Efficient liability law when parties genuinely disagree

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Abstract

This paper extends the classic economic approach to liability law to the case in which injurer and victim entertain different beliefs about the probability of harm and thus rely on different "causal models." Under strict liability, the precaution level is pegged to the causal model of the injurer; under negligence, to that of the victim. By relying on the notions of Pareto efficiency and No Betting Pareto efficiency, the paper shows that negligence is the optimal liability rule when the injurer believes that the probability of harm is higher than the victim does, while strict liability with overcompensatory damages is the optimal rule in the opposite case. The same results apply to bilateral accidents and product-related harms.

Keywords: *negligence vs. strict liability, scientific uncertainty, Hand's rule, No Betting Pareto Dominance*

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"Every other creature can see what is. Our gift, which may sometimes be a curse, is that we can see what might have been." Judea Pearl

1 Introduction

In the case that was bound to mold contemporary negligence law, *United States v. Carrol Towing, 159 F.2d 169,* 1947, a tug operator had retied the plaintiff's barge to a pier while shifting other barges around. The readjustment of the ties resulted in the barge breaking loose and drifting into a tanker. The tanker's propeller broke a hole in the barge below the water line, eventually causing it to sink. The relevant issue was whether the absence of the plaintiff's bargee from the barge constituted contributory negligence. Had the bargee been aboard, he would have noticed the hole in the barge in time to prevent its sinking. In his famous decision, Justice Learned Hand argued that:

> Since there are occasions when every vessel will break from her moorings, and since, if she does, she becomes a menace to those about her; the owner's duty, as in other similar situations, to provide against resulting injuries is a function of three variables: (1) The probability that she will break away; (2) the gravity of the resulting injury, if she does; (3) the burden of adequate precautions. Possibly it serves to bring this notion into relief to state it in algebraic terms: if the probability be called P; the injury, L; and the burden, B; liability depends upon whether B is less than L multiplied by P: i.e., whether B < PL.

This formulation underscores the fact that the determination of negligence inevitably relies on an explanatory or causal model in which a conduct or, more often, the lack of a conduct, leads with some probability to adverse consequences. The simple structure of the problem is the following: under conduct A, harm occurs with probability $pr(H|A)$; under conduct B, harm occurs with probability $pr(H|B)$. Given the costs of A and B, and the magnitude of harm, should the lawmaker encourage the injurer to engage in conduct A or B?

Traditional economic analysis of torts engages in this type of exercise by presuming that $pr\left(H|\,A\right)$ and $pr\left(H|\,B\right)$ are "objective" probabilities known to all parties, including the court. In this paper, I will focus instead on the case in which probabilities cannot be easily calculated, either because evidence is scarce or because evidence is subject to conflicting interpretations. This implies that parties might reasonably disagree on the relevant probabilities, or, more generally, on the statistical/causal model governing the events. This paper will thus rely on "subjective" probabilities, representing parties' beliefs about the plausibility of different outcomes.[1]

The case for subjective probabilities is particularly strong with respect to technologies that are new and that are, therefore, relatively untested, and with respect to harms that occur with low frequency and that escape the statistical surveys.[2] Even for harms that are relatively frequent, however, it may be difficult to disentangle, in a univocal way, the impact that the injurer's conduct has on the actual occurrence of harm, due to the presence of confounding factors and long causal chains.[3] So, disagreement on the proper causal model is likely to emerge among the parties.[4]

In this paper, I assume that injurer and victim formulate divergent beliefs about the probability of harm, given the precaution level chosen by the injurer. I restrict the attention to beliefs that are "reasonable," that is, that are compatible with the evidence available. This formulation fits a pluralistic legal system, open to a variety of legitimate explanatory models. The normative analysis will be conducted by focussing

[1] This formulation does not do justice to the notion of "cause" underpinning tort liability. Yet, it suffices to analyze the problem. Subjective probabilities are associated with the names of Frank Ramsey, Bruno de Finetti, and Leonard Savage.

[2] The debate on the liability of self-driving cars, for instance, has to cut through a massive dose of uncertainty. A study by the Rand corporation estimates that, to demonstrate their reliability in terms of fatalities and injuries, self-driving cars would have to be driven for billions of miles, which could take hundreds of years (Kalra and Paddock (2016)).

[3] Explanations of why competing interpretations of the data can survive in the long run are provided, among others, by Al-Najjar (2009), Acemoglu et al. (2016), Montiel Olea et al. (2019) and Mailath and Samuelson (2020).

[4] It should be noted that tort law hinges more on the common sense of ordinary people than on the analytical precision of the scientific discourse (see Gilles (1994) and Keating (1996)). In turn, common sense tends to focus on the factors that make the difference with respect to the "normal" outcome (Hart and Honoré (1985)).

on the features that a Pareto efficient system should have, that is, on the features that injurers and victims themselves would choose, if they were to design the legal system together. While this exercise departs from the traditional economic analysis of torts, which posits that parties share the same "true" beliefs, it is in fact in line with the economic analysis of insurance markets, which recognizes that the individual "cost of risk" has an unavoidable subjective component.[5]

The analysis of this paper also departs from the behavioral literature, which emphasizes the myriad of biases and mistakes that affect people's relationship with the concept of risk.[6] While I recognize that careful reflection would allow parties to correct (most of) their mistakes, I assume that the self-correction process does not necessarily converge to a unique shared belief (or causal model): parties may ultimately agree to disagree in their assessments.[7]

Once we recognize that multiple explanatory models have a legitimate standing in the legal system, the issue arises of which model should guide the determination of liability and the allocation of the losses. In the paper, I compare strict liability with negligence.

Under strict liability, the conduct is decided by the injurer, and is thus pegged to her explanatory model. The injurer minimizes her expected "cost of accidents," which includes the cost of precaution and the expected damages awards. Here, the policy variable in the hands of the lawmaker is the level of damages. Optimal damages should at the same time provide the injurer with incentives to take precautions and allocate the risk between the parties, ideally to the party for which harm is less likely. So, damages should be undercompensatory if injurers are risk pessimistic (they believe that harm is more likely than the victim does), while they should be overcompensatory if injurers

[5] Machina (2013) notes that: "The classic distinction between casino-type *gambling decisions* and real-world *insurance decisions* is that the former involve objective probabilities which are well specified and agreed upon, whereas the latter involve individuals' and firms' subjective beliefs over the likelihoods of alternative events or states of nature."

[6] See Halbersberg and Guttel (2014) and Luppi and Parisi (2018), and references therein.

[7] This perspective is in line with the research in the social sciences, that tends to view risk as a socially constructed concept. As quipped by a leading scholar: "Although [...] dangers are real, there is no such thing as “real risk” or “objective risk” (Slovic (1992)) .

are risk optimistic, at the precaution level associated with full compensation.

Under negligence, the loss falls on the victim when the injurer takes the due level of care (this is the case, unless the standard of care is extremely high: in that case, we turn again to the strict liability case). So, the policy variable in the hands of the lawmaker is the standard of care. Since the risk is shouldered by the victim, the standard of care should be pegged to the victim's explanatory model.

