frac{\partial \sigma^2_{\mu_I}(\pi_j(x))}{\partial x}, \quad (6)$$

an increase in care reduces the variance of the mean probability of harm $p(x)$ (thanks to Assumption 2) and affects the level of ambiguity borne by the agents. If care does

themselves correlated.

[26]Since the certainty equivalents are monotone transformations of the welfare levels of the parties $\left[C_I(x) = v_I^{-1}(W_I),\ \text{etc.}\right]$, the maximization of their sum yields an ex-ante Pareto efficient outcome. Because certainty equivalents are independent of income, the efficient outcome is unique (up to direct income transfers).

not increase the variance of the priors, $\frac{\partial \sigma^2_{\mu_I}(\pi_j(x))}{\partial x} \leq 0$, then: $\Psi'_I(x) < 0$. From (6) and (5), we get that incentives to take care increase with the index of risk aversion ρ_I, while they increase with the index of ambiguity aversion θ_I if, and only if, $\frac{\partial \sigma^2_{\mu_I}(\pi_j(x))}{\partial x} < 0$. Care increases with damages d if, and only if, the following condition holds:

$$p'(x_0) + [1 + (n-1)\varrho] \ \Psi'_I(x_0)\, d < 0. \tag{7}$$

Condition (7) posits that an increase in the level of care reduces the "cost of accidents" for the injurer, which includes the expected liability and the uncertainty premium.[27] In what follows, I will assume that condition (7) is met. This condition is surely met when care does not increase ambiguity: $\frac{\partial \sigma^2_{\mu_I}(\pi_j(x))}{\partial x} \leq 0$.

By differentiation of (4), using (5), we get:

$$\begin{aligned} L^{S\,\prime}(d) = \ & \frac{\partial x_0}{\partial d} n \left[p'(x_0)(h-d) + \tfrac{1}{2}\Psi'_V(x_0)\ (h-d)^2 \right] \\ & + n[1 + (n-1)\varrho]\ \Psi_I(x_0)\ d - n\Psi_V(x_0)\ (h-d). \end{aligned} \tag{8}$$

An increase in damages has two effects: i) it provides the injurer with additional incentives to take care and hence to reduce the "externality" she exerts on the victims (uncompensated harm and the attendant uncertainty premia), and ii) it shifts the uncertainty burden from the victims to the injurer.[28]

By implicit differentiation of (8), we get: $\frac{\partial d^*}{\partial \rho_V} > 0$. Furthermore, if $\frac{\partial \sigma^2_{\mu_V}(x_0)}{\partial x} \leq 0$, then $\frac{\partial d^*}{\partial \theta_V} > 0$.

Note that for $d = h$, the "externality" effect vanishes and marginal social loss collapses to

$$L^{S\prime}(h) = n[1 + (n-1)\varrho]\ \Psi_I(x_0)\ h \geq 0.$$

With fully compensatory damages $(d = h)$, incentives to take care would be appropri-

[27]This condition might not be met when investment in prevention substantially increases the dispersion of the prior beliefs, the injurer is highly averse to ambiguity and weakly averse to risk.

[28]An increase in damages increases both the extent of insurance and protection of the victims. It has been shown that both risk and smooth ambiguity aversion increase the self-insurance expenditure (Dionne and Eeckhoudt (1985), Snow (2011) and Alary et al. (2013)). The impact of risk and ambiguity aversion on self-protection, instead, is generally not univocal (see footnote 32).

ately set, since the injurer fully internalizes the consequences of her actions. However, the uncertainty would not be optimally allocated, since all of the burden would be placed on the injurer. If the injurer is not uncertainty neutral (i.e., if $\Psi_I(x_0) > 0$), the allocation of uncertainty can be improved at the margin - with a negligible effect on the welfare of the victims - by reducing damages and shifting some of the uncertainty on the victims. The benefit for the injurer is of the first order, the cost for the victims of the second order.

Proposition 1 *Strict liability. If the injurer is not uncertainty neutral, damages should be less than fully compensatory: $d^* < h$. Optimal damages increase with the index of risk aversion of the victims, while they increase with their index of ambiguity aversion if care reduces the variance of their priors.*

Under strict liability, courts control the level of the damages awarded. Using this tool, they should try and achieve two goals: i) provide incentives to take care, and ii) allocate the uncertainty burden. The first goal would be accomplished if damages were set equal to harm. This outcome, however, is not optimal in terms of uncertainty allocation, unless the injurer is uncertainty neutral. Thus, damages should leave a share of the loss on the victims.[29]

2.2 Negligence

Under a negligence rule, the injurer pays compensatory damages $d = h$ only if she does not meet the due standard of care $\bar{x}$. Care is assumed to be verifiable in court. Unless the standard is prohibitively high, the injurer will prefer to meet it and avoid liability.

[29] In this model, the Injurer cannot escape responsibility. Thus, the standard rationale for punitive damages does not apply.

I will thus assume that $x = \bar{x}$.[30] The optimal standard should be set so as to minimize

$$L^N(\bar{x}) = \bar{x} + np(\bar{x})\,h + n\tfrac{1}{2}\Psi_V(\bar{x})\;h^2. \tag{9}$$

All the uncertainty is borne by the victims.

The optimal standard $\bar{x}$ should solve:

$$1 = -n\;p'(\bar{x})\,h + n\tfrac{1}{2}\;\Psi'_V(\bar{x})\;h^2 : \tag{10}$$

an additional dollar spent on precaution should reduce expected harm and the uncertainty premia of the victims by one dollar. From (6) (adapted to the victim) and Assumption 2, by implicit differentiation, we get: $\frac{\partial \bar{x}}{\partial \rho_V} > 0$; while $\frac{\partial \bar{x}}{\partial h} > 0$ if, and only if: $p'(\bar{x}) + \Psi'_V(\bar{x})\,h < 0$. Furthermore, $\frac{\partial \bar{x}}{\partial \theta_V} > 0$ if, and only if: $\frac{\partial \sigma^2_{\mu_V}(\pi_j(\bar{x}))}{\partial x} < 0$. Hence, the following.

Proposition 2 *The optimal standard of care increases with the degree of risk aversion of the victims. It increases with the degree of ambiguity aversion of the victims if, and only if, care reduces the variance of their priors.*

The latter result identifies the condition under which ambiguity supports a cautionary approach to liability law*:* uncertainty about the probability of harm calls for a tighter safety standard if, and only if, care reduces the variance of the prior beliefs of the victims. While ambiguity surely increases their uncertainty premia, one cannot say a priori whether it calls for greater prevention effort.[31] The standard for newly devel-

[30]The injurer prefers to be negligent only if $\bar{x} > x^* + np(x^*)\,h + \frac{1}{2}n\,[1 + (n-1)\,\varrho]\;\Psi_I(x^*)\,h^2$, where x^* maximises injurer's welfare when she is liable. If that is the case, however, then $\bar{x} + np(\bar{x})\,h + \frac{1}{2}n\Psi_V(\bar{x})\,h^2 > x^* + np(x^*)\,h + \frac{1}{2}n\,[1 + (n-1)\,\varrho]\;\Psi_I(x^*)\,h^2$, and the lawmaker itself would definitely prefer that the injurer did not meet the standard. The results of the paper also hold if damages (paid by the negligent injurer) differ from harm. However, damages cannot be too low, as otherwise the injurer prefers not to meet the standard and strict liability de facto applies.

[31]Snow (2011) proves that if beliefs take a multiplicative shape: $\pi(x) = p(x)(1 + \varepsilon)$, where ε is an independent random variable with zero mean, then the investment in self-protection of an agent increases with her degree of (smooth) ambiguity aversion. In the liability set-up, this implies that the optimal standard increases with the degree of ambiguity aversion of the victims (even for non-small harms). Alary et al. (2013) consider instead the case in which beliefs become more dispersed as the

oped technologies should be tighter only if additional care makes victims less uncertain about the probability of harm.

In some cases, the use of new prevention technologies might increase the uncertainty instead of reducing it (as in the case of a novel treatment for a well-know disease that has never been tested before, as suggested by Alary et al. (2013)). Ambiguity aversion militates against the use of these uncertainty-laden technologies.

2.3 Strict liability vs. negligence

Both negligence and strict liability provide second best solutions to the concomitant problems of optimal uncertainty allocation and harm prevention. Which rule is preferable? Under negligence, the uncertainty is fully placed on the victims and the standard of care is (optimally) set by the courts. Under strict liability, uncertainty is shared at the optimum, and the level of care is chosen by the injurer.

To compare strict lability and negligence, let us start from the special case in which damages are equal to harm: $d = h$. Here, constrained social loss amounts to:

$$\widehat{L}^{SL}(x^c) = x^c + np(x^c)\,h + \tfrac{1}{2}n\,[1+(n-1)\,\varrho]\;\;\Psi_I(x^c)\;\;h^2, \tag{11}$$

where x^c is the level of care chosen by the injurer (eq. 5).

For any given level of care x, constrained strict liability (11) yields a lower ex-post social loss than negligence (eq. 9) if, and only if:

$$\begin{aligned}\widehat{L}^{SL}(x) < L^N(x) &\Leftrightarrow \tfrac{1}{2}n\,[1+(n-1)\,\varrho]\,\Psi_I(x)\;\;h^2 < n\tfrac{1}{2}\Psi_V(x)\;\;h^2 \\ &\Leftrightarrow \Psi_I(x) < \frac{1}{[1+(n-1)\,\varrho]}\Psi_V(x)\,. \end{aligned}\tag{12}$$

Given x, a rule placing the whole loss on the injurer is preferable to a rule placing it entirely on the victims if, and only if, the index of uncertainty aversion of the injurer is less than that of the victims divided by $[1+(n-1)\,\varrho]$. The latter factor accounts for the correlation across harms (making loss spreading relatively preferable).

self-protection effort increases [e.g. $\pi(x) = p(x) + \varepsilon(1-p(x))$]. In this case, ambiguity aversion decreases the self-protection effort. My model is consistent with both insights.

