Efficient liability law with costly insurance

Luigi Alberto Franzoni*

June 2024

Abstract

This paper revisits the normative foundations of liability law by exploring its risk-allocation properties. It builds on the realistic assumption that parties are averse to risk and that insurance is costly. Risk aversion and costly insurance advocate for a higher standard of care under negligence and for larger damage awards under strict liability. When the victim can suffer concomitant harms and is not insured, the standard of care and the damage awards increase with the degree or correlation across harms.

.

Keywords: *negligence law, strict liability, insurance, concomitant harms, superadditivity.*

JEL Code: K13

* *Correspondence to:* Luigi A. Franzoni, Department of Economics, Piazza Scaravilli 2, 40126 Bologna, Italy.

1 Introduction

In this paper, I take the endeavor of studying the liability system from an insurance perspective. I conceive the liability system as a *risk allocation* mechanism that at the same time provides parties with incentives to take precaution and distributes the risk across them. This risk allocation system is complemented by the insurance market, which provides risk coverage at a price.

I consider a classic costly-precautions set up under the realistic assumption that parties - victims and injurers - are averse to risk and that private insurance is costly.[1] I investigate how the liability system can, together with the insurance sector, meet the demand for insurance of the parties. The analysis focuses on the most common liability regimes: negligence and strict liability.

In a negligence regime, as far as injurers meet the standard of care, the loss falls on the victims. Risk aversion amplifies the cost of harm and hence calls for a higher standard of care. When (costly) insurance is available, victims will buy partial insurance against their losses. The optimal standard will increase with the cost of first-party insurance.

In a strict liability regime, the share of the loss falling on injurers and victims, respectively, depends on the damage awards set by the courts. Both injurers and victims might be interested in purchasing insurance. Optimal damages will depend on the insurance costs of the parties; damages should be undercompensatory when victims have access to cheaper insurance, as one might reasonably expect.

If victims can be subject to multiple harms or when injurers can harm multiple victims simultaneously, the cost of risk bearing depends on the *correlation* across harms. Positive correlation on the victim's side occurs, for instance, when the victim's specific characteristics - like immunodeficiency, substance allergy, or, more generally, poor physical health - increase the probability that he/she suffers multiple harms at the same time. Positive correlation increases the risk burden of the victim and, when insurance is not available or is too costly, calls for an increase in the negligence standard or in

[1] In most insurance markets, administrative costs amount to 30-40% of the premium. They include underwriting expenses (to price, market, and issue policies) and loss adjustment expenses (to investigate, defend, adjust, and settle claims) (see Rejda et al. (2020)).

the damage awards (under strict liability). Correlation can also affect the injurer, e.g., when a poorly designed product can harm many consumers at the same time. This type of correlation has no impact under a negligence regime, because the loss is spread on the victims (when the injurer meets the standard). Under strict liability, correlation matters, but its impact is ambiguous. The transfer of risk from the injurer to the victims becomes more valuable (when harms are positively correlated), but the injurer has greater incentives to take care. So, optimal damages might increase or decrease.

While the risk allocation properties of the liability system have long been debated in the legal scholarship, formal contributions about this issue remain few.[2] In his classic contribution, Shavell (1982) investigates whether the availability of first-party and third-party insurance has a detrimental impact on the liability system. He shows that the answer is on the negative: while incentives to take precautions are likely to be diluted by insurance, the outcome remains efficient. Shavell focuses on the case in which insurance markets are perfectly competitive and insurance is cost-free.

Due to the complexity of the analysis, several authors have investigated the impact of risk aversion on the liability system by assuming specific shapes of the parties' utility functions. Greenwood and Ingene (1978) study optimal risk sharing rules between a polluting firm and the victims using a local approach. Nell and Richter (2003) compare strict liability and negligence under CARA utilities. Using an Arrow-Pratt approximation, in Franzoni (2017), I study the impact of risk and ambiguity aversion, while in Franzoni (2016), I investigate the relative desirability of strict liability (with perfect compensation) and negligence when harms are correlated across victims. Negligence outperforms strict liability when harms are positively correlated. The opposite applies when harms are negatively correlated. In contrast to Franzoni (2016), the present contribution focuses on the impact of insurance cost and the structure of risk on the traditional liability rules (optimal standard under negligence and optimal damages under

[2] The insurance properties of the liability system are often associated to its "loss-spreading" function (as famously articulated by Justice Traynor in *Escola v. Coca-Cola Bottling Co.,* 1944). See also *Restatement (Third) of Product Liability,* § 2 cmt. a. Loss spreading arguments are deemed important also with respect to harms caused by emerging digital tecnologies (see Geistfeld et al. (2022), p. 374). Tort liability and the insurance system have been described as "binary stars" revolving around each other and forming an intertwined gravitational field (Abraham (2008)).

strict liability). I make no restrictive assumptions on the shape of the utility functions. I posit that precautions reduce the extent of harm, rather than its probability. This allows me to draw directly from the theory of insurance demand. In the Appendix, I show how results can be generalized.

The case of the concomitant harms suffered by the same victim touches on the classic issue of the joint liability of multiple tortfeasors (see, for instance, Kornhauser (2013)). In my model, however, injurers inflict "distinct" harms to the victims, so each injurer is responsible for her own part.[3] Daughety and Reinganum (2014) addresses the issue of cumulative harm assuming that product-related harm increases nonlinearly with the quantity consumed. Risk aversion and positive correlation induce a form of superadditivity that bears similarity to their case of the jointly cumulative harms, exemplified by the "Diner's dilemma" where the various foods on the menu may be contaminated by different bacteria or toxins, and where the infections compound on each other. Daughety and Reinganum focus on the implication of superadditivity on efficient consumption and market performance. I focus instead on deterrence and risk sharing.

In what follows I first study the impact of risk aversion on the liability system in the absence of insurance, and then introduce the availability of costly insurance.

2 Negligence rule

Let us consider the case in which the risk prospect depends on the precaution level x taken by a party called "injurer."[4] Precaution costs are $c(x)$, with $c' > 0, c'' \geq 0$. Let $h(x)$ be the harm suffered by the victim, with $h'(x) < 0$: the greater the precaution

[3] Harms are *distinct* as in the case in which "two defendants independently shoot the plaintiff at the same time, and one wounds him in the arm and the other in the leg" (*Restatement (Second) of Torts* § 433A cmt a). Each injurer is responsibile for the injury that she causes. In my model, harms are not necessarily simultaneous: they just happen to occur within the same relevant time interval.

[4] Note that by calling an agent "injurer" I am implicitly embedding the model in a specific legal setup, in which the injurer's actions legally cause harm to the victim. This setup clearly determines how far one should go in the causation chain (A causes B that causes C that causes D, etc.) and who is to be held responsible along the chain.

taken by the injurer and the smaller the (pecuniary) harm suffered by the victim.[5]

In this section, I consider the case in which the loss falls on the victim as far as the injurer meets the standard of care $\overline{x}$ (the "due care" level). If the injurer does not meet the standard, she has to pay damages equal to $d = h(x)$.[6]

The analysis also captures the case in which the injurer is subject to regulatory standards (like emission standards or technology standards) enforced through pecuniary or criminal sanctions.

The expected utility of the injurer is:

$$EU_I(x) = \begin{cases} (1-p)\, u(y_I - c(x)) + pu(y_I - c(x) - h(x)) & \text{for } x < \overline{x}, \\ u(y_I - c(x)) & \text{for } x \geq \overline{x}, \end{cases} \tag{1}$$

which can also be written as

$$EU_I(x) = \begin{cases} u(y_I - c(x) - p\; h(x) - RP_I(h(x))) & \text{for } x < \overline{x}, \\ u(y_I - c(x)) & \text{for } x \geq \overline{x}. \end{cases}$$

where y_I is the injurer's income and $RP_I(h(x))$ is the risk premium associated with the prospect of loosing $h(x)$ with probability p.