Strict liability and negligence are based on different risk models and they yield different levels of precaution. Yet, they can be easily compared. The following intuitive results apply. *If, given the precaution level induced by strict liability, the injurer believes that harm is more likely than the victim does, it is preferable to shift the loss from the injurer to the victim and to opt for the negligence rule. If, given the precaution level induced by negligence, the victim believes that harm is more likely than the injurer does, it is preferable to shift the loss to the injurer and to opt for the strict liability rule.*

The same insight applies to bilateral care torts - in which both the injurer and the victim exert care - and, significantly, to product liability in competitive markets. When consumers are relatively more pessimistic than the injurers about the safety of the product, strict liability with contributory or comparative negligence is the efficient liability regime. In this ideal regime, damages should exceed harm. The damages prospect is highly valued by the pessimistic consumers, while it comes at a low (expected) cost to the producers. In turn, when consumers are more optimistic than the injurers, negligence should apply. The standard of care, however, should follow the consumers' explanatory model (and thus depend on how effective precautions are, in their view).[8]

It should be emphasized how the policy prescriptions of this paper sharply differ from those arising from the behavioral literature. The latter tends to support strict liability for product related harms as a way to protect consumers from their own mistakes. If consumers formulate erroneous estimates of the probability of harm, they end up

[8] This observation resonates with the language of the frequently used *consumer expectation test*, which posits that a product is unreasonably dangerous if it is "dangerous to an extent beyond that which would be contemplated by the ordinary consumer" (*Restatement (Second) of Torts* § 402A, comment (g)). The efficient test, however, is not an absolute one, but a relative one, where consumers' expectations are balanced against the cost of safety.

attaching the wrong value to the product. This, in turn, distorts their consumption behavior (they buy too much or too little). Strict liability with fully compensatory damages provides here an "insulation strategy:" it insures consumers against their own miscalculations and it allows markets to regain their efficiency properties.[9] This view presupposes that the risk estimates of the consumers are wrong, while those of the production managers are correct.

The pluralistic approach underlying the current model offers a different perspective. It posits that the risk estimates of the consumers (as well as those of the manages) are legitimate ones, as far as they meet weak reasonableness criteria. When consumers are less pessimistic than the producers, negligence should apply. In this case, consumers value a (suitable) price reduction more than a promise of compensation for product related harms. In turn, when consumers believe that products are more harmful than producers do (and there is no evidence that proves them wrong), strict liability should apply and damages should exceed harm. The inclusion of punitive elements in damages assessment represents an efficient means to encourage pessimistic consumers to join the market.[10]

No betting. In the paper, I rely on the classic notion of Pareto efficiency, which regards an outcome as socially desirable if parties themselves would agree to it (and no third parties are affected). Pareto efficiency is usually regarded as a sensible "minimal" requirement: it allows the policy maker to rule out outcomes that parties unanimously regard as inferior. It has been argued, however, that Pareto efficiency might be less compelling when parties entertain diverging prior beliefs.

The issue become clear if we consider pre-trial litigation. Suppose that two litigants believe that they will prevail in court. Both parties are willing to "bet" that they will win: they are willing to sink resources to try the odds of adjudication. Here, the trial represents a Pareto efficient outcome (both parties prefer it to a pretrial settlement)

[9] This perspective goes back to the early contributions of Goldberg (1974) and Spence (1977). The concept of "insulation strategy" is developed by Jolls and Sunstein (2006).

[10] Note how the divergent beliefs model provides a simple and intuitive justification for product liability. Under the classic perspective, this justification must instead be pegged to some form of market failure (see Polinsky and Shavell (2010)).

on the basis of expectations that cannot both be correct. So, even if both parties would vote for "trial" against "settlement," one cannot find a *common reason* that would support the decision to go to trial. In the terminology of Mongin (2016), this represent a case of "spurious unanimity:" the consent is unanimous, but it follows from the mechanical aggregation of incompatible viewpoints.

This criticism has prompted Gilboa et al. (2014) to refine the Pareto criterion, so as to winnow out agreements in which the parties' gains are driven uniquely by inconsistent speculative bets (parties bet against each other's beliefs). The *No Betting Pareto Dominance* ($NBPD$) requirement postulates that an agreement represents a morally compelling improvement if: i) it is a Pareto improvement given the beliefs of the parties, and ii) one can find a hypothetical belief under which the agreement is a Pareto improvement, when this belief is shared by all parties. I show that the efficiency rationale developed in this paper meets, with one exception, the *NBPD* criterion.

Let us suppose that the victim believes harm to be less likely than the injurer does and that, therefore, a shift from strict liability to negligence is Pareto efficient, in the sense that parties prefer negligence to strict liability given their beliefs. The "shared reasoning" for this "trade" could be the following. The victim tells the injurer: "I am willing to switch to negligence, and thus bear the full risk burden, on condition that you provide me with ex-ante compensation (on the basis of my optimistic belief) and that, after the trade, precautions are pegged to my risk model instead of yours. This trade leaves me indifferent, while you make a gain because you can get rid of a risk that you regard as high at a relatively low price. I know that you think I am wrong. Yet, you should consider that if I were right, you would still make a gain, because after the trade the precaution level would be pegged to the correct beliefs (mine) instead of the wrong ones (yours). So, independently of who is right, you will make a gain." This argument shows that the liability shift would be unanimously agreed upon even if the parties shared a common belief, that of the victim. Such a situation cannot arise in pre-trial litigation, where the party that is wrong cannot gain from going to trial.

The shift from negligence to strict liability is somewhat harder to justify. Under strict liability, (optimal) damages are affected by the victim's beliefs. So, even if the injurer were right, she would be induced to under- or over-invest in precaution to meet the victim's wrong belief. This implies that the victim does not necessarily gain from allowing the injurer to decide the precaution level, when the injurer is right. In this case, the efficient trade might have to be supported by a purely fictitious belief. And even so, $NBPD$ fails if precaution expenditure under strict liability is exceedingly high (see Condition (11) below).

Literature. From its very beginning, the economic analysis of tort law has been forced to address the issue of how to define people's rational behavior under the prospect of harm. The classical literature, pioneered by Brown (1973) and Diamond (1974), analyses the impact of different liability rules using the concept of Nash equilibrium under a common prior. Of special relevance is the contribution of Shavell (1980) that compares the strict liability and the negligence rules. Under the hypothesis of risk neutrality, both systems are able to induce (the same level of) efficient precaution.[11] The classic literature follows traditional game theory and builds on the "Harsanyi doctrine," which posits that different rational agents independently placed in a situation of complete ignorance will necessarily formulate the same common belief.[12]

A more sophisticated perspective on the parties' beliefs has emerged in contemporary decision theory, which has focused on the difference between "aleatory uncertainty" (situations in which the odds are known) and "epistemic uncertainty" (situations in which the odds are unknown). Building on this literature, Teitelbaum (2007) presents a liability model in which victims lack confidence in their estimates of the probability of harm (in line with the neo-additive ambiguity model of Chateauneuf et al. (2007)). The lack of confidence "distorts" the victims away from the correct probability measure, inducing them to overweight low probability risks. The efficient policy therefore requires victims to be insulated: the loss should be placed on the ambiguity-neutral injurer. Chakravarty and Kelsey (2017) extend Teitelbaum's model to bilateral accidents and show how an ambiguity neutral court can partially "correct" the distortion due to the

[11] A very rich literature, surveyed by Shavell (2007) and Arlen (2015), considers extensions of the basic set-up to account for - among other things - judgement proofness, liability of firms, risk aversion, and incentives to sue.

[12] This proposition goes under the name of "evidentialism" in epistemology (see Feldman and Warfield (2010) for a philosophical overview). The Harsany doctrine has been increasingly challenged both by theory and applied research (see Morris (1995) and Marinacci (2015)).

parties' aversion to ambiguity.

Franzoni (2017) employs the smooth ambiguity model of Klibanoff et al. (2005) to account for the case in which parties entertain multiple prior beliefs (parties are not certain about the probability of harm). In that paper, I assume that parties' beliefs share the same mean, and focus on the impact of risk and ambiguity aversion. The optimal liability rule is the one that allocates the loss to the party that either formulates the most precise estimates of the probability of harm or is less averse to uncertainty. In the current model, I consider the simpler case in which parties are risk and ambiguity neutral. Yet, they entertain divergent beliefs because they rely on different causal models (so, there is radical disagreement).[13]

Differently from tort theory, non-common priors have been popular in litigation theory, where the parties' observed failure to settle can be explained by their different expectations about the trial's outcome. Recent additions to this influential literature include Spier and Prescott (2019), and Vasserman and Yildiz (2019) (see references therein).