The following sharp conditions point to the best uncertainty bearers:

$$\begin{aligned} &\textit{Condition } I\text{: for all } x,\ \Psi_I(x) < \tfrac{1}{[1+(n-1)\varrho]}\Psi_V(x), \\ &\textit{Condition } V\text{: for all } x,\ \Psi_I(x) > \tfrac{1}{[1+(n-1)\varrho]}\Psi_V(x). \end{aligned}$$

Under Condition *I,* for all levels of care, the injurer is the best uncertainty bearer. This Condition is met when harms are uncorrelated and the injurer is less averse to risk and/or to ambiguity than the victims. Condition V applies, instead, when harms are correlated and victims are numerous.

Let us suppose that Condition I holds. Given the optimal level of care under negligence x^n, in view of eq. (12), strict liability with compensatory damages is preferable to negligence: $\widehat{L}^{SL}(x^n) < L^N(x^n)$. Social loss is even lower, under constrained strict liability, if the injurer is free to chose the level of care x^c that maximizes her welfare (the welfare level of the victims is not affected): $\widehat{L}^{SL}(x^c) \leq \widehat{L}^{SL}(x^n)$. Social loss further decreases if damages are optimally set: $L^{SL}(x_0) < \widehat{L}^{SL}(x^c)$, where x_0 is the level of care taken by the injurer when $d = d^* < h$. Thus, if Condition I holds, strict liability dominates negligence.

Let us suppose now that Condition V holds. Given the level of care x^c chosen by the injurer under strict liability with compensatory damages, negligence entails a lower social loss: $L^N(x^c) < \widehat{L}^{SL}(x^c)$. Social loss further decreases, under negligence, if the level of care is optimally chosen by the courts: $L^N(x^n) \leq L^N(x^c)$. We have thus proved the following:

Proposition 3 ***Strict liability vs. negligence.***

i) if Condition I holds, strict liability dominates negligence when damages are fully compensatory $(d = h)$. *Strict liability dominates a fortiori if damages are optimally set by the courts.*

ii) If Condition V holds, negligence dominates strict liability when damages are fully compensatory $(d = h)$.

Proposition 3 exploits the symmetry between strict liability and negligence when damages are fully compensatory: both rules place all uncertainty on one side. Thus, the comparison between the two rules can be carried out by testing the ability of the loss bearing party to tolerate risk and ambiguity.[32]

If Condition I holds, the injurer is the best uncertainty bearer because harms are weakly correlated and she is less averse to risk and/or to ambiguity (i.e., she has a lower degree of ambiguity aversion or her beliefs are less dispersed). Strict liability with either compensatory or optimal damages dominates negligence.

If Condition V applies, the victims are the best uncertainty bearers. Negligence dominates strict liability when damages are compensatory, but not necessarily when damages are optimally set. In the latter case, dominance can only be obtained under stronger conditions.

From (9) and (4), one can see that

$$L^N(x^s) < L^S(x^s) \Leftrightarrow \Psi_V(x^s)\,h^2 < [1+(n-1)\varrho]\,\Psi_I(x^s)\,d^{*2} + \Psi_V(x^s)\,(h-d^*)^2,$$

where x^s is the care level chosen by the injurer under strict liability, which simplifies to

$$L^N(x^s) < L^S(x^s) \Leftrightarrow \frac{d^*}{h} > 2\,\frac{\Psi_V(x^s)}{\Psi_V(x^s) + [1+(n-1)\varrho]\,\Psi_I(x^s)}. \tag{13}$$

Since $d^* < h$, inequality (13) can be met only if $\Psi_V(x^s) < [1+(n-1)\varrho]\,\Psi_I(x^s)$.

Note that $\frac{\Psi_V(x^s)}{\Psi_V(x^s)+[1+(n-1)\varrho]\Psi_I(x^s)}$ converges to zero if $\Psi_V(x^s)$ becomes small or if n becomes large (when $\varrho > 0$), while optimal damages d^* do not (see Appendix A2). Thus, inequality (13) is met if ρ_V and θ_V are both sufficiently small, and/or n is large. If that is the case, then

$$L^N(x^n) \leq L^N(x^s) < L^S(x^s),$$

where x^n is the optimal level of care chosen by the courts: negligence dominates strict liability.

Proposition 4 *When damages are optimally set by the courts, negligence dominates*

[32] If $\sigma^2_{\mu_V}(\pi_j(x))$ and $\sigma^2_{\mu_I}(\pi_j(x))$ are affected in different ways by x, one can have situations in which neither Condition I nor V hold (victims might be the best uncertainty bearers for some levels of x, but not for others). Note, however, that dominance of strict liability only requires: $\Psi_I(x^n) < \frac{1}{[1+(n-1)\varrho]}\Psi_V(x^n)$. Dominance of negligence only requires: $\Psi_I(x_0) > \frac{1}{[1+(n-1)\varrho]}\Psi_V(x_0)$.

strict liability if the victims of correlated harms are numerous and/or the victims are weakly averse to uncertainty.

Also for this Proposition, note that the condition used is sufficient but not necessary.

If harms are not correlated, each accident can be treated as a separate case. Here, strict liability is marginally superior as it allows uncertainty to be spread between the injurer and each victim (while retaining incentives to take care). When victims are numerous and harms are correlated, negligence appears to be the superior liability rule. It provides incentives to take care while spreading the loss at the same time. Strict liability, in theory, could also serve a similar uncertainty-spreading function, on the condition that damages are very low. The incentives to take care, however, would be lost.

3 Bilateral accidents

Under many circumstances victims can take measures to reduce the incidence of harm. In this section, I focus on the case in which each victim can affect his likelihood of suffering harm. For instance, by wearing protective cloths, an individual can reduce the risk of burn injuries. Care decisions of individual victims can affect the correlation coefficient. For simplicity, I assume that when all victims take the same level of care, the correlation coefficient is equal to the constant ρ.

I concentrate on two liability rules: simple negligence and strict liability with the defence of contributory negligence. The latter defence is necessary to provide victims with incentives to take care (see Shavell (2007)).

In Appendix A3, I show that the analysis of Section 2 carries over to the bilateral setup. Both liability rules are able to provide incentives to take care. Under strict liability with contributory negligence, the injurer selects care so as to minimize the difference between his liability burden and the cost of care; victims take care so as to avoid liability. Optimal damages are under-compensatory. Under negligence, the injurers meets the standard of care; victims select care so as to minimize the difference between the burden of harm and the cost of care. The optimal standard of care for the injurer increases with the degree of risk aversion of the victims, while it increases with their degree of ambiguity aversion if care (of both sides) reduces the variance of the prior of the victims (on the assumption that cross-effects do not go in the opposite direction or that they are small enough). In the comparison between strict liability and negligence, **Propositions 3 and 4 apply**.

4 Insurance

Insurance against liability claims for bodily injury and property damage arising out of premises, operations, products, and completed operations is usually available to business organizations, under so called CGL policy.[33] Insurance often comes together with "loss control" provisions, aimed at reducing liability risk (Baker and Siegelman (2013)). In what follows, I extend the model to the case in which a third party can provide insurance to the parties. This third party can be an insurance company or any contractually related party (with sufficiently deep pockets). The insurer is assumed to be uncertainty averse.[34] His beliefs are correct on average. Under strict liability (third-party) insurance is purchased by the injurer. The insurer can observe the level of care taken by the injurer. Under negligence, (first-party) insurance is purchased by the victims.

Let us start with the case where liability is strict. The insurance contract specifies the premium paid by the injurer, w_I, the level of care to be taken by the injurer x_I, and the deductible t_I. The certainty equivalent of the insurer (S) is

$$C_S\left(x_I\right) = w_I - np\left(x_I\right)\left(d - t_I\right) - \tfrac{1}{2}n\left[1 + \left(n-1\right)\varrho\right]\Psi_s\left(x_I\right)\left(d - t_I\right)^2, \qquad (14)$$

where $\Psi_s\left(x_I\right) \geq 0$ is the uncertainty index of the insurer. Clearly, the more correlated

[33]Correlation across harms has long been considered an argument against strict liability, because it can make liability insurance hard to get. See Epstein (1985), Geistfeld (2009) and Hylton (2013).

[34]The reasons why insurance companies behave like risk averse agents are reviewed by Baker and Siegelman (2013). Kunreuther et al. (1995) documents significant ambiguity aversion by insurers, and advances several hypotheses as to why ambiguity-averse insurers survive in a competitive market. The actuarial literature refers to ambiguity as "parameter uncertainty."

the claims and the greater the uncertainty cost for the insurer.