Maximization of EU_I is equivalent to minimization of the injurer's loss

$$L_I(x) = \begin{cases} c(x) + p\; h(x) + RP_I(h(x)) & \text{for } x < \overline{x}, \\ c(x) & \text{for } x \geq \overline{x}. \end{cases}$$

The concept of injurer's loss greatly simplifies the presentation, and I will heavily build on it. In places, however, it will be necessary to go back to the original expected utility formulation.

[5]This formulation, in which precautions affect the magnitude of harm, and not its probability, better suits the study of the correlation across harms. The main insights, however, carry over to the alternative case.

[6]Alternatively, one could assume that damages are equal to the additional harm resulting from the untaken precautions: $d = h(x) - h(\overline{x})$. The latter formulation accounts for the causation requirement of negligence law (see Kahan (1989) and Schweizer (2016)). Since in equilibrium the injurer will meet the standard of care, for our purposes the two formulations are equivalent.

The expected utility of the victim is

$$EU_V(x) = \begin{cases} v(y_V), & \text{for } x < \overline{x}, \\ (1-p)v(y_V) + pv(y_V - h(x)), & \text{for } x \geq \overline{x}, \end{cases} \tag{2}$$

where y_V is the victim's income, p is the accident probability and $h(x)$ the harm suffered.

The maximization of EU_V is equivalent to the minimization of the victim's loss:

$$L_V(x) = \begin{cases} 0 & \text{for } x < \overline{x}, \\ ph(x) + RP_V(h(x)) & \text{for } x \geq \overline{x}, \end{cases}$$

where $RP_V(h(x))$ is the risk premium of the victim.

The injurer will meet the standard of care $\overline{x}$ if

$$\textit{Condition } S\text{:}\;\; c(\overline{x}) < \min_x \left(c(x) + ph(x) + RP_I(h(x))\right)$$

is met. The term on the right hand side represents the minimal loss when the harm is borne by the injurer. Condition S is not met when the standard is set to such a high level that bearing liability is actually cheaper than meeting the standard. For our purposes, what matters is that Condition S is met at the optimal standard. In Appendix A1, a simple sufficient condition for S to hold at the optimum is provided. If Condition S is not met at the optimum, the injurer is liable for the harm caused and the analysis of Section 3 below (strict liability) applies.

Let us assume that Condition S is met and that the injurer meets the standard of care $\overline{x}$. The efficient standard is obtained from the minimization of Social Loss (see Appendix A2):

$$SL = L_I(\overline{x}) + L_V(\overline{x}) = c(\overline{x}) + ph(\overline{x}) + RP_V(h(\overline{x})).$$

The optimal standard solves

$$c'(\overline{x}^*) = -ph'(\overline{x}^*) - h'(\overline{x}^*)\, RP_V'(h(\overline{x}^*)). \tag{3}$$

The marginal cost of precaution should be equal to its marginal benefit, which includes the reduction in expected harm and the reduction in the risk borne by the victim.

A better insight can be obtained by delving in the risk premium expression. Using (2), the optimality condition becomes:

$$\underbrace{c'(\overline{x}^*)}_{\text{marginal cost}} = \underbrace{-ph'(\overline{x}^*)\ \frac{v'(y_V - h(\overline{x}^*))}{(1-p)\,v'(y_V) + pv'(y_V - h(\overline{x}^*))}}_{\text{marginal benefit}} \equiv b'(\overline{x}^*)\,. \tag{4}$$

The marginal benefit of precaution is equal to the amount of income that the victim is willing to pay (ex-ante) to benefit from a reduction in the magnitude of harm. The increase in utility due to the reduction in harm is converted in dollars by dividing it by the marginal utility of income before the accident occurs.

The marginal benefit $b'(x)$ corresponds to the victim's willingness to pay for insurance. We have: $b'(x) \geq ph'(x)\,, b'(x) < h'(x)$, and $b''(x) < 0$.

The following properties can be easily established (see Appendix A3).

Proposition 1 *The optimal standard balances the cost of precaution and the victim's willingness to pay for insurance.*

i) If the victim becomes more averse to risk, the optimal standard increases.

ii) If the probability of harm increases, the optimal standard increases.

iii) If harm uniformly increases given precautions, the optimal standard increases.

iv) When the victim's income increases, the optimal standard decreases if the victim has Decreasing Absolute Risk Aversion.

The efficient standard balances costs and benefits of precaution. The benefits of precaution are measured by the willingness of the victim to pay for a reduction in the magnitude of harm ("demand for insurance"). In turn, this willingness to pay depends, in a simple way, on the victim's income level and degree of risk aversion. Since most people have DARA, *iv*) implies that the standard should increase when the victims are subject to a negative income shock (if they are poorer, they attach a greater value to insurance coverage against a fixed loss).[7]

Discrete example 1. Let us consider the case in which the victim's utility function exhibits a constant degree of relative risk aversion equal to 0.3.[8]. Let the risk of accident be equal to 1/100 and let the victim's income be equal to \$70,000 per year. Let us consider a precautionary measure that brings down the magnitude of harm, in case of accident, from \$50,000 to nil. The expected value of this measure is 1/100 x 50,000=\$500. Taking into account the victim's aversion to risk, the insurance value of the precautionary measure is \$583 (so roughly 17% larger than the expected value).[9]

Optimal standard when the victim is insured

Let us suppose that the victim can purchase first-party insurance with loading factor $\lambda_V \geq 0$. Given harm $h(x)$, the victim is offered insurance with a premium $\pi(\delta)$ that depends on the deductible δ (the amount of harm that remains on the victim's shoulders).[10] Specifically, the premium is

$$\pi(\delta) = (1 + \lambda_V) p (h(x) - \delta).$$

The optimal deductible minimizes the victim's loss:

$$\begin{aligned} L_V &= \pi(\delta) + p\delta + RP_V(\delta) \\ &= (1 + \lambda_V) p (h(x) - \delta) + p\delta + RP_V(\delta), \end{aligned}$$

where $RP_V(\delta)$ is the risk premium associated to the prospect of losing δ with probability p.

[7] These observations mimic classic results in the theory of insurance demand. See Schlesinger (2013) for a survey.

[8] This is a conservative value consistent with the estimates of Barseghyan et al. (2013), based on insurance choices. Estimates of the degrees of risk aversion under CRRA span a large range, roughly from 0.2 to 4.5, and are affected by a variety of factors that include, among other things, the individuals' age, gender, and education level.

[9] This value is relatively insensitive to the probability of harm (the scaling factor is roughly the same with $p = 1/100$ and $p = 1/10,000$).

[10] A share of the harm could also remain on the victim's shoulders due to the deliberate exclusion of specific types of losses.

The optimal deductible δ^* solves (at an interior solution):

$$\begin{aligned} -(1+\lambda_V)\,p + p + \frac{\partial RP_V(\delta^*)}{\partial \delta} &= 0, \text{ i.e.} \\ \frac{\partial RP_V(\delta^*)}{\partial \delta} &= \lambda_V p. \end{aligned} \tag{5}$$

The optimal deductible balances the cost of insurance with the benefit of a reduced risk burden. The higher the loading factor, and the higher the deductible. As far as the loading factor is positive, the victim buys less than full insurance. If the loading factor is very large, $\lambda > \frac{1}{p}\frac{\partial RP_V(h(x))}{\partial \delta}$, the victim prefers not to buy insurance and $\delta^* = h(x)$.