Section 2 provides the introductory definitions. Section 3 analyses strict liability and Section 4 negligence. The two liability rules are compared in Section 5. Section 6 extends the results to bilateral accidents, while Section 7 deals with product liability. Section 8 examines *No Betting Pareto Dominance*, while Section 9 concludes.

2 Divergent beliefs

I will start with the case in which only the injurer's conduct affects the probability of harm (unilateral care).

Let x denote the (continuous) level of the precaution exerted by the injurer. When precautions x are taken, the injurer believes that the probability of harm is $p_I(x)$, while the victim believes that the probability of harm is $p_V(x)$. I assume that these beliefs are compatible with the evidence available at the time when the activity is carried

[13]This parsimonious model captures most of the features associated with first-order risk and ambiguity aversion, in the sense of Segal and Spivak (1990) and Lang (2017). See Appendix A4.

out and that they cannot be manipulated.[14] These beliefs originate from explanatory models that provide alternative causal links between the conduct of the injurer and the eventual injury suffered by the victim. For the sake of simplicity, I assume that these beliefs are continuos and continuously differentiable, and that $p_I'(x) < 0$ and $p_V'(x) < 0$ for all $x \geq 0$.[15] Both the injurer and the victim are risk-neutral.

Parties agree on the magnitude of harm suffered by the victim, h, and the cost of precaution, $c(x)$. The cost of precaution is increasing and convex (with $c'(0) = 0$).

The following diagrams illustrate several patterns of belief divergence.

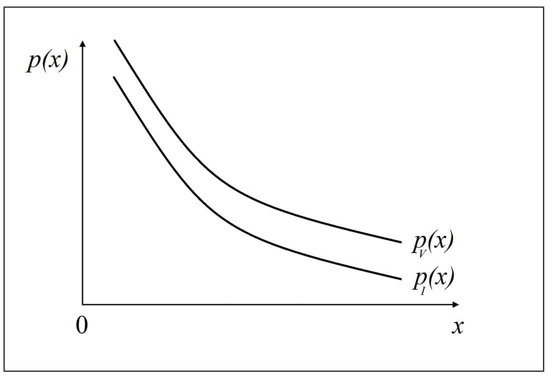


Fig. 1.

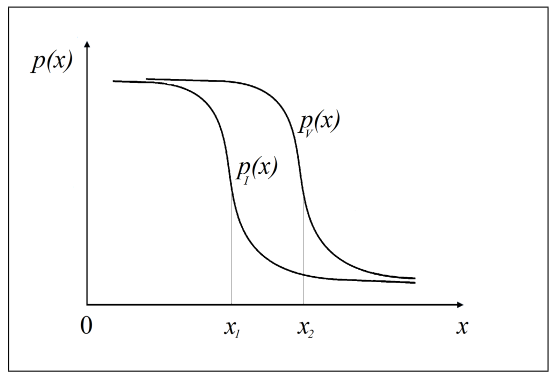
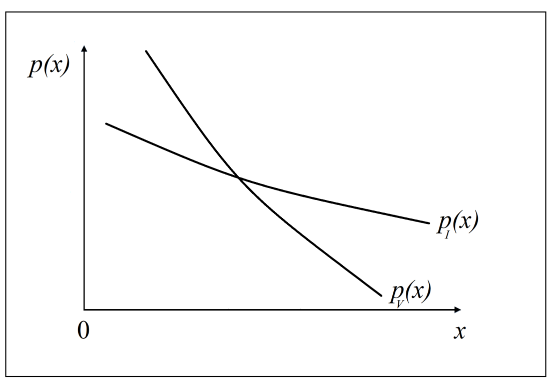


Fig 2.



[14]Beliefs could also be "imprecise," in the sense that, given x, parties expect the probability of harm to belong to a range, say $p(x) \in [\underline{p}(x), \overline{p}(x)]$, and assign a likelihood to each value belonging to the interval ("multiple prior model"). If individuals are ambiguity neutral, as I assume, the imprecision of the beliefs is irrelevant: all that matters is the mean value of the beliefs.

[15]This assumption rules out the case in which a precautionary measure is regarded as risk-reducing by one party and risk-increasing by the other. This assumption, however, is not required to prove the main result of the paper (see footnote 21).

Fig 3.

In Fig. 1 parties agree on the efficacy of precaution (p_V and p_I have the same slopes), but they disagree on the magnitude of the risk. In Fig. 2 parties disagree about the "safety threshold" emerging from a dose-respose model: the injurer believes that safety is achieved with precaution level x_1, while the victim believes that it is achieved with precaution level x_2. In Fig. 3 parties disagree on the efficacy of precaution: the victim assigns to precautions a greater capacity to reduce risk.

In places, I will consider these special cases:

i) the injurer is *risk-optimistic* if $p_I(x) < p_V(x)$ for all $x \geq 0$. The injurer always believes that harm is less likely than the victim does;

ii) the injurer is *precaution-optimistic* if $|p'_I(x)| > |p'_V(x)|$ for all $x \geq 0$. The injurer always believes that precautions are more effective at reducing the probability of harm than the victim does.

The reverse definitions apply in the case of "pessimism."

In Fig. 1 and 2 the Injurer is risk-optimistic but not precaution-optimistic; in Fig. 3 the injurer is precaution-pessimistic but not risk-pessimistic.

The lawmaker decides the liability rule governing the activity and, when the injurer is liable, the amount of the damages d to be awarded to the victim. Damages can under-compensate the victim (for example, by not including pain and suffering) as well as over-compensate the victim (for example, by including a punitive component).

I will compare the two classic liability rules: strict liability and negligence.

3 Strict liability

Under strict liability, the injurer is liable for the harm caused to the victim independently of the level of precaution taken.[16]

[16] For simplicity, the scope of liability - the set of the injuries for which the injurer can be held liable - is taken as given. If the scope has to be pegged to some explanatory model, then it should be the victim's.

The cost of accidents for the injurer is

$$L_I^s(x) = c(x) + p_I(x)\, d.$$

It includes the cost of precaution and the expected liability (calculated using the injurer's belief).[17]

The injurer minimizes $L_I^s(x)$ and thus selects x^s so that

$$c'(x^s) = -p_I'(x^s)\ \ d : \tag{1}$$

one dollar spent in precaution reduces her expected liability by one dollar. The level of precaution is pegged to the injurer's explanatory model. From (1), we know that x^s increases with d. With an abuse of notation, in places I will write $x^s = x^s(d)$.

The cost of accidents for the victim is

$$L_V^s(d) = p_V(x^s)(h - d).$$

The latter is equal to expected uncompensated harm, i.e., the difference between harm suffered and damages received, times the probability that harm occurs. Note that $L_V^s(d)$ can be negative, because damages can exceed harm (and thus the victim can benefit from the accident).

We can now turn to the Pareto efficient policy. This is the policy that parties themselves would agree to, if they were to contract about it. Specifically, the efficient damages level is the one that minimizes Social Loss (the total cost of accidents):

$$SL^s(d) = L_I^s(x^s) + L_V^s(d) = c(x^s) + p_V(x^s)\, h + [p_I(x^s) - p_V(x^s)]\, d.$$

Social Loss includes the precaution costs borne by the injurer, the expected harm borne by the victim (and thus calculated using his belief), and an additional term that captures the disagreement between injurer and victim about the probability that

[17] The minimization problem is well behaved if, for all $x \geq 0 : c''(x) + p_I''(x)\, d > 0$, which is assumed to hold.

damages will be awarded.