The certainty equivalents of injurer and victims are, respectively:

$$C_I(x_I) = i_I - x_I - w - np(x_I)\, t_I - \tfrac{1}{2} n \left[1 + (n-1)\varrho\right] \; \Psi_I(x_I) \; d_I^2, \tag{15}$$
$$C_V(x_I) = i_V - p(x_I)(h-d) - \tfrac{1}{2} \Psi_V(x_I)(h-d)^2. \tag{16}$$

The insurer and the injurer will choose the deductible and the level of care x_I that maximize their joint surplus: $JS_{IS}(x_I) = C_I(x_I) + C_S(x_I)$. Thus,

$$\frac{\partial C_I(x_I)}{\partial x} + \frac{\partial C_S(x_I)}{\partial x} = 0, \tag{17}$$
$$\frac{\partial C_I(x_I)}{\partial t_I} + \frac{\partial C_S(x_I)}{\partial t_I} = 0. \tag{18}$$

From eq. (18), we get the optimal deductible: $t_I = \frac{\Psi_S(x_I)}{\Psi_S(x_I)+\Psi_I(x_I)} d$.
Optimal damages are obtained from the maximization of social welfare:

$$SW = JS_{IS}(x_I) + nC_V(x_I),$$

where x_I meets (17). Thus, optimal damages should meet:

$$\frac{\partial SW}{\partial d} = \frac{\partial JS_{IS}(x_I)}{\partial d} + n\frac{\partial C_V(x_I)}{\partial d} + \frac{\partial JS_{IS}(x_I)}{\partial x_I}\frac{\partial x_I}{\partial d} + n\frac{\partial C_V(x_I)}{\partial x_I}\frac{\partial x_I}{\partial d} =$$
$$= \frac{\partial C_S(x_I)}{\partial d} + n\frac{\partial C_V(x_I)}{\partial d} + n\frac{\partial C_V(x_I)}{\partial x_I}\frac{\partial x_I}{\partial d} = 0.$$

For $d = h$, we have $\frac{\partial C_V(x_I)}{\partial x_I} = \frac{\partial C_V(x_I)}{\partial d} = 0$, and $\left.\frac{\partial SW}{\partial d}\right|_{d=h} = \frac{\partial C_S(x_I)}{\partial d} < 0$. If the insurer (and the injurer) are not uncertainty neutral, damages should be less than fully compensatory: $d^* < h$. If care reduces the variance of the priors, optimal damages increase with ρ_V and θ_V, and they decrease with ρ_S and θ_S.

Under *negligence*, the injurer bears no liability (assuming that she meets the standard of care $\bar{x}$). If harm occurs, the insured victims bear the deductible t_V, and the insurer: $h - d_V$. The deductible optimally shares uncertainty between the insurer and the victims:

$$t_V = \frac{[1+(n-1)\varrho]\,\Psi_S(\bar{x})}{[1+(n-1)\varrho]\,\Psi_S(\bar{x})+\Psi_V(\bar{x})}h.$$

Higher correlation across harms calls for a larger deductible.

The standard of care x^n is optimally chosen by the courts so as to maximize social welfare: $SW^N(\bar{x}) = C_I(\bar{x}) + C_S(\bar{x}) + nC_V(\bar{x})$, or equivalently, to minimize social loss:

$$L^N(\bar{x}) = \bar{x} + np(\bar{x})\,h + \tfrac{1}{2}n\,[1+(n-1)\varrho]\,\Psi_S(\bar{x})\,(h-t_V)^2 + \tfrac{1}{2}n\Psi_V(\bar{x})\,t_V^2.$$

Let us compare strict liability and negligence. Given the optimal standard of care under negligence x^n, strict liability with fully compensatory damages dominates negligence if, and only if,

$$\begin{aligned}\widehat{L}^{SL}(x^n) < L^N(x^n) \Leftrightarrow n\,[1+(n-1)\varrho]\left[\Psi_I(x^n)\,t_I^2 + \Psi_S(x^n)\,(h-t_I)^2\right] <\\ n\,[1+(n-1)\varrho]\,\Psi_S(x^n)\,(h-t_V)^2 + n\Psi_V(x^n)\,t_V^2.\end{aligned} \tag{19}$$

Let us artificially fix $t_I = t_V$ (that is, the deductible chosen by the injurer under strict liability is equal to the deductible chosen by the victims under negligence). If that is the case, from (19), strict liability with compensatory damages dominates negligence if, and only if, $\Psi_I(x^n) < \frac{1}{n[1+(n-1)\varrho]}\Psi_V(x^n)$, that is, if and only if, Condition I holds. If the injurer and the insurer can freely chose the deductible t_I and the level of care x_I, their welfare level further increases, while the welfare level of the victims is not affected (since $d = h$). Social loss under strict liability goes down. A fortiori, if damages are optimally set by the courts, social loss further decreases. To sum up, *if Condition I holds, unconstrained strict liability strictly dominates negligence.*

Vice versa, negligence dominates strict liability with compensatory damages if

$$\begin{aligned}L^N(x^c) < \widehat{L}^{SL}(x^c) \Leftrightarrow n\,[1+(n-1)\varrho]\,\Psi_S(x^c)\,(h-t_V)^2 + \Psi_V(x^c)\,t_V^2\\ < n\,[1+(n-1)\varrho]\left[\Psi_I(x^c)\,t_I^2 + \Psi_S(x^c)\,(h-t_I)^2\right],\end{aligned}$$

where x^c is the level of care chosen by the injurer and the insurer when damages are perfectly compensatory. If we fix $t_V = t_I$, we get $L^N(x^c) < \widehat{L}^{SL}(x^c)$ if, and only if, Condition V applies. Again, the victims and the insurer can do better by choosing the optimal deductible t_V, without affecting the injurer's welfare. Courts can further reduce social loss by optimally setting the standard of care $x^n \neq x^c$. Thus, *if Condition V holds, negligence dominates constrained strict liability.*[35] By the same logic, it can be proved that negligence dominates (unconstrained) strict liability when harms are correlated and victims are numerous. Hence, **Proposition 3 and 4 also apply to liability with insurance.**

Liability insurance with unobservable care is studied in Appendix A4. I show that under Condition V, negligence dominates strict liability with compensatory damages. Dominance of strict liability can be obtained under stronger (sufficient) conditions. Among other things, I prove that under strict liability, *if damages are optimally set, it makes no difference whether insurance is purchased by the injurer or the victims.*

5 Products liability

In this Section, I show how the analysis extends to the case in which the accident is caused by products sold in a competitive market. For simplicity, let us assume that each consumer purchases only one unit of the product. Let x and h be, respectively, the expenditure in safety and the level of harm per unit of product. The safety level is not observable by the consumers.[36] Let $Q_D(P)$ represent the number of units demanded, given the price P.

Let us consider strict liability first. The "full price" for the consumers is

$$P^C = m + p(x)(h-d) + \tfrac{1}{2}\Psi_V(x)(h-d)^2,$$

where m is the market price, $h-d$ uncompensated harm, and x the per-unit expenditure in safety. Uncertainty about the degree of safety of the product reduces the demand

[35] If $\Psi_I(x) = \frac{1}{[1+(n-1)\varrho]}\Psi_V(x)$, then $t_I = t_V$, and negligence and strict liability with compensatory damages are equally efficient.

[36] For simplicity, I do not consider more sophisticated policies available to producers, including signalling through prices, third-party certification, warranties, recalls, and ex-post warnings. See the thorough survey of Daughety and Reinganum (2013).

for the product.

Given the market price m, total consumer surplus is

$$CS\left(Q^D(m)\right) = \int_0^{Q^D(m)} \left[Q_D^{-1}(z) - m - p(x)(h-d) - \tfrac{1}{2}\Psi_V(x)(h-d)^2\right] dz.$$

Producer profits are equal to revenue minus costs: $\Pi(x,Q) = mQ - C(Q,x)$, with

$$C(Q,x) = F + Q\left[c + x + p(x)d\right] + \tfrac{1}{2}Q\left[1 + (Q-1)\varrho\right]\Psi_I(x)d^2,$$

where F is the fixed cost, c the marginal cost, x the per-unit safety expenditure, $p(x)d$ the per-unit expected liability, and $\frac{1}{2}Q\left[1+(Q-1)\varrho\right]\Psi_I(x)d^2$ the total uncertainty burden. Given the market price, the producer sets Q and x so that

$$\begin{cases} C'_Q(Q,x) = & c + x + p(x)d + \frac{1}{2}\left[1 + (2Q-1)\varrho\right]\Psi_I(x)d^2 & = m \\ C'_x(Q,x) = & Q\left(1 + p'(x)d + \frac{1}{2}\left[1+(Q-1)\varrho\right]\Psi'_I(x)d^2\right) & = 0. \end{cases}$$

Note that, if losses are correlated, then $C'_Q(Q,x) > 0$: correlation produces "diseconomies of scale."[37]

Total surplus is

$$\begin{aligned} &W^s(Q,x) = CS(Q) + \Pi(x,Q) = \textstyle\int_0^Q \left[Q_D^{-1}(z)\right] dz \\ &-F - Q\left\{c + x + p(x)h + \tfrac{1}{2}\Psi_V(x)(h-d^s)^2 + \tfrac{1}{2}\left[1+(Q-1)\varrho\right]\Psi_I(x)d^2\right\}. \end{aligned}$$

At the market equilibrium, the quantity Q^s maximizes surplus given x, while x is set by the producer so as to maximize her profit given the market price and, thus, the quantity. Since consumers cannot directly observe x, variations in safety do not command changes

[37] Since safety and quantity are interdependent, the standard separability between market structure and safety performance fails to apply. In this article, I do not address the issue of the "resilience" of liability rules to changes in market performance (see Daughety and Reinganum (2014)).

in market prices (see Shavell (1980)). Thus,

$$\begin{aligned} Q_D^{-1}(Q^s) - c - x - p(x)h - \tfrac{1}{2}\left[1 + (2Q^s - 1)\varrho\right]\Psi_I(x)d^2 - \tfrac{1}{2}\Psi_V(x)(h-d)^2 &= 0 \\ 1 + p'(x)d + \tfrac{1}{2}\left[1 + (Q^s - 1)\varrho\right]\Psi_I'(x)d^2 &= 0 \end{aligned} \tag{20}$$

By setting d, courts affect both the quantity produced and the level of safety of the products. It can be easily seen that $d^* < h$ if consumers are averse to uncertainty.