The optimal standard $\overline{x}^*$ solves now:

$$\min_{\overline{x}} SL = L_I + L_V = c(\overline{x}) + (1+\lambda_V)\,p\,(h(\overline{x}) - \delta^*) + p\delta^* + RP_V(\delta^*),$$

with

$$\begin{aligned} \frac{\partial SL}{\partial \overline{x}} &= \frac{\partial L_I}{\partial \overline{x}} + \frac{\partial L_V}{\partial \overline{x}} + \frac{\partial L_V}{\partial \delta^*}\frac{\partial \delta^*}{\partial \overline{x}} = \frac{\partial L_I}{\partial \overline{x}} + \frac{\partial L_V}{\partial \overline{x}} \\ &= c'(\overline{x}) + (1+\lambda_V)\,ph'(\overline{x}), \end{aligned}$$

where $\frac{\partial L_V}{\partial \delta^*} = 0$ due to the optimality of δ^*. The optimal standard meets therefore

$$c'(\overline{x}^*) = -ph'(\overline{x}^*)(1+\lambda_V): \tag{6}$$

the benefit of increased precaution now includes the saved insurance costs $ph'(\overline{x}^*)\,\lambda_V$.

Since $\lambda_V p = \frac{\partial RP_V(\delta^*)}{\partial \delta}$ (eq. 5), the marginal benefit of precaution can be rewritten as

$$b'(\overline{x}) = ph'(\overline{x}) + h'(\overline{x})\frac{\partial RP_V(\delta^*)}{\partial \delta}, \tag{7}$$

where

$$\frac{\partial RP_V(p,\delta^*)}{\partial \delta} < \frac{\partial RP_V(h(x))}{\partial h(x)}$$

for $\delta^* < h(x)$ (see Appendix A4). The insurance benefit of precaution is now smaller than in eq. (3) because the victim is partially insured (he only loses the deductible

δ^*).

Proposition 2 *Insured victim. The optimal standard solves*

$$c'(\overline{x}^*) = -ph'(\overline{x}^*)(1+\lambda_V).$$

The marginal benefit of precaution is equal to the expected reduction in harm and the expected reduction in insurance costs. The optimal standard increases with the first-party insurance loading factor λ_V*.*

The risk borne by the victim can be mitigated by two means: first-party insurance and injurer's greater precautions. The optimal standard balances these means. If the loading factor becomes very large, $\lambda > \frac{1}{p}\frac{\partial RP_V(h(x))}{\partial\delta}$, the victim forfeits insurance and eq. (3) applies.

Proposition (2) can be easily implemented. It requires the lawmaker to base its evaluation of the benefits of precaution on the expected reduction in harm scaled up by first-party insurance costs. As noted above, the loading factor normally lies in the 30-40% range.

Discrete example 2. Let us consider again the CRRA example. With a 30% loading factor, the optimal deductible is $\delta^* = \$41,031$ (so the victim is insured only for $\$8,969$). The value of the precautionary measure is now equal to \$577. This amount includes the expected harm (\$500), the saved insurance costs (\$27) and the cost of risk bearing (\$50).

3 Strict liability

Under strict liability the injurer is liable for damages independently of her investment in precaution. This liability regime applies to specific torts, most relevantly to harms caused by defective products, harms resulting from hazardous activities, and environmental harms.

Let us consider now the case in which the lawmaker decides the share k of the harm that should be compensated: $d = kh(x)$, with $k \geq 0$. If $k < 1$, damages undercompensate the victim (for example, by excluding pain and suffering). If $k > 1$, they overcompensate the victim (for example, by entailing a punitive component). To fix ideas, for the time being let us assume that $k \leq 1$ (so, the victim buys insurance against a loss, not a gain).

Given k, the expected utility of the injurer is

$$EU_I(x) = (1-p)\,u(y_I - c(x)) + pu(y_V - c(x) - kh(x)).$$

Maximization of $EU_I(x)$ is equivalent to the minimization of

$$L^I = c(x) + pkh(x) + RP_I(kh(x)),$$

where the $RP_I(kh(x))$ is the risk burden associated with the prospect of losing $kh(x)$ with probability p.

The injurer will therefore select the precaution level x^s that minimizes L^I :

$$c'(x^s) = k\ h'(x^s)\left[p + \ RP_I'(kh(x^s))\right]. \tag{8}$$

Eq. (8) parallels eq. (3). The same comparative statics results apply.

Lemma 1 *The injurer selects the level of precaution x^s that balances the cost of precaution and the damages burden. i) If the injurer becomes more averse to risk, the precaution level x^s increases. ii) If the probability of harm increases, the precaution level x^s increases. iii) If damages uniformly increase given precautions, the precaution level x^s increases. iv) When the injurer's income increases, the level of precaution x^s decreases if the injurer has Decreasing Absolute Risk Aversion.*

Let us consider now the optimal level of the damage awards.

The losses for the two parties are:

$$L^I = c(x^s) + pkh(x^s) + RP_I(kh(x^s)),$$
$$L^V = p(1-k)\ h(x^s) + RP_V((1-k)h(x^s)).$$

Both injurer and victim bear some risk. Social loss is:

$$SL = L^I + L^V = c(x^s) + ph(x^s) + RP_I(kh(x^s)) + RP_V((1-k)h(x^s)),$$

where x^s meets eq. (8).

So (omitting arguments),

$$\begin{aligned}\frac{\partial SL}{\partial k} &= \frac{\partial x^s}{\partial k}\frac{\partial L^I}{\partial x} + \frac{\partial x^s}{\partial k}\frac{\partial L^V}{\partial x} + h(x^s)\ RP_I' - h(x^s)RP_V' \\ &= \underbrace{\frac{\partial x^s}{\partial k}\left[(1-k)\ h'(x^s)(p+RP_V')\right]}_{\text{deterrence}} + \underbrace{h(x^s)\ (RP_I' - RP_V')}_{\text{risk shifting}},\end{aligned} \tag{9}$$

since $\frac{\partial L^I}{\partial x} = 0$.

An increase in damages (for $k < 1$): i) induces a reduction in the externality that the injurer exerts on the victim ("deterrence"), ii) increases the risk burden of the injurer, iii) reduces the risk burden of the victim.

For $k = 1^-$(full compensation), the deterrent effect vanishes and we get:

$$\lim_{k\to 1^-}\frac{\partial SL}{\partial k} = RP_I'(h(x^s)) > 0.$$

Let us briefly consider the case with $k > 1$ (over-compensation). We have $\frac{\partial SL}{\partial k} > 0$, since an increase in damages has a detrimental effect on both victim and injurer: increased precautions reduces the gain of the (overcompensated) victim; the risk burdens of both injurer and victim increase.

These observations prove that optimal damages are undercompensatory: $k^* < 1$ (as first shown by Shavell (1982)). Under expected utility, parties can bear very small losses at a negligible cost. So, under the optimal compensation rule, a positive share of the loss is left on the victim.

This leads us to the next result (proof in Appendix A5).

Proposition 3 *Strict liability. Optimal damages balance deterrence with the optimal allocation of the risk burden.*

i) Optimal damages are undercompensatory: $d^* < h(x^s)$.

ii) If the victim becomes more averse to risk, optimal damages increase.

iii) When the victim's income increases, optimal damages d^* *decrease if the victim has Decreasing Absolute Risk Aversion.*

Proposition 3 highlights the impact of risk aversion on optimal compensation: damages should be less than fully compensatory, they increase with the victim's degree of risk aversion, and they decrease with the victim's income (under DARA).