We get:

$$\frac{\partial SL^s(d)}{\partial d} = \frac{\partial L_I^s(x^s)}{\partial x^s}\frac{\partial x^s}{\partial d} + \frac{\partial L_V^s(x^s)}{\partial x^s}\frac{\partial x^s}{\partial d} + [p_I(x^s) - p_V(x^s)].$$

Since $\frac{\partial L_I(x^s)}{\partial x^s} = 0$ (from eq. 1), we get

$$\frac{\partial SL^s(d)}{\partial d} = p_V'(x^s)\ \frac{\partial x^s}{\partial d}(h-d) + [p_I(x^s) - p_V(x^s)]. \tag{2}$$

An increase in damages has two effects: it increases the incentives for the injurer to invest in precaution and thus reduce the uncompensated harm borne by the victim, and it shifts risk from the victim to the injurer (a risk to which they attach a different value). The former effect reduces social loss only if damages are undercompensatory ($d < h$). If damages are overcompensatory, the victim is in fact harmed by an increase in precaution. The risk transfer effect reduces social loss if, and only if, the injurer believes harm to be less likely than the victim does, at the relevant level of precaution: $p_I(x^s) < p_V(x^s)$.

If parties share the same beliefs, only the first effect matters and optimal damages are perfectly compensatory: $d^* = h$. If parties do not share the same belief, however, damages should also cater for the optimal allocation of risk. Starting from $d = h$, a change in damages has a negligible impact on the first effect (there is no externality), while it allows for the transfer of risk from the pessimistic to the optimistic party. So, damages should go up if $p_I(x^s) < p_V(x^s)$, while they should go down if $p_I(x^s) > p_V(x^s)$.

The previous observation provides us with the optimal direction of change at $d = h$. Assuming that SL^s is quasi-convex, this piece of information is sufficient to identify the global optimum.

Proposition 1 *Strict liability. Optimal damages strike a balance between the need to provide optimal incentives for the generation of uncompensated harm (reduce negative* *externality, increase positive externality) and the need to optimally allocate the risk:*

$$-\frac{\partial x^s}{\partial d} p'_V (x^s) \ (h - d^*) = p_I (x^s) - p_V (x^s) \,. \tag{3}$$

If the injurer believes that harm is more probable than the victim does at $d = h$*, optimal damages are under-compensatory.*

If the victim believes that harm is more probable than the injurer does at $d = h$*, optimal damages are over-compensatory.*

Note that the force that drives damages away from the fully compensatory solution is the disagreement about the probability of harm, and not about the efficacy of precaution $[p'(x)]$. Optimal damages are further away from the compensatory level, the greater this disagreement.

Remark 1. This set-up provides a justification for punitive damages different from the classic one, pegged to the possibility that the responsible party escapes liability. Here, over-compensatory damages serve an allocative function: they provide the victim with a "lottery ticket" to which he attaches a value that exceeds the cost for the injurer.

Remark 2. This set up can be easily extended to the case with K injurers (each with her own belief $p_{I_i}(x)$) and M random victims (each with his own belief $p_{Vj}(x)$).[18] Optimal damages should here solve:

$$-\sum_{i=1}^{K} \frac{\partial x_i^s}{\partial d} \, \overline{p}'_V (x_i^s) (h - d^*) = \sum_{i=1}^{K} \left[p_{I_i} (x_i^s) - \overline{p}_V (x_i^s) \right],$$

where $\overline{p}'_V (x_i^s)$ is the expected decrease in the probability of harm caused by injurer i: $\overline{p}'_V (x_i^s) = \frac{1}{M} \sum_{j=1}^{M} p'_{Vj} (x^s)$, and $\overline{p}_V (x_i^s)$ the average probability of harm: $\overline{p}_V (x_i^s) = \frac{1}{M} \sum_{j=1}^{M} p_{Vj} (x^s)$, both calculated from the victim's standpoint.

[18] For simplicity, I assume that harms are simply additive. So, each victim can be involved in up to M independent accidents.

4 Negligence

Under a negligence rule, the injurer is liable for damages only if she does not meet the standard of care $\bar{x}$. Care is assumed to be verifiable in court. If damages are not less than harm and the standard is not excessively high, the injurer will prefer to meet it and avoid liability.[19] The optimal standard of care should be set so as to minimize

$$SL^n(\bar{x}) = L_I^n(\bar{x}) + L_V^n(\bar{x}) = c(\bar{x}) + p_V(\bar{x})\, h.$$

The injurer bears the cost of precaution while the victim bears the risk of harm.

The optimal standard x^n should solve:[20]

$$c'(x^n) = -p_V'(x^n)\, h. \tag{4}$$

An additional dollar spent in precaution should reduce the harm expected by the victim by one dollar.

Proposition 2 *The efficient level of the standard of care balances the cost of precaution borne by the injurer with the risk borne by the victim.*

In the determination of the standard of care, courts should realize that if the injurer meets the standard prescribed by the law, the risk falls on the victim. The "reasonable person" upon which the standard is defined is a person that puts herself in the shoes of those who might be harmed (and not in her own). If the victim believes that precautions are highly effective (large absolute value of $p_V'(x)$), the standard of care should be high.

Remark 1. If victims are randomly drawn from a set of M individuals with different

[19] The injurer prefers to be negligent if $c(\bar{x}) > c(x^s) + p_I(x^s)\, h$, where x^s minimizes the injurer's cost of accident when she is liable and pays damages $d = h$ (see eq. 1). If this inequality holds, then $c(\bar{x}) + p_V(\bar{x})\, h > c(x^s) + p_I(x^s)\, h$, and negligence is dominated by strict liability with compensatory damages (and a fortiori by strict liability with optimal damages).

[20] The condition: $c''(x) + p_V''(x)\, h > 0$ for all $x \geq 0$ is sufficient to guarantee the convexity of the minimization problem.

beliefs, what matters is the average belief. The optimal standard x^n should solve:

$$c'(x^n) = -\frac{1}{M}\sum_{j=1}^{M} p'_{V_j}(x^n)\ h. \tag{5}$$

We can now compare the performance of the two liability regimes.

5 Strict liability vs. negligence

To compare the two liability rules, let us first consider the level of precaution emerging under each of them.

Under strict liability, the optimal level of care solves:

$$c'(x^s) = -p'_I(x^s)\, d^*,$$

where $d^* > h$ if, and only if, $p_I(x^s) < p_V(x^s)$ at $d = h$.

Under negligence, the optimal level of care solves:

$$c'(x^n) = -p'_V(x^n)\, h.$$

The following simple conditions are sufficient (though not necessary) to determine the relationship between x^s and x^n.

Lemma 1 *If the injurer is risk- and precaution-optimistic, then* $x^s > x^n$.

If the injurer is risk- and precaution-pessimistic, then $x^s < x^n$.

If the injurer is precaution-optimistic, then $x^s(h) > x^n$. If she is also risk-optimistic, then $d > h$, and $x^s(d) > x^s(h) > x^n$. The opposite applies when the injurer is risk and precaution-pessimistic.

Let us now compare social loss under the two regimes. We have:

$$\begin{aligned} SL^n(x^n) &< SL^s(d^*) \Leftrightarrow \\ c(x^n) + p_V(x^n)h &< c(x^s) + p_V(x^s)h + [p_I(x^s) - p_V(x^s)]d^*. \end{aligned} \tag{6}$$

The socially preferable liability rule is the one that yields the least social loss. We have,

$$\begin{aligned} SL^n(x^n) &< SL^s(d^*) \Leftrightarrow \\ c(x^n) + p_V(x^n)h - [c(x^s) + p_V(x^s)h] &< [p_I(x^s) - p_V(x^s)]d^*. \end{aligned}$$

Since $x^n = \arg\min_x[c(x) + p_V(x)h]$, the term on the LHS cannot be positive. So, if $p_I(x^s) > p_V(x^s)$, then $SL^n(x^n) < SL^s(d^*)$.

Since $d^* = \arg\min_d[SL^s(d)]$, we must have

$$SL^s(d^*) \leq SL^s(h) = c(x^s(h)) + p_I(x^s(h))h.$$

In turn, since, $x^s(h) = \arg\min_x[c(x) + p_I(x)h]$, we must have

$$c(x^s(h)) + p_I(x^s(h))h \leq c(x^n) + [p_I(x^n)]h.$$

So, if we have: $p_I(x^n) < p_V(x^n)$, then

$$SL^s(d^*) \leq c(x^n) + p_I(x^n)h < c(x^n) + p_V(x^n)h = SL^n(x^n).$$

This leads to the following:

Proposition 3 ***The efficient liability rule:***
i) if $p_I(x^s) > p_V(x^s)$, negligence dominates strict liability.
ii) if $p_I(x^n) < p_V(x^n)$, strict liability dominates negligence.