Under negligence, the injurer meets the standard $\overline{x}$ so as to avoid liability. Again, a greater level of safety would not be recognized by the consumers and, hence, does not pay off. Total surplus is

$$W^n(Q, \overline{x}) = \int_0^Q \left[Q_D^{-1}(z)\right] dz - Q\left[c + \overline{x} + p(\overline{x})h + \tfrac{1}{2}\Psi_V(\overline{x})h^2\right].$$

Courts set $\overline{x} = x^n$, while the market sets Q^n so that $\frac{\partial W^n(Q^n, x^n)}{\partial Q} = 0$ given x^n. The optimal standard solves

$$1 + p'(x^n)h + \tfrac{1}{2}\Psi_V'(x^n)h^2 = 0 \tag{21}$$

(thanks to the Envelope theorem, the impact of x on Q can be disregarded).

Let us compare negligence and strict liability with compensatory damages ($d = h$). If the producer were forced to set $x = x^n$, strict liability would dominate under the following condition:

$$\text{Condition } I^P: \qquad \Psi_I(x^n) < \tfrac{1}{[1+(Q^n-1)\varrho]}\Psi_V(x^n).$$

If the producer is allowed to set $x = x^s$, costs decrease and total surplus under strict liability further increases (consumers can purchase additional units).

Reverse. Suppose that under negligence the courts sets $\overline{x} = x^s$. Negligence dominates if the following condition holds:

$$\text{Condition } V^P: \qquad \Psi_I(x^s) < \tfrac{1}{[1+(Q^s-1)\varrho]}\Psi_V(x^s).$$

Total surplus further increases if the court can freely set $\overline{x} = x^n$.

Thus, the following holds:

Proposition 5 ***Products liability.***

i) if Condition I^P holds, strict liability dominates negligence when damages are fully compensatory $(d = h)$. Strict liability dominates a fortiori if damages are optimally set by the courts.

ii) If Condition V^P holds, negligence dominates strict liability when damages are fully compensatory $(d = h)$.

For a similar argument, the equivalent of Prop. 4 holds: When damages are optimally set, negligence dominates strict liability if harms are correlated and the number of consumers is high and/or if consumers are weakly averse to uncertainty.

In the classic literature, strict liability is preferred in the case in which risk-neutral consumers misperceive risks (see, for example, Shavell (2007) and Geistfeld (2009)). In my model, consumers do not misperceive risks; rather, they are simply averse to uncertainty. Additionally, there is no reason that manufacturers should not be averse to uncertainty as well, especially when liability generates correlated claims. The choice between liability rules should thus be guided by the comparative advantage of the parties to bear uncertainty, as Prop. 5 illustrates.

6 Final remarks

The fundamental issue of liability law - whether the loss should be borne by victims or non-negligent injurers- has been addressed in this paper by comparing the ability of parties to bear uncertainty. Uncertainty is taken to include both calculable risk and ambiguity. Four main factors serve to guide the analysis: i) the disposition of the parties towards risk, ii) their disposition towards ambiguity, iii) the dispersion of their beliefs, and iv) the interdependence of harms.

Ambiguity is of special relevance for toxic torts, due to our scant knowledge of the biological mechanisms for disease development. Here, experts can provide conflicting opinions, all of which come with some degree of plausibility.[38] In the presence of inconclusive or conflicting evidence, the uncertainty faced by the victims can be very large. My model suggests that courts should tighten the standard of care if, and only if, this contributes to reduce the dispersion of their beliefs.

Whether accidents are unilateral or bilateral and whether parties are insured has little effect, on the hypothesis that the insurer is not uncertainty-neutral, as suggested by the present industry structure.

Strict liability proves marginally superior to negligence when harms are uncorrelated and injurer and victims have similar attitudes towards uncertainty. Here, strict liability does a better job of allocating uncertainty, for it apportions a share of the loss to the victims, who can efficiently bear some uncertainty. In other non-EU models, such as RDEU and CEU, this insight does not apply because uncertainty imposes a (first-order) cost to the victims. In these models, what matters most is the degree of pessimism of the parties, which negatively influences their ability to bear uncertainty (see Appendix A6).

Strict liability might serve an important role for harms caused by new products whose level of safety is highly uncertain in the eyes of the consumers. In this case, both producers and consumers benefit from the fact that (partial) insurance is bundled together with the product, as a way of reducing the consumers' reluctance to purchase. This argument, however, only holds true for flaws generating weakly correlated claims.

When harms are correlated and the number of victims is large, negligence proves definitely superior: it provides incentives to exercise due care, and it spreads the loss over a large number of parties. Remarkably, this applies to all models considered, as risk spreading trumps pessimism/optimism and ambiguity attitudes of the parties (see Prop. 4 and 6). In uncertain environments, *the dose ultimately makes the poison.*

That negligence law can aptly serve a risk-spreading function may come as a surprise

[38] Junk science is obviously excluded, comporting with *Daubert v. Merrel Dow Pharmaceuticals, Inc.* 509, U.S. 579 (1993). Conflicting expert opinions are ubiquitous in toxic torts. See Comment c "Toxic substances and disease", Restatement (Third) of Torts, § 28. Sometimes uncertainty concerns the relationships between the extent of exposure and occurrence of harm, as in the case of the controversial "single fibre" theory for the insurgence of asbestos diseases (see *Moeller v. Garlock Sealing Technologies,LLC*, 660 F.3d 950, (6th Cir. 2011).

to lawyers following the enterprise liability tradition, who maintain that strict liability allows manufacturers to "take advantage of their unique position to spread the risk of loss among all who use the product" (Supreme Court of Colorado in *Boles v. Sun Ergoline, Inc.*, 223 P.3d 724, 2010).[39] In fact, when harms are correlated, consumers are better off if insurance against risk is not bundled with the product.

The result pointing to the superiority of negligence for correlated harms is strikingly in step with products liability law, which subjects to the negligence inquiry harms deriving from systematic flaws, such as design defects and failures to warn.

As a final caveat, I would like to emphasize that my analysis ignores many factors pertinent to the choice between negligence and strict liability that are relevant for the policy debate. Among these, the administrative costs of the tort and insurance systems, the impact of industry structure, and the overlap between liability law and regulation.

[39] Along the same lines runs the famous seventh factor listed by Wade (1973) for determination of liability: "The feasibility, on the part of the manufacturer, of spreading the loss by setting the price of the product or carrying liability insurance." Courts have been widley receptive of Wade's factors (Owen (2008)). Recent cases citing risk-spreading as a social policy motivation for strict liability include: *Faddish v. Buffalo Pumps*, 881 F. Supp. 2d 1361 (S.D. Fla. 2012), *Gammie v 1568-1572 Third Ave., LLC*, NY Slip Op 30579(U), (Sup. Ct. NY. County 2011), *Nelson v. Superior Ct.*, 50 Cal. Rptr.3d 684 (Cal. Ct. App. 2006). Explicit reference to the risk-spreading rationale was made in the controversial decision *Beshada v. Johns-Manville Products Corp.*, 442 A.2d 539 (N.J. 1982), which paved the way to asbestos litigation.

7 Appendix

A1. Given the investment in care x, let μ be the probability distribution describing the agent's beliefs about accident probabilities $\pi(x)$. These probabilities can belong to an interval or a discrete set. For any probability $\pi(x)$, the expected utility of the agent is: $EU_{\pi(x)} = (1-\pi(x))\,u(i) + \pi(x)\,u(i-\ell)$, where i is her net income and ℓ the loss. The welfare functional is

$$W = E_\mu\left(\varphi\left(EU_{\pi(x)}\right)\right), \tag{22}$$

where E_μ is the expectation over the prior distribution of $\pi(x)$, and φ a function capturing the agent's attitude towards ambiguity.

If φ is linear, the maximization of W is equivalent to the maximization of

$$\overline{W} = E_\mu\left(EU_{\pi(x)}\right) = (1 - E_\mu(\pi(x)))\,u(i) + E_\mu(\pi(x))\;u(i-\ell) = EU_{p(x)},$$

where $p(x) = E_\mu(\pi(x))$ is the mean of the possible accident probabilities (those belonging to the prior set). In this case, the agent behaves like an Expected Utility maximizer: she only cares about the reduced probability $p(x)$ of the compound lottery, and is said to be "ambiguity neutral."