The impact of an increase in the injurer's degree of risk aversion on optimal damages cannot be signed: on the one hand, a transfer of risk from the injurer to the victim becomes more valuable (this calls for greater damages). On the other, the injurer has greater incentives to take precautions (this calls for lower damages). The net effect is ambiguous.

Strict liability with insured parties

Let us assume that both the injurer and the victim can purchase insurance.[11] The loading factor for third-party insurance is λ_I, while the loading factor for first-party insurance is λ_V. Each party decides how much insurance to purchase: δ_I is the deductible of the injurer, δ_V the deductible of the victim. The insurance company can observe the precaution level (i.e., the insurance company is involved in "loss control" activities). Again, for the time being let us assume that $k \leq 1$.

The loss of the injurer is now

$$L^I = c(x) + p(kh(x) - \delta_I)(1 + \lambda_I) + p\delta_I + RP_I(p, \delta_I).$$

[11] In the moves sequence, first the courts set damages, and then parties purchase insurance. So, damages are *not conditional* on whether parties have purchased insurance. Note further that, as will be shown below, the victim has no incentive to buy insurance coverage in excess of his uncompensated loss: he does not want to be compensated twice for the same harm. The collateral source rule does not apply here.

So, given x, the optimal δ_I should solve

$$\frac{\partial RP_I\left(p,k_I^*\right)}{\partial\delta_I}=\lambda_I\ p. \tag{10}$$

The optimal precaution x^S solves (using 10)

$$\begin{aligned}\frac{\partial L_I}{\partial x}&=c'\left(x^S\right)+h'\left(x^S\right)pk\left(1+\lambda_I\right)=0,\ \text{i.e.}\\ c'\left(x^S\right)&=-pk\ h'\left(x^S\right)\left(1+\lambda_I\right).\end{aligned}$$

The marginal benefit of precaution now includes the reduction in expected liability and the reduction in the insurance cost.

The victim chooses the deductible δ_V^* so that (in line with eq. (10), assuming an interior solution):

$$\frac{\partial RP_V\left(p,\delta^*\right)}{\partial\delta_V}=\lambda_V\ p.$$

The optimal compensation k^* should solve

$$\begin{aligned}\min_k SL^S&=L_I+L_V\\ &=c\left(x^S\right)+p\left(kh\left(x^S\right)-\delta_I^*\right)\left(1+\lambda_I\right)+p\delta_I^*+RP_I\left(\delta_I^*\right)\\ &+p\left(\left(1-k\right)h\left(x^S\right)-\delta_V^*\right)\left(1+\lambda_V\right)+p\delta_V^*+RP_V\left(\delta_V^*\right),\end{aligned}$$

with

$$\begin{aligned}\frac{\partial SL}{\partial k}&=\frac{\partial x}{\partial k}\frac{\partial L_V}{\partial x}+\frac{\partial L_I}{\partial k}+\frac{\partial L_V}{\partial k}\\ &=\frac{\partial x}{\partial k}ph'\left(x^S\right)\left(1-k\right)\left(1+\lambda_V\right)+ph\left(x^S\right)\left(1+\lambda_I\right)\\ &-ph\left(x^S\right)\left(1+\lambda_V\right),\end{aligned}$$

that is

$$\frac{\partial SL}{\partial k}=\underbrace{\frac{\partial x}{\partial k}ph'\left(x^S\right)\left(k-1\right)\left(1+\lambda_V\right)}_{\text{deterrence}}+\underbrace{ph\left(x^S\right)\left(\lambda_I-\lambda_V\right)}_{\text{insurance costs shifting}}. \tag{11}$$

Again, an increase in damages (k) has two effects: on the one hand, it provides the injurer with greater incentives to take precaution. This reduces the externality that the injurer exerts on the victim ("deterrence"). On the other hand, it shifts risk from the victim to the injurer. This induces the injurer to buy extra insurance at cost λ_I, while the victim saves λ_V.

At $k = 1^-$, we have:

$$\lim_{k \to 1^-} \frac{\partial SL}{\partial k} = ph\left(x^S\right)\left(\lambda_I - \lambda_V\right),$$

which is positive if $\lambda_I > \lambda_V$. If this is not the case, optimal damages are fully compensatory.

It should be noted here that overcompensatory damages cannot be optimal: for $k > 1$ deterrence is excessive and both injurer and victim have to pay insurance costs.

Proposition 4 *Optimal damages balance deterrence with the optimal allocation of the insurance costs.*

If $\lambda_I \leq \lambda_V$, optimal damages are fully compensatory: $k^* = 1$.

If $\lambda_I > \lambda_V$, optimal damages are under-compensatory: $k^* < 1$. They increase with λ_V .

Optimal damages are under-compensatory only if the victim has access to cheaper insurance.

It might be argued here that, even if injurer and victim have access to the same insurance market, the loading factor for the injurer is likely to be higher. This is because third-party insurance costs account for loss-control activities and for larger loss adjustment expenses (due to the defence costs associated with litigation and settlement negotiation).[12]

[12] See Harrington and Niehaus (2012), p. 146.

4 Concomitant harms

In this Section, I analyze the impact of the risk structure on the liability system. Let us first consider the case in which a victim can suffer several harms caused by different injurers. Positive correlation arises when harms tend to occur together. Positive correlation may be due to a latent factor, say the poor health condition of the individual, that makes him/her prone to injury.[13] I assume that parties are not insured, either because insurance is not available or is too costly.[14]

Precaution x_1, taken by Injurer 1, reduces harm $h_1(x_1)$, while precaution x_2, taken by Injurer 2, reduces harm $h_2(x_2)$. Harm one and two can occur simultaneously, with the following probabilities:

	0	$h_1(x_1)$	*marginal*
0	p_0	p_1	$1-\pi_2$
$h_2(x_2)$	p_2	p_3	π_2
marginal	$1-\pi_1$	π_1	

The victim suffers: no harm with probability p_0, harm $h_1(x_1)$ with probably p_1, harm $h_2(x_2)$ with probability p_2, and both harms with probability p_3. Clearly, $p_0+p_1+p_2+p_3=1$.

To focus on the impact of correlation, let us assume for simplicity that the two harms are perfectly symmetric: precautions entail the same costs, $c_1(x_1)=c_2(x_2)=c(x)$, and they have the same impact on harm $h_1(x_1)=h_2(x_2)=h(x)$. The two harms occur with the same marginal probabilities: $\pi_1=\pi_2=\pi$.

Let us define $r=p_3-\pi^2$, where r is the covariance between harms. If $r>0$, harms are positively correlated, if $r<0$ they are negatively correlated.[15] We have: $p_1=p_2=(1-\pi)\pi-r$, and $p_0=(1-\pi)^2+r$.

[13] Under the eggshell skull rule, the particular vulnerability of the victim does not exempt the injurers from liability.

[14] The same arguments go through when parties are insured, under the assumption that correlation of harms calls for a higher insurance premium.

[15] In fact, the correlation between harms is $\rho=\frac{p_3-\pi_1\pi_2}{\sqrt{\pi_1(1-\pi_1)}\sqrt{\pi_2(1-\pi_2)}}=\frac{r}{\pi(1-\pi)}$.