If the victim believes that harm is less likely than the injurer does, at the precaution level arising under strict liability, then negligence is the optimal rule. If the injurer believes that harm is less likely than the victims does, at the precaution level arising under negligence, then strict liability is the optimal rule.[21]

Note that conditions i) and ii) are "local" ones (they apply to two specific precaution levels). So, we can have situations in which neither condition holds. In that case, liability rules can be compared by directly referring to ineq. (6).

When the injurer is *risk-pessimistic*, strict liability alleviates the burden of the injurer by entailing undercompensatory damages. This, however, is not enough. The optimal liability rule is negligence, and it places all the risk on the victim. If the injurer is also *precaution-pessimistic*, the level of care ends up being higher than under strict liability.

When the injurer is *risk-optimistic*, the optimal rule is strict liability with overcompensatory damages. This rule entails an insurance component (the injurer insures the victim against his own pessimism). If the injurer is also *precaution-optimistic*, the level of care ends up being higher that under negligence.

The difference in beliefs breaks the classic equivalence result, which posits that strict liability and negligence are equally able to induce the (same) efficient level of precaution.

6 Bilateral care

When the probability of harm depends on the precautions taken by both injurer and victim, the same logic applies. Now, the beliefs of injurer and victim have additional reasons to diverge, because beliefs entail an additional layer of complexity (an additional dimension).

The beliefs of injurer and victim are, respectively, $p_I(x, y)$ and $p_V(x, y)$, where x is the level of care taken by the injurer and y the level of care taken by the victim. Both x and y reduce the probability of harm, for both parties. Parties know the beliefs of each

[21] Note that the proof of Proposition 3 only requires that the set of the precaution levels is compact and that the cost and the belief functions are lower-semicontinuos.

other. The focus is on the Nash equilibrium, which is known to be robust to diverging priors in the case with two players (see Aumann and Brandenburger (1995)).

With bilateral accidents, strict liability needs to be supplemented by a contributory negligence defence to be efficient. So, let us compare "strict liability with contributory negligence" with "simple negligence."[22]

Under the optimal policy, strict liability (with contributory negligence) and simple negligence yield different precaution levels, labeled $\widehat{x}^s, \widehat{y}^s$ and $\widehat{x}^n, \widehat{y}^n$, respectively. Using a logic similar to that of Section 5, the following result can be established (see Appendix A1).

Proposition 4 ***Bilateral care:***

i) if $p_I(\widehat{x}^s, \widehat{y}^s) > p_V(\widehat{x}^s, \widehat{y}^s)$*, negligence dominates strict liability with contributory negligence.*

ii) if $p_I(\widehat{x}^n, \widehat{y}^n) < p_V(\widehat{x}^n, \widehat{y}^n)$*, strict liability with contributory negligence dominates negligence.*

Proposition 4 mimics Proposition 3. The efficient rule is the one that minimizes social loss.

When one of the two parties uniformly believes harm to be more likely than the other party does, for all combinations of x and y, the choice of the liability rule turns out to be particularly simple: negligence is preferable if the injurer is risk-pessimistic, strict liability is preferable if the injurer is risk-optimistic.

Again, the choice of the liability rule impinges on the level of precaution and the allocation of risk. Under strict liability with contributory negligence the risk is borne prominently by the injurer, who decides the precaution level according to her risk model. Some residual risk, positive (if $d^* < h$) or negative (if $d^* > h$) is borne by the victim, whose only job is to meet the standard of care set by the courts. We have $d^* > h$ if, and only if, the injurer believes harm to be more likely than the victim does at the precaution levels associated with $d = h$.

[22] Other rules are equally efficient, like negligence with contributory negligence and negligence with comparative negligence. See Shavell (2007).

Under negligence the risk falls entirely on the victim, who decides how much care to take based on her risk model. The injurer just has to meet the standard of care set by the courts, which balances costs and benefits of precaution using the victim's risk model.

7 Product liability

Product liability concerns harm caused by defective products. Contrary to the cases of the previous sections, here harm affects parties that are in a contractual relationship.[23]

Let us suppose that markets are perfectly competitive. Let x be the expenditure in safety per unit of product. The safety level is not observable by the consumers.[24] Consumers share the same belief $p_V(x)$ about the probability of harm. Firms are identical, and they share the belief $p_I(x)$.

If we compare the two liability regimes, the results of Section 5 apply (see Appendix A2).

Proposition 5 ***Product liability:***

i) if $p_I(x^s) > p_V(x^s)$, negligence dominates strict liability.

ii) if $p_I(x^n) < p_V(x^n)$, strict liability dominates negligence.

Clearly, if the way in which the consumers use the product has an impact on the probability of harm, then Proposition 4 applies.

This result can be used to apportion liability with respect to new, relatively untested, products (like autonomous vehicles). If consumers are *risk-pessimistic*, strict liability should apply and damages should be over-compensatory. This would allow firms to retain consumers who are wary of the product by providing them with a lottery ticket,

[23]The law distinguishes across three types of harm. Those due to manufacturing defects, those due to design defects, and those related to inadequate warnings. The analysis applies to all types of harm, but it is particularly relevant for design defects, for which the divergence in the beliefs can be substantial.

[24]For simplicity, I do not consider more sophisticated policies available to producers, including signaling through prices, third-party certification, warranties, recalls, and ex-post warnings. See the thorough survey of Daughety and Reinganum (2015).

whose value is, in fact, the higher the more pessimistic they are. At the optimum, however, the prize for the harmed consumer cannot be too large, as this would lead firms to take excessive care.

If consumers are *risk-optimistic*, negligence should apply and the standard of care should be pegged to the consumers' beliefs. So, "consumers' expectations" should play an important role.[25] These expectations should be balanced against the cost of precaution.

The optimal liability rule maximizes total surplus. If two types of firms competed in the market, those subject to a negligence rule and those subject to strict liability (and harms were correctly attributed to the responsible party), firms subject to the efficient rule would survive, while the others would be driven out of business.

The differential belief perspective complements the classic asymmetric information perspective, which argues that firms can offer "warranties" to signal the safety of their products (Spence (1977)). Here, firms offer (over) compensation for product related harms not to convince doubtful consumers that their product is safe, but to insure them against their unwavering skepticism.

8 No Betting Pareto Efficiency

Several authors have argued that Pareto efficiency is less compelling when people entertain different beliefs. A classic example is the case of a prospective trial in which all litigants believe that they have the best chances of prevailing. The optimistic litigants will forfeit the opportunity to settle and will incur trial costs. Such a choice meets their preferences, yet it might be questionable: parties will incur a certain loss (the trial costs) in exchange for the opportunity to "bet" on the trial outcome, where the bet is valuable only because parties cannot agree on a common expectation. If parties shared a common belief - of whatever type - they would certainly prefer to settle out

[25] Consumers expectations loom large in product design defect liability, both in the US and in the EU (design defects are normally subject to a negligence regime).

of court.[26]

In this section, I take this criticism at face value and consider the "No Betting" approach developed by Gilboa et al. (2014). These authors offer a tool to distinguish trades based on purely antagonistic bets (as in the litigation example) from trades that serve a genuine insurance purpose. According to these authors: "unanimity about a given claim—say, that trade is desirable—becomes more compelling when *unanimity about the reasoning* that leads to it is also possible" (emphasis added). Specifically, a policy move meets the $NBPD$ criterion if: i) it is a Pareto improvement under the parties' beliefs, and ii) there exists at least one hypothetical belief under which the move remains a Pareto improvement, when this belief is shared by all affected parties.[27]