If φ is concave, the agent is averse to mean preserving spreads of the beliefs:

$$E_\mu\left(\varphi\left(EU_{\pi(x)}\right)\right) < \varphi\left(E_\mu\left(EU_{\pi(x)}\right)\right).$$

For any probability $\pi(x)$, the certainty equivalent of the accident lottery (such that $u\left(c_{\pi(x)}\right) = EU_{\pi(x)}$) can be written as:

$$c_{\pi(x)} = i - \pi(x)\,\ell - \tfrac{1}{2}\rho\sigma^2_{\pi(x)}\ell^2 + o\left(\ell^2\right), \tag{23}$$

where $\pi(x)\,\ell$ is the expected loss, $\sigma^2_{\pi(x)} = \pi(x)(1-\pi(x))$ the variance of the unit loss, ρ the Arrow-Pratt degree of absolute risk aversion of the utility function, and $o\left(\ell^2\right)$ an expression that includes terms of third and higher order. If the loss is small or if u''' is close to zero, the last term can be neglected.[40]

[40] Inclusion of third and higher order terms would make the analysis more accurate, but less suitable for policy analysis. The merits of the mean-variance approach for the Bernoulli

If we let

$$w_{\pi(x)} = \pi(x) + \tfrac{1}{2}\rho\ \sigma^2_{\pi(x)}\ \ell, \tag{24}$$

the certainty equivalent becomes: $c_{\pi(x)} \simeq i - \ell\ w_{\pi(x)}$, where $w_{\pi(x)}$ is a random variable that depends on $\pi(x)$. Let $v(i) = \varphi(u(i))$. Thus, we can write the welfare functional as[41]

$$W = E_\mu\left(v\left(c_{\pi(x)}\right)\right).$$

By using a second order expansion, we get an approximation for the total certainty equivalent $C(x)$, with $v(C(x)) = E_\mu\left(v\left(c_{\pi(x)}\right)\right)$, which takes into account the uncertainty over $w_{\pi(x)}$:

$$C(x) = i - \ell\ E_\mu\left(w_{\pi(x)}\right) - \tfrac{1}{2}\lambda_v \ell^2\ \sigma^2_\mu\left(w_{\pi(x)}\right) + o\left(\ell^2\right),$$

where $\lambda_v = -\frac{v''\left(i-\ell\ E_\mu\left(w_{\pi(x)}\right)\right)}{v'\left(i-\ell\ E_\mu\left(w_{\pi(x)}\right)\right)}$ is the Arrow-Pratt index of absolute risk aversion of the v function. From eq. (24), we get

$$E_\mu\left(w_{\pi(x)}\right) = p(x) + \tfrac{1}{2}\rho\ \ell\ E_\mu\left(\sigma^2_{\pi(x)}\right),$$

where $p(x) = E_\mu(\pi(x))$ is the mean accident probability, and

$$\sigma^2_\mu\left(w_{\pi(x)}\right) = \sigma^2_\mu(\pi(x)) + \sigma^2_\mu\left(\tfrac{1}{2}\rho\ \sigma^2_{\pi(x)}\ell\right) + 2Cov\left(\pi(x), \tfrac{1}{2}\rho\sigma^2_{\pi(x)}\ell\right).$$

Thus (omitting the argument of $\pi(x)$),

$$\begin{aligned}
&C(x) = \\
&i - \ell\left[p(x) + \tfrac{1}{2}\rho\ell E_\mu\left(\sigma^2_\pi\right)\right] - \tfrac{1}{2}\lambda_v\ell^2\left[\sigma^2_\mu(\pi) + \left(\tfrac{1}{2}\rho\ell\right)^2\sigma^2_\mu\left(\sigma^2_\pi\right) + \rho\ell Cov\left(\pi, \sigma^2_\pi\right)\right] + o\left(\ell^2\right) = \\
&i - p(x)\,\ell - \tfrac{1}{2}\rho\ell^2 E_\mu\left(\sigma^2_\pi\right) - \tfrac{1}{2}\lambda_v\ell^2\sigma^2_\mu(\pi) - \ell^4\left(\tfrac{1}{2}\rho\right)^2\sigma^2_\mu\left(\sigma^2_\pi\right) - \tfrac{1}{2}\lambda_v\rho\ell^3 Cov\left(\pi, \sigma^2_\pi\right) + o\left(\ell^2\right) = \\
&i - p(x)\,\ell - \tfrac{1}{2}\rho\ell^2 E_\mu\left(\sigma^2_\pi\right) - \tfrac{1}{2}\lambda_v\ell^2\sigma^2_\mu(\pi) + o\left(\ell^2\right).
\end{aligned}$$

The total uncertainty equivalent is thus approximately equal to: i) income less the expected

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distribution are explored by Chiu (2011). The impact of downside risk aversion ($u''' > 0$) on self-protection is investigated in Chiu (2010).

[41]I am grateful to Fabio Maccheroni and Massimo Marinacci for providing the steps needed to reconcile my approximation to their general result (presented in Maccheroni et al. (2013), Appendix A1). My approximation applies to unilateral risks, theirs to symmetric risks. Related approximations are obtained by Jewitt and Mukerji (2011) and Izhakian and Benninga (2011)

loss, ii) less the mean of the Arrow-Pratt risk premium, iii) less a term which depends on the variance of the belief.

Since $v(i) = \varphi(u(i))$ and $\frac{v''}{v'} = \frac{\varphi''}{\varphi'} + \frac{u''}{u'}$, we get $\lambda_v = \theta + \rho$, with $\theta = -\frac{\varphi''}{\varphi'}$. Hence, omitting third and higher order terms:

$$\begin{aligned} C(x) &\simeq i - p(x)\ell - \tfrac{1}{2}\rho\, \ell^2\, E_\mu\left(\sigma^2_{\pi(x)}\right) - \tfrac{1}{2}[\theta + \rho\,]\,\ell^2\, \sigma^2_\mu(\pi(x)) \\ &\simeq i - p(x)\ell - \tfrac{1}{2}\rho\ell^2\left[E_\mu\left(\sigma^2_{\pi(x)}\right) + \sigma^2_\mu(\pi(x))\right] - \tfrac{1}{2}\theta\, \ell^2\sigma^2_\mu(\pi(x)). \end{aligned}$$

Note that

$$\begin{aligned} E_\mu\left(\sigma^2_{\pi(x)}\right) &= E_\mu(\pi(x)(1-\pi(x))) \\ &= p(x) - E_\mu\left(\pi(x)^2\right) = p(x) - \left[\sigma^2_\mu(\pi(x)) + p(x)^2\right] \\ &= p(x)(1-p(x)) - \sigma^2_\mu(\pi(x)) = \sigma^2_{p(x)} - \sigma^2_\mu(\pi(x)). \end{aligned}$$

Thus,

$$C(x) \simeq i - p(x)\ \ell - \tfrac{1}{2}\ \rho\ \sigma^2_{p(x)}\ell^2 - \tfrac{1}{2}\theta\ \sigma^2_\mu(\pi(x))\ \ell^2.$$

Under ambiguity aversion, the certainty equivalent is equal to income less expected loss less the risk premium attendant with the mean probability $p(x)$, less an ambiguity premium which depends on the variance of the beliefs $\sigma^2_\mu(\pi(x))$. The uncertainty premium $UP(x) = E_\mu(\pi(x)\ell) - C(x)$ is:

$$UP(x) = \tfrac{1}{2}\ \rho\ \sigma^2_{p(x)}\ \ell^2 + \tfrac{1}{2}\ \theta\ \sigma^2_\mu(\pi(x))\ \ \ell^2 \equiv \tfrac{1}{2}\Psi(x)\,\ell^2. \tag{25}$$

The uncertainty premium is equal to the sum of the risk and ambiguity premia.

Let us consider the uncertainty premium of the injurer. When an accident occurs, the injurer bears a loss ℓ for any victim affected. Let z_j be a random variable that takes value 1 if victim $j \in \{1, 2, ..., n\}$ is involved in the accident, and value 0 otherwise. Both the injurer and the victims formulate beliefs about the probability distribution over $\{z_1, z_2, ..., z_n\}$, which meet Assumptions 1 and 2. The correlation across harms is assumed to be fixed and to be independent of x. For any belief and any couple of victims j and k:

$$\frac{Cov(z_j, z_k)}{\sigma_{z_j}(x)\ \ \sigma_{z_k}(x)} = \varrho \in [0, 1].$$

The mean total payment of the injurer amounts to:

$$E_{\mu_I}\left(\sum_{j=1}^{n}\pi_j\left(x\right)\ \ell\right)=np\left(x\right)\ell.$$

The variance of the mean total payment (calculated using the mean marginal probability $p\left(x\right)$) depends on the correlation coefficient ϱ:

$$\begin{aligned}\sigma^2\left(\sum_{j=1}^{n}p\left(x\right)\ \ell\right)&=\sum_{j=1}^{n}\sum_{k=1}^{n}Cov\left(z_j,z_k\right)=n\sigma_{z_j}^2\left(x\right)\ell^2+n\left(n-1\right)\varrho\sigma_{z_j}^2\left(x\right)\ell^2=\\&=n\left[1+\left(n-1\right)\varrho\right]\ p\left(x\right)\left(1-p\left(x\right)\right)\ell^2.\end{aligned}$$

When accidents are highly correlated, the mean total payment is subject to great variations.

Given that the correlation across beliefs is also equal to ϱ, the variance of the injurer's beliefs (around their mean) is

$$\sigma_{\mu_I}^2\left(\sum_{j=1}^{n}\pi_j\left(x\right)\ell\right)=\sum_{j=1}^{n}\sum_{k=1}^{n}Cov\left(\pi_j\left(x\right),\pi_k\left(x\right)\right)=n\left[1+\left(n-1\right)\varrho\right]\sigma_{\mu_I}^2\left(\pi_j\left(x\right)\right)\ell^2.$$

Again, if ϱ is large, beliefs are subject to great variation. Beliefs assigning a high probability to accident j go hand in hand with beliefs assigning high probability to accident k.

The certainty equivalent for the injurer can be written as

$$\begin{aligned}C_I\left(x\right)&=i_I-x-p\left(x\right)n\ell-\tfrac{1}{2}\rho_I n\left[1+\left(n-1\right)\varrho\right]p\left(x\right)\left(1-p\left(x\right)\right)\ell^2\\&-\tfrac{1}{2}\theta\ n\left[1+\left(n-1\right)\varrho\right]\ \sigma_{\mu_I}^2\left(\pi_j\left(x\right)\right)\ell^2\\&=i_I-x-p\left(x\right)n\ell-\tfrac{1}{2}n\left[1+\left(n-1\right)\varrho\right]\Psi_I\left(x\right)\ell^2.\end{aligned}$$

The uncertainty premium for the injurer is larger when harms are correlated.