Negligence. The expected utility of the victims is

$$\begin{aligned} EU_V = & \left((1-\pi)^2 + r\right) v\left(y_V\right) + \left(\left(1-\pi\right)\pi - r\right) v\left(y_V - h\left(x_1\right)\right) \\ & + \left(\left(1-\pi\right)\pi - r\right) v\left(y_V - h\left(x_2\right)\right) + \left(\pi^2 + r\right)\ v\left(y_V - h\left(x_1\right) - h\left(x_2\right)\right). \end{aligned}$$

The marginal benefits of precaution are now (omitting arguments):

$$b_1'\left(x_1, x_2\right) = -h_1' \frac{\left(\left(1-\pi\right)\pi - r\right) v'\left(y_V - h_1\right) + \left(\pi^2 + r\right) v'\left(y_V - h_1 - h_2\right)}{EU_V'}, \tag{12}$$

$$b_2'\left(x_1, x_2\right) = -h_2' \frac{\left(\left(1-\pi\right)\pi - r\right) v'\left(y_V - h_2\right) + \left(\pi^2 + r\right) v'\left(y_V - h_1 - h_2\right)}{EU_V'}, \tag{13}$$

with

$$\frac{\partial b_1'\left(x_1, x_2\right)}{\partial r} > 0, \quad \frac{\partial b_2'\left(x_1, x_2\right)}{\partial r} > 0.$$

When harms become more positively correlated, the risk burden of the victim goes up and the insurance value of precaution increases. On the basis of this observation, in Appendix A6 I prove the optimal standards $\overline{x}_1$ and $\overline{x}_2$ increase with r.

Strict liability. Under strict liability, each injurer j bears a share k_j of the harm, with $j \in \{1, 2\}$. The residual parts of the harms are borne by the victim and they can be correlated.

The optimal compensation shares k_1 and k_2 should meet

$$\frac{((1-\pi)\pi-r)v'(y_V-h_1)+\left(\pi^2+r\right)v'(y_V-h_1-h_2)}{EU_V'} \left[h_1 - \frac{\partial x_1^s}{\partial k_1}\left(1-k_1\right) h_1'\right] = \frac{p\ u_1'(-)h_1}{(1-p)u_1'(+)+u_1'(-)}, \tag{14}$$

$$\frac{((1-\pi)\pi-r)v'(y_V-h_1)+\left(\pi^2+r\right)v'(y_V-h_1-h_2)}{EU_V'} \left[h_2 - \frac{\partial x_2^s}{\partial k_2}\left(1-k_2\right) h_2'\right] = \frac{p\ u_2'(-)h_2}{(1-p)u_2'(+)+pu_2'(-)}, \tag{15}$$

where u_1 is the utility function of Injurer 1 and u_2 is the utility function of Injurer 2, $(-)$ represents the payoff of the injurer when the harm occurs, and $(+)$ the payoff of the injurer when the harm does not occur.

As r increases (harms become more positively correlated), the left hand sides of eqs. (14) and (15) increase: the victim nets a greater benefit from insurance. Optimal damages become higher.

Proposition 5 *Concomitant harms.*

Negligence. If the correlation between the harms affecting the victim increases, the optimal precaution standards increase.

Strict liability. If the correlation between the harms affecting the victim increases, optimal damages increase.

In the presence of victims who are likely to suffer concomitant harms, the standards of precaution should be higher. Relatedly, in a strict liability regime, the victim should be more generously compensated.

Note that the result applies also when the concomitant harm is not the result of a tortuous conduct. If harm 1 is positively correlated with a financial loss, for example, then the optimal standard for harm 1 is larger.

Robustness. It is important to emphasize that the previous results are not limited to the case in which precautions only affect the magnitude of harm. Analogous results apply to the case in which precautions affect both the magnitude and the probabilities of harm (p_0 to p_3).

Again, let harms be symmetric ($h_1(x_1) = h_2(x_2) = h(x)$). Let $\pi = \pi(x_1, x_2)$ be the marginal probabilities of harm, with $\frac{\partial \pi(x_1,x_2)}{\partial x_1} < 0$, $\frac{\partial \pi(x_1,x_2)}{\partial x_2} < 0$, and let $r = r(x_1, x_2)$ be the covariance between harms. In Appendix A7, I show that *if precautions reduce the covariance as well as the marginal probability of harm, precaution standards (under negligence) and damages (under strict liability) should be larger*.

Superadditivity. It should be noted how positive correlation across harms, combined with risk aversion, makes harms "superadditive:" the concomitant occurrence of harm one and harm two inflicts to the victim an effective loss that is larger than the sum of the two harms. The interdependence of the harms has an impact on the optimal precaution levels. Under negligence, superadditivity entails larger precaution standards: precautions become more valuable because the loss is amplified by the compounding of the harms. A similar effect arises under strict liability: because the uncompensated shares of the harm compound on each other, precautions become more valuable to the victim. Efficient damages become larger.[16]

Conversely, negative correlation induces "subadditivity" of harms, as in the extreme case in which one object can only be destroyed once (say, driver one and driver two independently crash into the same property). Subadditivity reduces the total loss resulting from the two accidents. It calls for lower standards and lower damages.[17]

Correlation across victims

The previous analysis has investigated the correlated nature of the harms affecting the same victim. A related issue concerns the correlation of harms across victims, which might arise, for example, when a badly designed product is brought to the market (positive correlation across victims) or when a single bullet is accidentally shot (negative correlation across victims). The correlation across victims has no impact on the optimal negligence standard, because the losses are borne by the victims (each victim bears her own loss).

Correlation of harms matters, however, under a regime of strict liability, because it induces correlation in the liability outlays of the injurers.[18] Here, the equivalent of Lemma 1 applies: *given the damages, the injurer will take greater precautions if harms are positively correlated across victims and lower precautions if harms are negatively correlated across victims.*

As for the optimal damages level, the impact of correlation is ambiguous, as it acts like a variation in the injurers' degree of risk aversion. Take the case of positive

[16]Kornhauser and Revesz (1989) investigates the consequences of superadditivity for non-distinct harms under joint and several liability. Daughety and Reinganum (2014) studies product-related harms that increase nonlinearly with the quantity consumed. Superadditivity affects the market relationship across firms and has an impact on market performance.

[17]When harms are superadditive, precautions become "substitutes:" precaution one makes precaution two less valuable (if harm one does not occur, the victim is less sensitive to harm two). When harms are subadditive, precautions become "complements:" precaution one makes precaution two more valuable (if driver one has not crashed into the property, driver two has to be more careful). In a joint liability situation - if damages are not properly adjusted - over or underinvestment is likely to occur (see Guttel and Leshem (2014) and Guttel et al. (2021)).

[18]Note that also corporations tend to display aversion to risk. In fact, they often purchase insurance (*Commercial General Liability* policies). The reasons why this is so are reviewed by Baker and Siegelman (2013).

correlation. While the transfer of risk from the injurer to the victim becomes more valuable, the injurer has greater incentives to take precautions. So, optimal damages might increase or decrease.

5 Conclusions

The efficiency perspective pursued by this paper postulates that standards of care and damage awards should maximize the welfare of the parties. In other terms, the paper identifies the features that parties themselves would choose, if they could design the liability system together. In this perspective, victims formulate a "demand" for insurance, which is met in part by the insurance sector and in part by the liability system. The demand of the victims follows the same pattern as the demand that can be observed in standard insurance markets. The costs of the insurance market can also be easily assessed. This implies that the normative implications of risk aversion can be easily translated in data-driven policy recommendations.

Once we conceive the liability system as a risk-allocation mechanism, the following factors become central for the analysis: i) the cost of private insurance, and ii) the dependence structure of the harms. Costly insurance and positive correlation (on the victim's side) increase the benefits of precaution: they call for higher negligence standards and higher damage awards (under strict liability). Conversely, cheap insurance and negative correlation call for lower standards and smaller damages.