Let us consider the efficiency of negligence vis-à-vis strict liability. Negligence Pareto dominates strict liability if a "trade" from the latter to the former benefits both parties. The losses incurred by the parties under the two regimes are

Strict Liability	*Negligence*
$L_I^s = c\left(x^s\right) + p_I\left(x^s\right) d^*,$	$L_I^n = c\left(x^n\right) + t,$
$L_V^s = p_V\left(x^s\right)\left(h - d^*\right),$	$L_V^n = p_V\left(x^n\right) h - t,$

where t is an (ex-ante) transfer from the injurer to victim, needed to convince her to accept the move. Let us fix $t = p_V\left(x^n\right) h - p_V\left(x^s\right)\left(h - d^*\right).$

The parties' gains from trade are:

$$\begin{aligned} L_I^s - L_I^n &= c\left(x^s\right) + p_I\left(x^s\right) d^* + p_V\left(x^s\right)\left(h - d^*\right) - \left[c\left(x^n\right) + p_V\left(x^n\right) h\right], \\ L_V^s - L_V^n &= 0, \end{aligned}$$

where $L_I^s - L_I^n > 0$ because the switch to negligence represents a Pareto improvement (see ineq. (6)).

[26] Spier and Prescott (2019) reconsider this classic result and confirm that the trial decision cannot be supported by a common belief also in the case in which parties can write contingent contracts that mitigate the trial outcome (like "high-low" agreements).

[27] Alternative criteria, based on different hypotheses on how to select the shared belief, are provided by Brunnermeier et al. (2014), and Gayer et al. (2014).

If parties take $p_V(x)$ as the "neutral" belief to asses the trade, we get $\widehat{L}_V^S - \widehat{L}_V^N = 0$ and

$$\begin{aligned}\widehat{L}_I^s - \widehat{L}_I^n &= c(x^s) + p_V(x^s)\, d^* - [c(x^n) + p_V(x^n)\, h - p_V(x^s)(h - d^*)] \\ &= c(x^s) + p_V(x^s)\, h^* - [c(x^n) + p_V(x^n)\, h] > 0,\end{aligned}$$

because $x^n = \arg\min_x [c(x) + p_V(x)\, h]$. So, the injurer gains also if she adopts the victim's belief. The common belief supporting $NBPD$ is the victim's belief.

The move from negligence to strict liability is more demanding, in terms of hypothetical beliefs. I consider a two-steps move: first, from negligence to strict liability with compensatory damages $(d = h)$, second, from strict liability with compensatory damages to to strict liability with optimal damages $(d = d^*)$.

The move from negligence to strict liability with compensatory damages follows a logic similar to that explained above. Again, the common belief supporting $NBPD$ is that of the optimistic party (the formal proof is in Appendix A3).

Let us focus on the move from compensatory damages to optimal damages. The losses are

Strict liability with comp. dam.	*Strict liability*
$L_I^{sc} = c(x^{sc}) + p_I(x^{sc})\, h,$	$L_I^s = c(x^s) + p_I(x^s)\, d^* + t,$
$L_V^{sc} = 0,$	$L_V^s = p_V(x^s)(h - d^*) - t,$

where x^{sc} is the precaution level chosen by the injurer when $d = h$. Note that $h - d^*$ can be positive or negative (to fix ideas, for the time being we can assume that it is positive).

In order to have $L_I^s < L_I^{sc}$ and $L_V^s \leq L_V^{sc}$, the transfer t should satisfy:

$$\begin{cases} t < c(x^{sc}) + p_I(x^{sc})\, h - c(x^s) - p_I(x^s)\, d^* \equiv \bar{t}, \\ t \geq p_V(x^s)(h - d^*) \equiv \underline{t}. \end{cases} \tag{7}$$

We have

$$\bar{t} \geq \underline{t} \Leftrightarrow c(x^{sc}) + p_I(x^{sc})\, h \geq c(x^s) + p_I(x^s)\, d^* + p_V(x^s)(h - d^*), \tag{8}$$

which holds because the move is Pareto efficient (by assumption).

If the move were judged according to a hypothetical belief $p_H(x)$, losses would be:

Strict liability with comp. dam.	*Strict liability*
$\widehat{L}_I^{sc} = c(x^{sc}) + p_H(x^{sc})\, h,$	$\widehat{L}_I^{s} = c(x^{s}) + p_H(x^{s})\, d^* + t,$
$\widehat{L}_V^{sc} = 0,$	$\widehat{L}_V^{s} = p_H(x^{s})\,(h - d^*) - t.$

The move would benefit both parties if

$$\begin{cases} t < c(x^{sc}) + p_H(x^{sc})\, h - c(x^{s}) - p_H(x^{s})\, d^* \equiv \bar{t}^H, \\ t \geq p_H(x^{s})\,(h - d^*) \equiv \underline{t}^H, \end{cases} \tag{9}$$

with

$$\bar{t}^H \geq \underline{t}^H \Leftrightarrow c(x^{sc}) + p_H(x^{sc})\, h \geq c(x^{s}) + p_H(x^{s})\, h. \tag{10}$$

Inequality (10) is a necessary condition for $NBPD$. If $d^* < h$, it posits that the reduction in precaution expenditure driven by optimal damages exceeds the hypothetical increase in expected harm: $c(x^{sc}) - c(x^{s}) \geq p_H(x^{s})\, h^* - p_H(x^{sc})\, h$. If $d^* > h$, it posits that the hypothetical decrease in expected harm exceeds the increase in precaution expenditure: $c(x^{s}) - c(x^{sc}) \leq p_H(x^{sc})\, h - p_H(x^{s})\, h$. If one picks the most extreme beliefs, $p_H(x^{sc}) = 1$ and $p_H(x^{s}) = 0$, inequality (10) boils down to

$$c(x^{sc}) - c(x^{s}) \leq h. \tag{11}$$

If Condition (11) does not hold, optimal damages surely entail a speculative ("betting") component.

The policy move meets $NBPD$ if one can find a t that meets both (7) and (9). This is the case if, and only if, $\bar{t}^H \geq \underline{t}$ and $\underline{t}^H \leq \bar{t}$, that is, if and only if:

$$\begin{cases} c(x^{sc}) + p_H(x^{sc})\, h \geq c(x^{s}) + p_H(x^{s})\, d^* + p_V(x^{s})\,(h - d^*), \\ c(x^{sc}) + p_I(x^{sc})\, h \geq c(x^{s}) + p_I(x^{s})\, d^* + p_H(x^{s})\,(h - d^*). \end{cases} \tag{12}$$

If we set $p_H(x^{s}) = p_V(x^{s})$, the second equation of (12) is met thanks to (8). We are left with the first equation.

For the case with $d^* < h$, let us consider the hypothetical beliefs: $p_H(x^{sc}) = p_H(x^s) = p_V(x^s)$. The first inequality of (12) becomes:

$$c(x^{sc}) \geq c(x^s),$$

which is met because $x^{sc} > x^s$. The necessary condition (10) is also met. So, the reduction of damages from $d = h$ to $d = d^*$ is supported by the hypothetical belief that expected harm will not be affected by the ensuing reduction in precaution.

For the case with $d^* > h$, let us consider the (most favorable) hypothetical belief: $p_H(x^{sc}) = 1$. The first inequality of (12) becomes:

$$c(x^s) - c(x^{sc}) \leq [1 - p_V(x^s)]\, h. \tag{13}$$

If condition (13) is met, also the necessary condition (10) is met. The increase in damages from $d = h$ to $d = d^*$ meets $NBPD$ if the ensuing increase in precaution expenditure is not too large. The following proposition summarizes the results.

Proposition 6 ***No Betting Pareto Dominance.***

If negligence Pareto dominates strict liability, then it also No Betting Pareto dominates it. No Betting Pareto dominance is supported by the beliefs of the victim.

If strict liability with compensatory damages Pareto dominates negligence, then it also No Betting Pareto dominates it. No Betting Pareto dominance is supported by the beliefs of the injurer.