A2. Strict liability vs. negligence. We have $L^N\left(x^s\right)<L^S\left(x^s\right)$ if, and only if (13):

$$L^N\left(x^s\right)<L^S\left(x^s\right)\Leftrightarrow\frac{d^*}{h}>2\ \frac{\Psi_V\left(x^s\right)}{\Psi_V\left(x^s\right)+\left[1+\left(n-1\right)\varrho\right]\Psi_I\left(x^s\right)}.$$

If the victim is uncertainty neutral ($\rho_V \to 0,\ \theta_V \to 0$), we have, from eq. (8) :

$$L^{S\ \prime}(d) = \frac{\partial x_0}{\partial d} n\ p'(x_0)(h-d) + \ n\left[1+(n-1)\varrho\right]\ \Psi_I(x_0)\ d. \tag{26}$$

For $d \to 0$, we get $L^{S\prime}(0) = \frac{\partial x_0}{\partial d} np'(x_0)\, h < 0$: optimal damages d^* do not drop to zero when the victims are uncertainty neutral. Thus, d^*/h is surely greater than $\frac{2\ \Psi_V}{\Psi_V + [1+(n-1)\varrho]\Psi_I}$ if ρ_V and θ_V are sufficiently small or n sufficiently large. This proves Proposition 4.

A3. Bilateral accidents.

Negligence. Let $\bar{x}$ be the due level of care for the injurer and $\mathbf{y} = (y_1, y_2,\ ..., y_n)$ the levels of care taken by the victims. If the injurer meets the standard of care (as I assume), any victim j will chose the level of care y_j that maximizes his certainty equivalent

$$C_{Vj} = i_j - y_j - p(\bar{x},\mathbf{y})\, h - \tfrac{1}{2} p(\bar{x},\mathbf{y})\left[1 - p(\bar{x},\mathbf{y})\right] h^2 \rho_V - \tfrac{1}{2}\theta_V \sigma^2_{\mu_V}\left(\pi_j(\bar{x},\mathbf{y})\right) h^2,$$

where $\pi_j(\bar{x},\mathbf{y})$ are the (shared) beliefs about the probability of accident for victim j.

Victim j will chose $y_j = \widehat{y}_j$ so that

$$1 + p'_{y_j}(\bar{x},\mathbf{y})\left(h + \tfrac{1}{2}\left(1 - 2p(\bar{x},\mathbf{y})\right) h^2 \rho_V\right) + \tfrac{1}{2}\theta_V \frac{\partial \sigma^2_{\mu_V}\left(\pi_j(\bar{x},\mathbf{y})\right)}{\partial y_j} h^2 = 0. \tag{27}$$

By symmetry, in equilibrium we will have $\widehat{y}_j = \widehat{y}$ for all victims $j \in N$.

Social loss is:

$$L^N(\bar{x}) = \bar{x} + n\hat{y} + np(\bar{x},\widehat{\mathbf{y}})\, h + n\tfrac{1}{2}\Psi_V(\bar{x},\widehat{\mathbf{y}})\, h^2, \tag{28}$$

with

$$\begin{aligned} L'^N(\bar{x}) = 1 + np'_x(\bar{x},\widehat{\mathbf{y}})\left(h + \tfrac{1}{2}\left(1 - 2p(\bar{x},\widehat{\mathbf{y}})\right) h^2\rho_V\right) + n\tfrac{1}{2}\theta_V \tfrac{\partial \sigma^2_{\mu_V}(\pi_j(\bar{x},\widehat{\mathbf{y}}))}{\partial x} h^2 + \\ n\tfrac{\partial \hat{y}_j}{\partial \bar{x}}\left[1 + p'_{y_j}(\bar{x},\widehat{\mathbf{y}})\left(h + \tfrac{1}{2}\left(1 - 2p(\bar{x},\widehat{\mathbf{y}})\right) h^2\rho_V\right) + \tfrac{1}{2}\theta_V \tfrac{\partial \sigma^2_{\mu_V}(\pi_j(\bar{x},\widehat{\mathbf{y}}))}{\partial y_j} h^2\right]. \end{aligned}$$

The term within square brackets is nil in view of (27).

Thus, the optimal standard of care should solve:

$$1 + np'_x(\bar{x},\widehat{\mathbf{y}})\left(h + \frac{1}{2}\left(1 - 2p(\bar{x},\widehat{\mathbf{y}})\right) h^2 \rho_V\right) + n\frac{1}{2}\theta_V \frac{\partial \sigma^2_{\mu_V}\left(\pi_1(\bar{x},\widehat{\mathbf{y}})\right)}{\partial x} h^2 = 0. \tag{29}$$

Eq. (27), together with (29), determine the equilibrium levels of care $x^N, \mathbf{y}^N$, (where N stands for negligence). By implicit differentiation, we get (omitting arguments)

$$sign\left[\frac{\partial x^N}{\partial \theta_V}\right] = sign\left[\frac{\partial^2 L^N}{\partial y^2}\frac{\partial^2 L^N}{\partial x \partial \theta_V} - \frac{\partial^2 L^N}{\partial x \partial y}\frac{\partial^2 L^N}{\partial y \partial \theta_V}\right],$$

with $\frac{\partial^2 L}{\partial y^2} \geq 0$ (since this is a minimum) and

$$\frac{\partial^2 L^N}{\partial x \partial y} = \frac{\partial^2 p(x,\hat{y})}{\partial x \partial y} n \left[h + \frac{1}{2}\left(1 - 2p\left(x, \hat{y}\right)\right) h^2 \rho_V\right] - n\frac{\partial p}{\partial x}\frac{\partial p}{\partial y} h^2 \rho_V + n\tfrac{1}{2}\theta_V \ h^2 \frac{\partial^2 \ \sigma^2_{\mu_V}(\pi_j(\bar{x},\hat{y}))}{\partial x \partial y},$$
$$\frac{\partial^2 L^N}{\partial x \partial \theta_V} = \tfrac{1}{2} n h^2 \frac{\partial \sigma^2_{\mu_V}(\pi_j(\bar{x},\hat{y}))}{\partial x}, \quad \text{and} \quad \frac{\partial^2 L^N}{\partial y \partial \theta_V} = \tfrac{1}{2} n h^2 \frac{\partial \sigma^2_{\mu_V}(\pi_j(\bar{x},\hat{y}))}{\partial y}.$$

Let us assume that $\frac{\partial^2 p(\bar{x},\hat{y})}{\partial x \partial y} \leq 0$ and $\frac{\partial^2 \sigma^2_{\mu_V}(\pi_j(\bar{x},\hat{y}))}{\partial x \partial y} \leq 0$: x and y are not substitutes with respect to accident probability and ambiguity.

If $\frac{\partial \sigma^2_{\mu_V}(\pi_j(\bar{x},\hat{y}))}{\partial x} < 0$ and $\frac{\partial \sigma^2_{\mu_V}(\pi_j(\bar{x},\hat{y}))}{\partial y} < 0$, then: $\frac{\partial x^N}{\partial \theta_V} > 0$, $\frac{\partial y^N}{\partial \theta_V} > 0$. In plain words, when the levels of care x and y reduce the ambiguity perceived by the victims, an increase in the victims' degree of ambiguity aversion calls for an increase in the due level of care, on the assumption that cross-effects do not go in the opposite direction (or that they are small enough).

Conversely, if $\frac{\partial \sigma^2_{\mu_V}(\pi_j(\bar{x},\hat{y}))}{\partial x} > 0$ and $\frac{\partial \sigma^2_{\mu_V}(\pi_j(\bar{x},\hat{y}))}{\partial y} > 0$, then: $\frac{\partial x^N}{\partial \theta_V} < 0$, $\frac{\partial y^N}{\partial \theta_V} < 0$.

We also have: $\frac{\partial x^N}{\partial \rho_V} > 0$, and $\frac{\partial y^N}{\partial \rho_V} > 0$.

Strict liability with the defence of contributory negligence. Let us assume that damages are such that it is in the interest of the victims to meet the due standard of care (in other words, damages are not too low). Victims will therefore exert care $\overline{\mathbf{y}} = (\overline{y}, \overline{y}, .., \overline{y})$. In turn, the injurer sets x° so that

$$1 + np'_x\left(x^\circ, \overline{\mathbf{y}}\right) d + \left[1 + (n-1)\varrho\right] \tfrac{1}{2} \frac{\partial^2 \Psi_I(x^\circ,\overline{\mathbf{y}})}{\partial x} d^2 = 0. \tag{30}$$

If $\frac{\partial \sigma^2_{\mu_I}(\pi_1(x^\circ,\overline{\mathbf{y}}))}{\partial x} < 0$, then: $\frac{\partial^2 \Psi_I(\pi_1(x^\circ,\overline{\mathbf{y}}))}{\partial x} < 0$ and $\frac{\partial x^\circ}{\partial d} > 0$.