Appendix

A1. Condition S. The injurer prefers to meet the standard of care $\overline{x}$ if

$$c(\overline{x}) < c(x^s) + ph(x^s) + RP_I(h(x^s)),$$

where

$$x^s = \arg\min\left[c(x^s) + ph(x^s) + RP_I(h(x^s))\right].$$

In turn, if the injurer is not liable, the optimal standard $\overline{x}^*$ should meet:

$$\overline{x}^* = \arg\min\left[c(\overline{x}) + ph(\overline{x}) + RP_V(h(\overline{x}))\right].$$

If the Condition:

$$RP_V(h(x^s)) < RP_I(h(x^s)) \tag{16}$$

is met, we have

$$\begin{aligned} c(\overline{x}^*) < c(\overline{x}^*) + ph(\overline{x}^*) + RP_V(h(\overline{x}^*)) < \\ c(x^s) + ph(x^s) + RP_V(h(x^s)) < c(x^s) + ph(x^s) + RP_I(h(x^s)). \end{aligned}$$

So, if Condition (16)is met, the injurer meets the optimal standard $\overline{x}^*$.

A2. The Pareto efficient negligence standard $\overline{x}^*$ is obtained from

$$\begin{aligned} &\max_x EU_V(x) = (1-p)v(y_V - t) + pv(y_V - t - h(x)) \\ &s.t. \quad EU_I(x) = u(y_I - c(x) + t) = k_I, \end{aligned}$$

where t is an ex-ante transfer from the victim to the injurer and k_I a constant.

The maximization problem can be rewritten as

$$\begin{aligned} &\max_x v(y_V - t - ph(x) - RP_V(h(x))) \\ &s.t.\ y_I - c(x) + t = u^{-1}(k_I) \equiv k_{2.} \end{aligned}$$

Since v is monotonic, the problem can be we written as (substituting for t) :

$$\max_x y_V - k_2 + y_I - c(x) - ph(x) - RP_V(h(x)). \tag{17}$$

Maximization of (17) is equivalent to the minimization of the Social Loss

$$SL = c(x) + ph(x) + RP_V(h(x)).$$

A3. From (4), optimal standard should meet

$$c'(\overline{x}^*) = -h'(\overline{x}^*) \frac{1}{1 + \frac{(1-p)}{p} \frac{u'(y_V)}{u'(y_V - h(\overline{x}^*))}}, \tag{18}$$

If the victims' utility function u is replaced by the function $v(y) = \varphi(u(y))$, with $\varphi' > 0$, $\varphi'' < 0$, then the optimal standard should meet

$$c'(\overline{x}^*) = -h'(\overline{x}^*) \frac{1}{1 + \frac{(1-p)}{p} \frac{\varphi'(u(y))u'(y_V)}{\varphi'(u((y_V - h(\overline{x}^*))))u'(y_V - h(\overline{x}^*))}} \tag{19}$$

For any $\overline{x}^*$, the RHS of eq. (19) is larger than the RHS of (18) since $\varphi'(u(y)) < \varphi'(u((y_V - h(\overline{x}^*))))$, due to the concavity of φ. So, if victims become more averse to risk, the optimal standard should increase. If the victim becomes infinitely averse to risk, the marginal benefit converges to $-h'(\overline{x}^*)$: the victim behaves as if the accident were to happen for sure. ii) From eq. (18), it is also clear that the marginal benefit of precaution increases if p increases. iii) Let the harm be equal to $h(x) + z$, where z is the baseline harm (a level of harm independent of the precaution level). As z increases, the marginal utility in the adverse state increases, and so does the demand for insurance. iv) From (18), it can be seen that the marginal benefit of precaution decreases with the victims' income if $\frac{u'(y_V)}{u'(y_V - h(\overline{x}^*))}$ increases in y_V, which is the case if, and only if: $u''(y_V)u'(y_V - h(\overline{x}^*)) - u'(y_V)u''(y_V - h(\overline{x}^*)) > 0$, i.e., $\frac{u'(y_V - h(\overline{x}^*))}{u''(y_V - h(\overline{x}^*))} > \frac{u'(y_V)}{u''(y_V)}$.

A4. With insurance, optimal standard should meet (from 7),

$$c'(\overline{x}^*) = -h'(\overline{x}^*) \frac{1}{1 + \frac{(1-p)}{p} \frac{u'(y_V)}{u'(y_V - \delta^*)}}. \tag{20}$$

Since $\delta^* \leq h(x)$, for any x, the RHS of (20) is less than the RHS of (18).

A5. Optimal damages are obtained from

$$\begin{aligned}
&\max EU_V(x) = (1-p)\,v(y_V - t) + pv(y_V - t - (1-k)\,h(x)) \\
&s.t. \quad EU_I(x) = (1-p)\,u(y_I - c(x^s) + t) + pu(y_V - c(x^s) - kh(x^s) + t) = c_I, \\
&\qquad\qquad x^s = \arg\max EU_I(x).
\end{aligned}$$

The Lagrangian is

$$\mathcal{L} = EU_V(k,t) + \lambda\,[EU_I(k,t) - c_I],$$

and the optimal solution solves

$$\begin{aligned}
\tfrac{\partial \mathcal{L}}{\partial k} &= \tfrac{\partial EU_V(x)}{\partial k} + \lambda\left[\tfrac{\partial EU_I(x)}{\partial k}\right] = 0, \\
\tfrac{\partial \mathcal{L}}{\partial t} &= \tfrac{\partial EU_V(x)}{\partial t} + \lambda\left[\tfrac{\partial EU_I(x)}{\partial t}\right] = 0, \\
\tfrac{\partial \mathcal{L}}{\partial \lambda} &= EU_I(x) - c_I = 0.
\end{aligned}$$

Solving for λ the first two equations yields:

$$\lambda = -\frac{\frac{\partial EU_V(x)}{\partial k}}{\frac{\partial EU_I(x)}{\partial k}} = -\frac{\frac{\partial EU_V(x)}{\partial t}}{\frac{\partial EU_I(x)}{\partial t}}.$$

or

$$\left.\frac{\partial t}{\partial k}\right|_V = \frac{\frac{\partial EU_V(x)}{\partial k}}{\frac{\partial EU_V(x)}{\partial t}} = \frac{\frac{\partial EU_I(x)}{\partial k}}{\frac{\partial EU_I(x)}{\partial t}} = \left.\frac{\partial t}{\partial k}\right|_I.$$

The term on the RHS measures how much money the victim is willing to pay to get additional insurance (an increase in damages); the RHS how much money the injurer is demanding to provide additional insurance.

By differentiation, we get (omitting arguments)

$$\frac{pv'(y_V - t - (1-k)h)h + \frac{\partial x^s}{\partial k}\frac{\partial EU_V}{\partial x}}{(1-p)v'(y_V - t) + pv'(y_V - t - (1-k)h)} = \frac{pu'(y_V - c - kh + t)h - \frac{\partial x^s}{\partial k}\frac{\partial EU_I}{\partial x}}{(1-p)u'(y_I - c(x^s) + t) + pu'(y_V - c(x^s) - kh + t)}$$

where $\frac{\partial EU_I(x)}{\partial x^s} = 0$ because x^s is optimally chosen by the injurer. This yields

$$\frac{pv'(-)\;\,h - \frac{\partial x^s}{\partial k} pv'(-)\;\,(1-k)\,h'}{(1-p)\,v'(+) + pv'(-)} = \frac{p\;u'(-)\,h}{(1-p)\,u'(+) + pu'(-)},$$

where $(-)$ represents the payoff when the accident occurs and $(+)$ the payoff when the accident does not occur. The latter equation can be rewritten as

$$\frac{\frac{\partial x^s}{\partial k} h' \; pv'(-)(1-k)}{(1-p)v'(+)+pv'(-)} + h\left[\frac{p \; u'(-)}{(1-p)u'(+)+pu'(-)} - \frac{pv'(-)}{(1-p)v'(+)+pv'(-)}\right] = 0, \quad (21)$$

which is the same as eq. (9) of the body. The first term is the "externality effect:" an increase in k induces an increase in the precaution and thus a reduction of the loss suffered by the victim. The second term (in square brackets) captures the shift in the risk burden: an increase in k raises the burden for the injurer and reduces that of the victim.