If $d^* < h$, the move from compensatory damages to optimal damages meets the No Betting criterion. If $d^* > h$, the move from compensatory damages to optimal damages meets the No Betting criterion if Condition (13) *is met (precaution expenditure does not increase too much).*

The notion of *No Betting Pareto Dominance* allows us to tell the case in which $d^* = h$ from the case in which $d^* \neq h$. In the former case, the choice of the efficient liability rule can find a common reasoning in the belief of the optimistic party. Intuitively, when we move from one liability rule to the other, two things happen: i) the risk is shifted from the pessimistic to the optimistic side, and ii) the precaution level is pegged to the optimistic's party explanatory model instead of the pessimistic's. The latter effect allows the pessimistic party to gain from the trade even if she is wrong and the other party is right: if that is the case, at least the precaution level is optimally set. So, and this distinguishes the liability setup from the litigation setup, the trade can provide a gain also to the party that happens to be wrong (and whose explanatory model is no longer employed to set the precaution level).

When $d^* \neq h$, this logic might fail because, under strict liability, the victim's beliefs affect optimal damages and hence the investment in precaution. Hence, the victim might not gain if the injurer is right: his "mistake" might distort the choice of the injurer to such an extent that the gain from pegging the precaution level to the correct explanatory model is completely dissipated. The trade from negligence to strict lability, in this case, might have to be supported by purely fictional beliefs, different from the injurer's. And this might not even be enough if the victim's pessimism drives the precaution expenditure to extremely high levels (see the necessary Condition (11)). If overcompensatory damages induce an increase in precaution costs that not even the most optimistic (shared) beliefs can support, we can reasonably say that damages serve a purely speculative function.

9 Final remarks

When injurers and victims entertain different beliefs about the likelihood of harm, the choice between liability rules inevitably implies a choice between statistical/causal models. This paper has pursued a contractarian approach: it suggests that the optimal rule is the one that parties themselves would choose, if they faced the issue. This is a deliberately "minimal" approach, that does not assign to the courts the duty to determine the "true" causal model - when such a model is not available - but just invites them to find the solution that best fits the interests of the affected parties.

The efficient solution entails strict liability when the least social cost results from the injurer's causal model, while it entails negligence when the least social cost results from the victim's causal model. Except for the case in which strict liability entails a very large precaution expenditure (due to the victim's pessimism), the choice of the liability rule is compatible with a deliberative process based on "common reasoning," under which the pessimistic party considers the possibility to be wrong. On this account, negligence is more robust to hypothetical reasoning than strict liability. The common reasoning supporting the choice of the negligence rule is the belief of one of the parties (the victim's). The common reasoning supporting the choice of the strict liability rule might have to be a purely hypothetical one (that the belief of the injurer is correct is not enough, because precautions also depend on the belief of the victim). If damages drive the precaution expenditure to an excessive level, the liability system ends up assuming a "speculative" nature.

The policy recommendations of the paper are based on the assumption that the beliefs of the parties are relatively stable and that they cannot be manipulated, and that the lawmaker is able to elicit them by proper means. With respect to product liability, the efficient solution can be brought about by the market itself, because it is in the interest of both parties to minimize social loss. On this account, punitive damages can be seen as an efficient tool used by firms to insure wayward consumers against their own pessimism.

The extension of the classic approach to the case in which parties entertain differential beliefs significantly increases the realism of the analysis, especially in the case of new products and processes. With respect to harms caused by robots, self-driving cars, and artificial intelligence, for instance, where some "experimentation" inevitably follows the introduction of new technology, it would not be surprising if the industry agreed to embrace a comprising strict liability regime able to overcome consumers' hesitancy.

Appendix

A1. **Bilateral care.**

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

$$c_I'\left(x^{\circ}\right)+\frac{\partial p_I'\left(x^{\circ},\overline{y}\right)}{\partial x}d=0, \tag{14}$$

with $\frac{\partial x^{\circ}}{\partial d}>0$.

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

$$SL^S\left(d\right)=c_I\left(x^{\circ}\right)+c_V\left(\overline{y}\right)+p_I\left(x^{\circ},\overline{y}\right)d+p_V\left(x^{\circ},\overline{y}\right)\left(h-d\right). \tag{15}$$

Thus, courts will set d^* and $\bar{y}$ so that, using (14):

$$\begin{aligned}
\frac{\partial SL^S(d^*)}{\partial\overline{y}} &= c_V'\left(\overline{y}\right)+\frac{\partial p_I(x^{\circ},\overline{y})}{\partial\overline{y}}d^*+\frac{\partial p_V(x^{\circ},\overline{y})}{\partial\overline{y}}\left(h-d^*\right)+\frac{\partial x^{\circ}}{\partial\overline{y}}\left[\frac{\partial p_V(x^{\circ},\overline{y})}{\partial x^{\circ}}\left(h-d^*\right)\right] &&=0,\\
\frac{\partial SL^S(d^*)}{\partial d} &= \frac{\partial x^{\circ}}{\partial d}\frac{\partial p_V(x^{\circ},\overline{y})}{\partial x^{\circ}}\left(h-d^*\right)+p_I\left(x^{\circ},\overline{y}\right)-p_V\left(x^{\circ},\overline{y}\right) &&=0.
\end{aligned} \tag{16}$$

For $d=h$, we have:

$$\frac{\partial SL^S\left(d\right)}{\partial d}=p_I\left(x^{\circ},\overline{y}\right)-p_V\left(x^{\circ},\overline{y}\right).$$

Thus, as in the unilateral case, if $p_I\left(x^{\circ},\overline{y}\right)>p_V\left(x^{\circ},\overline{y}\right)$ at the precaution levels associated with $d=h$, then $d^*>h$.

Negligence. Let $\bar{x}$ be the due level of care for the injurer and y the level of care taken by the victim. If the injurer meets the standard of care (as I assume), the victim will chose $y=\widehat{y}$ so that

$$c_V'\left(\widehat{y}\right)+\frac{\partial p_V\left(\bar{x},\widehat{y}\right)}{\partial\widehat{y}}h=0. \tag{17}$$

Social loss is:

$$SL^N\left(\bar{x}\right)=c_I\left(\bar{x}\right)+c_V\left(\hat{y}\right)+p_V\left(\bar{x},\widehat{y}\right)h, \tag{18}$$

with

$$\frac{\partial SL^N\left(\bar{x}\right)}{\partial\bar{x}}=c_I'\left(\bar{x}\right)+\frac{\partial p_V\left(\bar{x},\widehat{y}\right)}{\partial\bar{x}}h+\frac{\partial\widehat{y}}{\partial\bar{x}}\left[c_V'\left(\widehat{y}\right)+\frac{\partial p_V\left(\bar{x},\widehat{y}\right)}{\partial\widehat{y}}h\right].$$

The term within square brackets is nil in view of (17).

Thus, the optimal standard of care should solve:

$$c_I'(\bar{x}) + \frac{\partial p_V(\bar{x}, \widehat{y})}{\partial \bar{x}} h = 0. \tag{19}$$

Eq. (17) , together with (19), determine the equilibrium levels of care x^n, y^n.
Dominance. We have:

$$\begin{aligned}
&SL^N(x^n) < SL^S(d^*) \Leftrightarrow \\
&c_I(x^n) + c_V(y^n) + p_V(x^n, x^n)h < c_I(x^s) + c_V(y^s) + p_I(x^s, y^s)d^* + p_V(x^s, y^s)(h - d^*) \\
&c_I(x^n) + c_V(y^n) + p_V(x^n, y^n)h - [c_I(x^s) + c_V(y^s) + p_V(x^s, y^s)h] < [p_I(x^s, y^s) - p_V(x^s, y^s)]d^*.
\end{aligned}$$

Since $\{x^n, y^n\} = \arg\min_{x,y}[c_I(x) + c_V(y) + p_V(x, y)h]$, the term on the LHS cannot be positive. So, if $p_I(x^s, y^s) > p_V(x^s, y^s)$, then $SL^N(x^n) < SL^S(d^*)$.