Optimal damages are obtained from the minimization of (omitting arguments):

$$\begin{aligned} L^{SL}(d) = x^\circ + n\overline{\mathbf{y}} + np\left(x^\circ, \overline{\mathbf{y}}\right) h + \tfrac{1}{2}\left[1 + (n-1)\varrho\right] \Psi_I\left(x^\circ, \overline{\mathbf{y}}\right) d^2 \\ + n\tfrac{1}{2}\Psi_V\left(x^\circ, \overline{\mathbf{y}}\right)(h-d)^2. \end{aligned} \tag{31}$$

Thus, courts will set d and $\bar{y}$ (the same for all victims) so that, using (30):

$$\begin{aligned}
\tfrac{\partial L^{SL}(d)}{\partial \bar{y}} &= n + np'_{\bar{y}}\left(x^{\circ},\overline{\mathbf{y}}\right)h + \tfrac{1}{2}\left[1+(n-1)\varrho\right]\tfrac{\partial \Psi_I(x^{\circ},\overline{\mathbf{y}})}{\partial \bar{y}}d^2 + n\tfrac{1}{2}\tfrac{\partial \Psi_V(x^{\circ},\overline{\mathbf{y}})}{\partial \bar{y}}\left(h-d\right)^2 \\
&\qquad + \tfrac{\partial x^{\circ}}{\partial \bar{y}}n\left[p'_x\left(x^{\circ},\overline{\mathbf{y}}\right)(h-d) + \tfrac{1}{2}\tfrac{\partial \Psi_V(x^{\circ},\overline{\mathbf{y}})}{\partial x^{\circ}}\left(h-d\right)^2\right] \quad = 0 \\
\tfrac{\partial L^{SL}(d)}{\partial d} &= \left[1+(n-1)\varrho\right]\Psi_I\left(x^{\circ},\overline{\mathbf{y}}\right)d - n\Psi_V\left(x^{\circ},\overline{\mathbf{y}}\right)(h-d) \\
&\qquad + \tfrac{\partial x^{\circ}}{\partial d}n\left[p'_x\left(x^{\circ},\overline{\mathbf{y}}\right)(h-d) + \tfrac{1}{2}\tfrac{\partial \Psi_V(x^{\circ},\overline{\mathbf{y}})}{\partial x^{\circ}}\left(h-d\right)^2\right] \quad = 0.
\end{aligned} \tag{32}$$

For $d = h$, marginal loss simplifies to

$$\frac{\partial L^{SL}(d)}{\partial d} = \left[1+(n-1)\varrho\right]\Psi_I\left(x^{\circ},\overline{\mathbf{y}}\right)d \geq 0.$$

Thus, as in the unilateral case, at the optimum: $d^* < h$ if the injurer is not uncertainty neutral.

Dominance. Let us compare negligence and strict liability with fully compensatory damages ($h = d$). Given care levels x and $\mathbf{y} = (y_1, y_2, \ ..., y_n)$ constrained strict liability is preferable if, and only if (from 28 and 31):

$$\widehat{L}^{SL}(x,\mathbf{y}) < L^N(x,\mathbf{y}) \;\;\Leftrightarrow\;\; \left[1+(n-1)\varrho\right]\Psi_I(x,\mathbf{y}) < \Psi_V(x,\mathbf{y}), \tag{33}$$

as in the unilateral case (see ineq. 12).

If Condition I holds, then,

$$\widehat{L}^{SL}(x^n,\mathbf{y}^n) < L^N(x^n,\mathbf{y}^n),$$

where x^n and $\mathbf{y}^n$ are the levels of care taken by the parties under negligence. Social loss is even smaller, under $\widehat{L}^{SL}$, if the injurer takes the optimal level of care x°, given the level of care $\overline{\mathbf{y}}$ optimally set by the courts (under strict liability with contributory negligence). In fact, $(x^{\circ},\overline{\mathbf{y}})$ minimizes Social Loss: if the courts could also select x, they would just pick x° (this can be seen from the first order conditions). Thus,

$$\widehat{L}^{SL}(x^{\circ},\overline{\mathbf{y}}) \leq \widehat{L}^{SL}(x^n,y^n).$$

If courts can optimally chose d, social loss further decreases. Thus, strict liability dominates negligence.

Similarly, if Condition V holds, then,

$$L^N (x^s, \mathbf{y}^s) < L^{SL} (x^s, \mathbf{y}^s),$$

where x^s, and $\mathbf{y}^s$ are the levels of care under strict liability. Social loss further decreases if courts select the socially optimal standard x^n, while the victims select their welfare maximizing level of care $\mathbf{y}^n$. Again, $(x^n, \mathbf{y}^n)$ minimize social loss, even if x and y are chosen by different subjects (see eqs. (27) and (29)). Thus, also under bilateral accidents, Propositions 3 and 4 apply.

A4. **Insurance (Unobservable care)**. Under strict liability, the certainty premia of the parties have the shapes of eqs. (14)-(16) . Here, however, the care level is decided by the injurer so as to maximize her welfare only. The insurance contract between the injurer and the insurer can only specify the deductible t_I. The optimal deductible t_I^* satisfies

$$\frac{\partial JS_{IS}(x)}{\partial t_I} = \frac{\partial C_I(x)}{\partial t_I} + \frac{\partial C_S(x)}{\partial t_I} + \frac{\partial C_S(x)}{\partial x_I}\frac{\partial x_I}{\partial t_I} = 0, \tag{34}$$

where x_I is chosen by the injurer to maximize her welfare (i.e. $\frac{\partial C_I(x)}{\partial x_I} = 0$).

Optimal damages (under strict liability) will meet:

$$\frac{\partial SW}{\partial d} = \frac{\partial C_S(x_I)}{\partial d} + n\frac{\partial C_V(x_I)}{\partial d} + n\frac{\partial C_V(x_I)}{\partial x_I}\frac{\partial x_I}{\partial d} = 0. \tag{35}$$

Again, if $d = h$, then $\frac{\partial C_V(x_I)}{\partial x_I} = \frac{\partial C_V(x_I)}{\partial d} = 0$, and $\frac{\partial SW}{\partial d} < 0$.

Note, for future reference, that since $\frac{\partial C_S(x_I)}{\partial d} = -\frac{\partial C_S(x)}{\partial t_I}$, eq. (35) can be re-written in view of (34) as:

$$\frac{\partial C_I(x)}{\partial t_I} + \frac{\partial C_S(x)}{\partial x_I}\frac{\partial x_I}{\partial t_I} + n\frac{\partial C_V(x_I)}{\partial d} + n\frac{\partial C_V(x_I)}{\partial x_I}\frac{\partial x_I}{\partial d} = 0. \tag{36}$$

If insurance is purchased, instead, by the victim, the optimal deductible t_V solves

$$\frac{\partial C_S(x_I)}{\partial t_V} + n\frac{\partial C_V(x_I)}{\partial t_V} = 0, \tag{37}$$

and thus

$$t_V^* = \frac{\Psi_S(x_I)}{\Psi_S(x_I) + \frac{1}{[1+(n-1)\varrho]}\Psi_V(x_I)}(h-d). \tag{38}$$

Optimal damages solve

$$\frac{\partial SW}{\partial d} = \frac{\partial C_I(x_I)}{\partial d} + \frac{\partial C_S(x_I)}{\partial d} + \left[\frac{\partial C_S(x_I)}{\partial x_I} + n\frac{\partial C_V(x_I)}{\partial x_I}\right]\frac{\partial x_I}{\partial d} = 0, \tag{39}$$

where x_I meets $\frac{\partial C_I(x_I)}{\partial x_I} = 0$.

Since $\frac{\partial C_S(x_I)}{\partial d} = \frac{\partial C_S(x_I)}{\partial t_V}$, in light of (37) , eq. (39) and can be rewritten as

$$\frac{\partial C_I(x_I)}{\partial d} - n\frac{\partial C_V(x_I)}{\partial t_V} + \frac{\partial C_S(x_I)}{\partial x_I}\frac{\partial x_I}{\partial d} + n\frac{\partial C_V(x_I)}{\partial x_I}\frac{\partial x_I}{\partial d} = 0. \tag{40}$$

Eq. (40) yields exactly the same outcome as eq. (36) : *under strict liability, if damages are optimally set, it makes no difference whether insurance is purchased by the injurer or the victims.* In the first case, the injurer bears the deductible t_I and the victims $h-d$; in the latter, the injurer bears damages d and the victims t_V.

Further analysis shows that if $\frac{\partial \sigma^2_{\mu_V}}{\partial x} \leq 0$ and $\frac{\partial \sigma^2_{\mu_I}}{\partial x} \leq 0$, optimal damages increase with ρ_V and θ_V, and they decrease with ρ_S and θ_S.

Under negligence, the victims purchases insurance and the optimal deductible is given by (38) (where $d = 0$).

Let start with the dominance of strict liability. In order to find a sufficient condition for the dominance, I will use an indirect approach. Strict liability with liability insurance and optimal damages is socially preferable to strict liability with liability insurance and compensatory damages. In turn, the latter rule is preferable to strict liability with compensatory damages without insurance (here insurance affects the injurer and the insurer, but not the victims). Furthermore, strict liability with compensatory damages without insurance is preferable to strict liability with compensatory damages without insurance with a level of care different from that optimally chosen by the injurer (here, the level of care affects only the welfare level of the injurer). Finally, the latter liability rule dominates negligence (with insurance), given the optimal level of care chosen by the courts x^n, if, and only if,

$$\tilde{L}^{SL}(x^n) < L^N(x^n) \Leftrightarrow$$
$$[1+(n-1)\varrho]\,\Psi_I(x^n)\,h^2 < n\,[1+(n-1)\varrho]\,\Psi_S(x^n)\;\;(h-t_V^*)^2 + \Psi_V(x^n)\,t_V^{*2}.$$

By plugging in the optimal deductible t_V^*, the latter inequality boils down to

$$\text{Condition I2:}\quad \Psi_I(x^n) < \frac{\Psi_S(x^n)\,\Psi_V(x^n)}{[1+(n-1)\varrho]\,\Psi_S(x^n)+\Psi_V(x^n)}.$$

If Condition I2 holds, then strict liability with compensatory damages and no insurance dominates negligence. Unconstrained strict liability dominates a fortiori.