If the level of harm were insensitive to precautions ($\frac{\partial x^s}{\partial k} = 0$), then only the optimal risk allocation would matter and optimal damages would yield:

$$\frac{p \; u'(-)}{(1-p)u'(+)+pu'(-)} = \frac{pv'(-)}{(1-p)v'(+)+pv'(-)},$$

that is

$$\frac{u'(-)}{u'(+)} = \frac{v'(-)}{v'(+)}.$$

The ratio of the marginal utilities of money in the accident and non-accident states would be the same for both parties.

If $k \to 1^-$, the victim is perfectly insured ($v'(-) = v'(+)$) and the externality effect vanishes. We get

$$\lim_{k-1^-} \left.\frac{\partial t}{\partial k}\right|_V = h(x^s),$$

the price the victim is willing to pay to increase k is just the expected value of the loss. When the risk is very small, the victim behaves like a risk-neutral agent. Thus

$$\left.\frac{\partial t}{\partial k}\right|_I = h(x)\frac{p \; u'(-)}{(1-p)u'(+)+pu'(-)} > \left.\frac{\partial t}{\partial k}\right|_V = h(x):$$

the injurer is willing to pay a price greater than $h(x)$ to relinquish the risk: $k = 1$ cannot be optimal.

Eq. (21) can be rewritten as:

$$\frac{pv'(-)}{(1-p)v'(+)+pv'(-)}\left[h(x) - \frac{\partial x^s}{\partial k}(1-k)h'(x)\right] = \frac{p \; u'(-)h(x^s)}{(1-p)u'(+)+pu'(-)}. \quad (22)$$

At the optimum, $\left[h(x) - \frac{\partial x^s}{\partial k}(1-k)\,h'(x)\right]$ has to be positive.

We can then observe that, if the victim becomes more averse to risk (v is subject to a concave transformation), the LHS of (22) increases and optimal damages increase. Similarly, under DARA, when the victim's income increases, optimal damages increase.

A6. Concomitant harms. The marginal benefits of precautions x_1 and x_2 are (omitting arguments):

$$b_1'(x_1,x_2) = -h_1' \frac{1}{1+\frac{((1-\pi)^2+r)v'(y_V)+((1-\pi)\pi-r)v'(y_V-h_2)}{((1-\pi)\pi-r)v'(y_V-h_1)+(\pi^2+r)v'(y_V-h_1-h_2)}},$$
$$b_2'(x_1,x_2) = -h_2' \frac{1}{1+\frac{((1-\pi)^2+r)v'(y_V)+((1-\pi)\pi-r)v'(y_V-h_1)}{((1-\pi)\pi-r)v'(y_V-h_2)+(\pi^2+r)v'(y_V-h_1-h_2)}},$$

or, to ease notation,

$$b_1'(x_1,x_2) = -h_1' \frac{1}{1+\frac{p_0v_0'+p_2v_2'}{p_1v_1'+p_3v_3'}}, \tag{23}$$
$$b_2'(x_1,x_2) = -h_2' \frac{1}{1+\frac{p_0v_0'+p_1v_1'}{p_2v_2'+p_3v_3'}}, \tag{24}$$

The optimal standards should meet:

$$\begin{cases} b_1'(x_1,x_2) - c_1'(x_1) = 0, \\ b_2'(x_1,x_2) - c_2'(x_2) = 0, \end{cases}$$

where

$$b_{11}''(x_1,x_2) - c_{11}''(x_1) < 0 \Leftrightarrow$$
$$\left(-h_{11}'' \frac{1}{1+\frac{p_0v_0'+p_2v_2'}{p_1v_1'+p_3v_3'}} + h_1' \frac{\frac{-(p_0v_0'+p_2v_2')(p_1v_1''+p_3v_3'')}{\left(p_1v_1'+p_3v_3'\right)^2}(-h_1')}{\left(1+\frac{p_0v_0'+p_2v_2'}{p_1v_1'+p_3v_3'}\right)^2} - c_{11}'' \right) < 0,$$

which holds because $h_{11}'' > 0$, $c_{11}'' > 0$, $h_1' < 0$, $v_1'' < 0, v_3'' < 0$.

Note further that, at the optimum, we must have

$$\begin{aligned} \det H &= \det \begin{bmatrix} b_{11}'' - c_{11}'' & b_{12}'' \\ b_{21}'' & b_{22}'' - c_{22}'' \end{bmatrix} \\ &= \left(b_{11}'' - c_{11}''\right)\left(b_{22}'' - c_{22}''\right) - b_{21}''b_{12}'' \geq 0. \end{aligned}$$

In a symmetric solution, this implies that

$$\left|b''_{11} - c''_{11}\right| \geq \left|b''_{12}\right|.$$

From the theory of comparative statics we know that

$$\frac{\partial x_1}{\partial r} > 0 \iff \frac{\det \begin{bmatrix} \frac{\partial\left(b'_1 - c'_1\right)}{\partial r} & \frac{\partial\left(b'_1 - c'_1\right)}{\partial x_2} \\ \frac{\partial\left(b'_2 - c'_2\right)}{\partial r} & \frac{\partial\left(b'_2 - c'_2\right)}{\partial x_2} \end{bmatrix}}{\det H} > 0.$$

Thus

$$\begin{aligned} \frac{\partial x_1}{\partial r} > 0 \iff & \frac{\partial b'_1}{\partial r} \frac{\partial\left(b'_2 - c'_2\right)}{\partial x_2} < \frac{\partial\left(b'_1 - c'_1\right)}{\partial x_2} \frac{\partial b'_2}{\partial r} \\ \iff & \frac{\partial b'_1}{\partial r} \frac{\partial\left(b'_2 - c'_2\right)}{\partial x_2} < \frac{\partial b'_1}{\partial x_2} \frac{\partial b'_2}{\partial r}. \end{aligned}$$

Note that

$$\frac{\partial b'_1}{\partial r} > 0 \iff \left(v'_0 - v'_2\right)\left[p_1 v'_1 + p_3 v'_3\right] < \left[p_0 v'_0 + p_2 v'_2\right]\left(v'_3 - v'_1\right),$$

which holds because $v'_0 < v'_2$ and $v'_3 > v'_1$ due to the concavity of the utility function.