Note that if $\Psi_S(x^n)=0$ or $\Psi_V(x^n)=0$, then Condition I2 cannot be met. If $\Psi_S(x^n) = \Psi_V(x^n)$, then Condition I2 simplifies to: $\Psi_I(x^n) < \Psi_S(x^n)\,/\,[2+(n-1)\varrho]$.

For the dominance of negligence, the proof of the second part of Proposition 3 applies, mutatis mutandis.

A5. Does the main insight of my model extend beyond the mean-variance case? A univocal Pareto efficient liability rule can be identified by considering the amount that parties are willing to spend to obtain full insurance against the loss. Let us consider uncorrelated harms. Since the demand for insurance depends positively on both risk and ambiguity aversion of the parties (see Schlesinger (2013), Snow (2011), Alary et al. (2013)), strict liability with compensatory damages is preferable to negligence if the Degrees of Absolute Risk and Ambiguity aversion of the victims (ρ and θ, income dependent) are *both* greater than those of the injurer for any income level. In this case, the amount that victims are willing to pay ex-ante in order to be relieved from uncertainty is greater than the cost that uncertainty places on the injurer. Dominance of strict liability applies a fortiori (for the argument developed in Section 2.3), if courts can optimally set damages.

Let us consider now the case in which victims are numerous and harms are correlated. Given any belief about the accident probability, strict liability imposes a risk with infinite variance (and skewness) on the injurer, while negligence (under the level of care arising under strict liability) imposes risk with bounded variance on the victims. A standard risk sharing argument suggests that negligence is the dominant rule. Considering different beliefs and monotonically transforming expected utilities (ambiguity aversion) does not revert this result. The result applies a fortiori if courts can optimally set the standard.

A6. **Neo-additive capacity**.

Teitelbaum (2007) uses Choquet's Expected Utility theory to account for parties' aversion to ambiguity in a unilateral accident model under risk neutrality. Teitelbaum formalizes ambiguity along the lines of the neo-additive model of Chateauneuf et al. (2007), in which parties distinguish only three types of events: impossible, possible, and certain. In this model, ambiguity is defined as a lack of confidence in the probability of an accident. The more severe this lack of confidence, the further away agents move from Expected Utility by attaching greater weight to extreme payoffs (minimum and maximum utility). Thus, agents tend to display either pessimism or optimism, similarly to the diverging expectations model.

The neo-additive capacity model is equivalent to a multiple prior model in which the agent's beliefs belong to the core set $C\left(p\left(x\right)\right)=\{\pi\in[0,1]: p\left(x\right)\left(1-\delta\right)\leq\pi\leq p\left(x\right)\left(1-\delta\right)+\delta\}$, where $p\left(x\right)$ is the reference probability of accident. δ measures the ambiguity of the decision environment. The welfare function (associated to a simple accident) is $W\left(x\right)=\alpha\ \min_{\pi\in C(p(x))}EU_{\pi}+\left(1-\alpha\right)\ \max_{\pi\in C(p(x))}EU_{\pi}$, where α captures the pessimistic (large α) or optimistic (small α) attitude of the agent. Thus, for any level of precautions x, the agent attaches a positive weight only to the worst and the best priors [i.e. $\pi^{-}=p\left(x\right)\left(1-\delta\right)+\delta$ and $\pi^{+}=p\left(x\right)\left(1-\delta\right)$]. The average weight $w=\alpha\pi^{-}+\left(1-\alpha\right)\pi^{+}$ guides the agent's decisions (see Chateauneuf et al. (2007) and Teitelbaum (2007))[42].

For a loss equal to ℓ occurring with probability $p\left(x\right)$, the welfare function of a victim can be written as (omitting arguments):

$$\begin{aligned}
W_V\left(x\right) &= \alpha_V EU_{p(1-\delta)+\delta}+\left(1-\alpha_V\right)\ EU_{p(1-\delta)}= \\
&= \alpha_V\left[\left(1-p\left(1-\delta\right)-\delta\right)u_V\left(i_V\right)+\left(p\left(1-\delta\right)+\delta\right)u_V\left(i_V-\ell\right)\right]+ \\
&\left(1-\alpha_V\right)\left[\left(1-p\left(1-\delta\right)\right)u_V\left(i_V\right)+p\left(1-\delta\right)u_V\left(i_V-\ell\right)\right] \\
&= \left[1-p-\delta_V\left(\alpha_V-p\right)\right]u_V\left(i_V\right)+\left[p+\delta_V\left(\alpha_V-p\right)\right]u_V\left(i_V-\ell\right) \\
&= \left(1-w_V\left(x\right)\right)u_V\left(i_V\right)+w_V\left(x\right)\ u_V\left(i_V-\ell\right),
\end{aligned}$$

[42]The neo-additive model is formally equivalent to many other Non-EU models, including Rank Dependent Expected Utility and Prospect Theory if parties only experience losses (and no gains) (Teitelbaum (2007)).

where $w_V(x) = [p(x) + \delta_V(\alpha_V - p(x))]$ is the weight attached by the victim to the 'accident' event. $\delta_V \in [0,1]$ measures perceived ambiguity, or, more precisely, the degree by which victims lack confidence in the reference probability (and hence depart form standard Expected Utility). If $\alpha_V > p(x)$, the victims are "pessimist" and overweight the negative outcome. If $\alpha_V < p(x)$, the victims are "optimist" and overweight the positive outcome.

By applying a second order Taylor expansion to $W_V(x)$, we obtain the usual Arrow-Pratt approximation of the certainty equivalent:

$$c_V(x) = i_V - w_V(x)\ \ell - \frac{1}{2} w_V(x)\ (1 - w_V(x))\ \rho_V\ \ell^2. \tag{41}$$

Similarly, the certainty equivalent for the injurer bearing a loss ℓ for each victim is

$$c_I(x) = i_I - x - n w_I(x)\,\ell - \frac{1}{2} n\,[1 + (n-1)\,\varrho]\, w_I(x)\,(1 - w_I(x))\,\rho_I \ell^2, \tag{42}$$

where $w_I(x) = [p(x) + \delta_I(\alpha_I - p(x))]$, and ϱ is the correlation across harms.

The comparison of strict liability and negligence can be carried out along the lines of Section 2.3, thus yielding:

Proposition 6 *When harms are uncorrelated, strict liability is preferable if the injurer is more confident in his belief, less pessimist and less risk averse than the victims. When harms are correlated and the injurer is averse to risk, negligence dominates if n is sufficiently large.*

Note that for correlated harms negligence dominates independently of the degree of pessimism of the parties.

Two remarks, however, are in order. First, let us consider optimal standard setting. Under the negligence rule, the law maker sets the standard $\overline{x}$ so as to maximize $c_I(x) + n c_V(x)$, which is the same as minimizing

$$L_A^N(\overline{x}) = \overline{x} + n w_V(\overline{x})\,h + n \frac{1}{2} w_V(\overline{x})\,(1 - w_V(\overline{x}))\,\rho_V h^2.$$

Thus, $\overline{x}^*$ should meet (omitting arguments):

$$1 + w_V' \ n \left\{ h + \frac{1}{2}\rho_V h^2 \left(1 - 2w_V\right) \right\} =$$

$$1 + p' \left(1 - \delta_V\right) n \left\{ h + \frac{1}{2}\rho_V h^2 \left[1 - 2\left(p + \delta_V \left(\alpha_{_V} - p\right)\right)\right] \right\} = 0. \tag{43}$$

The optimal standard increases with the victims' degree of pessimism $(\alpha_{_V})$, while it increases with the their degree of risk aversion ρ_V if, and only if, $w_V\left(\overline{x}\right) < 1/2$. The standard decreases with ambiguity δ_V if, and only if,

$$-p'\left(\overline{x}\right) n \left\{ h + \frac{1}{2}\rho_V \ h^2 \left[1 - 2v_V\right] \right\} - p'\left(\overline{x}\right) n \left(1 - \delta_V\right) \rho_V \ h^2 \left(\alpha_{_V} - p\left(\overline{x}\right)\right) < 0,$$

which is met if victims are pessimist $(\alpha_{_V} - p\left(\overline{x}\right) > 0)$. Eq. (43) shows how ambiguity affects the precautionary choice in the neo-additive model. If victims have little confidence in the accident probability $p\left(x\right)$, the benefits of greater precautions will not be fully savored. So, **greater "likelihood insensitivity" (large δ_V) will tend to call for a lower standard.**[43]

Second. Let us consider optimal uncertainty sharing given the level of care x. If we differentiate social welfare $SW = c_I\left(x\right) + nc_V\left(x\right)$ with respect to damages d, we get (omitting arguments):

$$SW_d' = -nw_I - n\left[1 + \left(n-1\right)\varrho\right] w_I \left(1 - w_I\right) \rho_I d^2 + nw_V + w_V \left(1 - w_V\right) \rho_V \left(h - d\right)^2.$$

Hence,

$$\lim_{d \to h^-} SW_d' = -nw_I + nw_V - n\left[1 + \left(n-1\right)\varrho\right] w_I \left(1 - w_I\right) \rho_I h^2,$$

which is not necessarily negative. In contrast to the smooth model, here **fully compensatory damages might be optimal.** A shift of the loss from one side to the other affects both the uncertainty borne by the parties and their expected incomes. Expected incomes depend on the weights the parties attach to the accident, which might be different. Neo-additive ambiguity aversion elevates uncertainty to a first order effect, as shown, in a more general set-up, by Lang (2014).

[43] Estimates of likelihood insensitivity are provided by Abdellaoui et al. (2011).

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