In a symmetric solution, $\frac{\partial b'_1}{\partial r} = \frac{\partial b'_2}{\partial r}$, so

$$\begin{aligned} \frac{\partial x_1}{\partial r} > 0 \iff & \frac{\partial\left(b'_2 - c'_2\right)}{\partial x_2} < \frac{\partial b'_1}{\partial x_2} \iff \frac{\partial\left(b'_1 - c'_1\right)}{\partial x_1} < \frac{\partial b'_1}{\partial x_2} \\ \iff & -h''_{11} \frac{1}{1 + \frac{p_0 v'_0 + p_2 v'_2}{p_1 v'_1 + p_3 v'_3}} + h'_1 \frac{\frac{-\left(p_0 v'_0 + p_2 v'_2\right)\left(p_1 v''_1 + p_3 v''_3\right)}{\left(p_1 v'_1 + p_3 v'_3\right)^2}\left(-h'_1\right)}{\left(1 + \frac{p_0 v'_0 + p_2 v'_2}{p_1 v'_1 + p_3 v'_3}\right)^2} - c''_{11} < \\ & h'_1 \frac{\frac{\left(p_2 v''_2\right)\left(p_1 v''_1 + p_3 v''_3\right) - \left(p_0 v'_0 + p_2 v'_2\right) p_3 v''_3}{\left(p_1 v'_1 + p_3 v'_3\right)^2}\left(-h'_2\right)}{\left(1 + \frac{p_0 v'_0 + p_2 v'_2}{p_1 v'_1 + p_3 v'_3}\right)^2}. \end{aligned}$$

The latter inequality holds (given symmetry) if

$$\begin{aligned} \left(p_0 v'_0 + p_2 v'_2\right)\left(p_1 v''_1 + p_3 v''_3\right) < -\left(p_2 v''_2\right)\left(p_1 v'_1 + p_3 v'_3\right) + \left(p_0 v'_0 + p_2 v'_2\right) p_3 v''_3, \text{ i.e.} \\ \left(p_0 v'_0 + p_2 v'_2\right) p_1 v''_1 < -\left(p_1 v''_1\right)\left(p_1 v'_1 + p_3 v'_3\right), \end{aligned}$$

which is true because $v_1'' < 0$. This proves that $\frac{\partial x_1}{\partial r} > 0$.

Going through the same steps as in A5 (eq. 22), optimal damages under strict liability should meet

$$\begin{cases} \frac{((1-\pi)\pi-r)v'(y_V-h_1)+\left(\pi^2+r\right)v'(y_V-h_1-h_2)}{EU_V'}\left[h_1-\frac{\partial x_1^s}{\partial k_1}\left(1-k_1\right)h_1'\right]=\frac{p\ u_1'(-)h_1}{(1-p)u_1'(+)+u_1'(-)}, \\ \frac{((1-\pi)\pi-r)v'(y_V-h_1)+\left(\pi^2+r\right)v'(y_V-h_1-h_2)}{EU_V'}\left[h_2-\frac{\partial x_2^s}{\partial k_2}\left(1-k_2\right)h_2'\right]=\frac{p\ u_2'(-)h_2}{(1-p)u_2'(+)+pu_2'(-)}. \end{cases}$$

As r increases, the transfer of risk from the injurers to the victim becomes more valuable. Optimal damages increase.

A7. Precautions affect the probability of harm. The expected utility of the victim is given by

$$\begin{aligned} EU_V &= \left[(1-\pi_1)(1-\pi_2)+r\right]v\left(y_V\right)+\left[(1-\pi_2)\pi_1-r\right]v\left(y_V-h_1\left(x_1\right)\right) \\ &\quad +\left[(1-\pi_1)\pi_2-r\right]v\left(y_V-h_2\left(x_2\right)\right)+\left[\pi_1\pi_2+r\right]v\left(y_V-h_1\left(x_1\right)-h_2\left(x_2\right)\right), \end{aligned}$$

where $\pi_1,\ \pi_2$, and r, depend on x_1.and x_2

The marginal benefit of an increase in x_1 is equal to:

$$-\frac{\frac{\partial EU_V}{\partial \pi_1}\frac{\partial \pi_1}{\partial x_1}+\frac{\partial EU_V}{\partial \pi_2}\frac{\partial \pi_2}{\partial x_1}+\frac{\partial EU_V}{\partial r}\frac{\partial r}{\partial x_1}+\frac{\partial EU_V}{\partial h_1(x_1)}\frac{\partial h_1(x_1)}{\partial x_1}}{\frac{\partial EU_V}{\partial y}}.$$

Taking the effects on $\pi_1,\ \pi_2$, and $h_1\left(x_1\right)$ as given, let us focus on the effect on r.

We have (omitting arguments):

$$\frac{\partial r}{\partial x_1}\frac{\frac{\partial EU_V}{\partial r}}{\frac{\partial EU_V}{\partial y}}=-\frac{\partial r}{\partial x_1}\frac{v\left(y_V\right)-v\left(y_V-h_1\right)-v\left(y_V-h_2\right)+v\left(y_V-h_1-h_2\right)}{\frac{\partial EU_V}{\partial y}},$$

where, again,

$$v\left(y_V\right)-v\left(y_V-h_1\right)-v\left(y_V-h_2\right)+v\left(y_V-h_1-h_2\right)<0$$

by the concavity of the utility function. Precautions that increase the covariance between harms (given the marginals and the magnitudes of harm) are detrimental to the victim (and vice versa). In a symmetric solution, this is enough to prove that precaution standards should be higher if precautions reduce the covariance of the harms.

Similarly, under strict liability, the victim nets a larger benefit from an increase in the injurers' liability if precautions reduce the covariance between harms.

References

Abraham, K. (2008). *The Liability Century.* Cambridge: Harvard University Press.

Baker, T. and P. Siegelman (2013). The law and economics of liability insurance: a theoretical and empirical review. In J. Arlen (Ed.), *Research Handbook on the Economics of Torts.* Edward Elgar Publishing.

Barseghyan, L., F. Molinari, T. O'Donoghue, and J. C. Teitelbaum (2013). The Nature of Risk Preferences: Evidence from Insurance Choices. *American Economic Review 103*(6), 2499–2529.

Daughety, A. F. and J. F. Reinganum (2014). Cumulative harm and resilient liability rules for product markets. *Journal of Law, Economics, and Organization 30*(2), 371–400.

Franzoni, L. A. (2016). Correlated accidents. *American Law and Economics Review 18*(2), 358–384.

Franzoni, L. A. (2017). Liability law under scientific uncertainty. *American Law and Economics Review 19*(2), 327–360.

Geistfeld, M. A., E. Karner, B. A. Koch, and C. Wendehorst (2022). *Civil Liability for Artificial Intelligence and Software.* Berlin: De Gruyter.

Greenwood, P. and C. Ingene (1978). Uncertain externalities, liability rules, and resource allocation. *The American Economic Review 68*(3), 300–310.

Guttel, E. and S. Leshem (2014). The uneasy case of multiple injurers liability. *Theoretical Inquiries in Law 15*(2), 261–292.

Guttel, E., Y. Procaccia, and E. Winter (2021). Shared liability and excessive care. *The Journal of Law, Economics, and Organization 37*(2), 358–391.

Harrington, S. and G. Niehaus (2012). *Risk Management and Insurance.* New York: McGraw Hill.

Kahan, M. (1989). Causation and incentives to take care under the negligence rule. *The Journal of Legal Studies 18*(2), 427–447.

Kornhauser, L. A. (2013). Economic analysis of joint and several liability. In *Research handbook on the economics of torts*, pp. 199–233. Cheltenham: Edward Elgar Publishing.

Kornhauser, L. A. and R. L. Revesz (1989). Sharing damages among multiple tortfeasors. *Yale Law Journal 98*(5), 831–884.

Nell, M. and A. Richter (2003). The design of liability rules for highly risky activities: Is strict liability superior when risk allocation matters? *International Review of Law and Economics 23*(1), 31–47.

Rejda, G., M. McNamara, and W. Rabel (2020). *Principles of Risk Management and Insurance*. London: Pearson Education.

Schlesinger, H. (2013). The theory of insurance demand. In G. Dionne (Ed.), *Handbook of insurance*, pp. 167–184. New York: Springer.

Schweizer, U. (2016). Efficient incentives from obligation law and the compensation principle. *International Review of Law and Economics 45*, 54–62.

Shavell, S. (1982). On liability and insurance. *The Bell Journal of Economics 13*(1), 120–132.