Since $d^* = \arg\min_d[SL^S(d)]$, we must have

$$SL^S(d^*) \leq SL^S(h) = c_I(\overline{x}^s) + c_V(\overline{y}^s) + p_I(\overline{x}^s, \overline{y}^s)h,$$

where $\{\overline{x}^s, \overline{y}^s\}$ are the precaution levels that would be chosen, under strict liability, if d were equal to h.

To minimize $c_I(\overline{x}) + c_V(\overline{y}) + p_I(\overline{x}, \overline{y})h$, the lawmaker would chose $\{\overline{x}^s, \overline{y}^s\}$ so that

$$\begin{aligned}
c_I'(\overline{x}^s) + \frac{\partial p_I(\overline{x}^s, \overline{y}^s)}{\partial \overline{x}^s} h = 0, \\
c_V'(\overline{y}^s) + \frac{\partial p_I(\overline{x}^s, \overline{y}^s)}{\partial \overline{y}^s} h = 0.
\end{aligned}$$

These are precisely the conditions that hold under strict liability when $d = h$ (see eqs. 17 and 19). So, we must have:

$$c_I(\overline{x}^s) + c_V(\overline{y}^s) + p_I(\overline{x}^s, \overline{y}^s)h \leq c_I(x^n) + c_V(y^n) + p_I(x^n, y^n)h.$$

So, if we have: $p_I(x^n) < p_V(x^n)$, then, again,

$$SL^S(d^*) \leq c_I(x^n) + c_V(y^n) + p_I(x^n, y^n)\,h < c_I(x^n) + c_V(y^n) + p_V(x^n, y^n)\,h = SL^N(x^n).$$

A2. Product liability.

Let us consider the case in which markets are perfectly competitive. Let x be the expenditure in safety per unit of product. The safety level is not observable by the consumers. Consumers share the same belief $p_V(x)$ about the probability of harm. Firms are identical, and they share the belief $p_I(x)$. Let $Q_D(P)$ represent the number of units demanded, given the price P.

Let us consider strict liability first. Given the market price m, total consumer surplus is

$$CS\left(Q^D(m)\right) = \int_0^{Q^D(m)} \left[Q_D^{-1}(z) - p_V(x_s)(h-d) - m\right] dz.$$

From each unit, consumer obtain the benefit from consumption, they bear expected uncompensated harm, and they pay the price m.

The marginal willingness to pay of the consumers is

$$CS'\left(Q^A\right) = Q_D^{-1}(m) - p_V(x_s)(h-d) - m.$$

The payoff of a representative producer (Π) is

$$\Pi = mQ - F - Q\left[s + c(x_s) + p_I(x_s)\,d\right],$$

where mQ is the revenue, F the fixed cost, s the production cost, $c(x_s)$ the per-unit safety expenditure, $p_I(x_s)\,d$ the per-unit expected liability. Given the price m and damages d , the producers set

$$\frac{\partial \Pi}{\partial Q} = m - \left[s + c(x_s) + p_I(x_s)\,d\right] = 0, \tag{20}$$

$$\frac{\partial \Pi}{\partial x} = Q\left[c'(x_s) + p_I'(x_s)\,d\right] = 0. \tag{21}$$

Eq. (20) identifies the marginal cost for the firm. Eq. (21) yields the usual condition: $c'(x_s) = -p_I'(x_s)\, d$, which is independent of Q.

At the market equilibrium, the marginal willingness to pay of the consumers should be equal to the marginal cost, thus

$$s + c(x_s) + p_I(x_s)\, d = Q_D^{-1}(m) - p_V(x_s)(h-d).$$

Total surplus is therefore

$$\begin{aligned} W^s(Q,x) = CS(Q) + \Pi = \textstyle\int_0^Q \left[Q_D^{-1}(z)\right] dz \\ -F - Q\left\{s + c(x_s) + p_V(x_s)\, h - d\left(p_V(x_s) - p_I(x_s)\right)\right\}. \end{aligned}$$

At the market equilibrium, the quantity Q^s maximizes surplus given x_s, while x_s is dictated by (21).

Optimal damages solve :

$$\begin{aligned} &\tfrac{\partial W^s(Q,x)}{\partial d} = \underbrace{\frac{\partial\left(CS(Q)+\Pi\right)}{\partial Q}}_{0} \tfrac{\partial Q}{\partial d} + \tfrac{\partial (CS(Q))}{\partial x}\tfrac{\partial x}{\partial d} + \underbrace{\frac{\partial(\Pi)}{\partial x}}_{0}\tfrac{\partial x}{\partial d} + Q\left(p_V(x_s) - p_I(x_s)\right) \\ &= -Q\left[p_V'(x_s)(h-d^*)\right]\tfrac{\partial x}{\partial d} + Q\left(p_V(x_s) - p_I(x_s)\right) \\ &= Q\left[-p_V'(x_s)(h-d^*)\tfrac{\partial x}{\partial d} + p_V(x_s) - p_I(x_s)\right] = 0. \end{aligned}$$

So, we end up exactly with the same equations as in Section 3, and optimal damages are equal to d^*.

Under negligence, a similar logic applies. The optimal standard should solve:

$$\begin{aligned} \frac{\partial W^s(Q,x)}{\partial \overline{x}} &= \underbrace{\frac{\partial\left(CS(Q)+\Pi\right)}{\partial Q}}_{0}\frac{\partial Q}{\partial d} + \frac{\partial\left(CS(Q)+\Pi\right)}{\partial \overline{x}} \\ &= Q\left[c'(\overline{x}) + p_V'(\overline{x})\, h\right] = 0. \end{aligned} \tag{22}$$

Eq. (22)replicates eq. (4).

If we compare the two regimes, Proposition 3 applies.

A3. NBPD. Let us consider a move from negligence to strict liability with optimal damages.

The losses are

Negligence	Strict liability
$L_I^n = c(x^n)$,	$L_I^s = c(x^s) + p_I(x^s) d^* - t$,
$L_V^n = p_V(x^n) h$,	$L_V^s = p_V(x^s)(h - d^*) + t$,

where x^n can be greater or smaller than x^s.

In order to have $L_I^s < L_I^n$ and $L_V^s \leq L_V^n$ the transfer t should satisfy:

$$\begin{cases} t > c(x^s) + p_I(x^s) d^* - c(x^n) \equiv \underline{t}, \\ t \leq p_V(x^n) h - p_V(x^s)(h - d^*) \equiv \bar{t}. \end{cases} \tag{23}$$

We have

$$\bar{t} \geq \underline{t} \Leftrightarrow c(x^n) + p_V(x^n) h \geq c(x^s) + p_I(x^s) d^* + p_V(x^s)(h - d^*), \tag{24}$$

which holds because the move is Pareto efficient (by assumption).

If the move were to be judged according to a hypothetical belief $p_H(x)$, losses would be:

Negligence	Strict liability
$\widehat{L}_I^n = c(x^n)$,	$\widehat{L}_I^s = c(x^s) + p_H(x^s) d^* - t$,
$\widehat{L}_V^n = p_H(x^n) h$,	$\widehat{L}_V^s = p_H(x^s)(h - d^*) + t$.

The move would benefit both parties if

$$\begin{cases} t > c(x^s) + p_H(x^s) d^* - c(x^n) \equiv \underline{t}^H, \\ t \leq p_H(x^n) h - p_H(x^s)(h - d^*) \equiv \bar{t}^H. \end{cases} \tag{25}$$

with

$$\bar{t}^H \geq \underline{t}^H \Leftrightarrow c(x^n) + p_H(x^n) h \geq c(x^s) + p_H(x^s) h. \tag{26}$$

Inequality (26) is a necessary condition for $NBPD$.

The policy move meets $NBPD$ if one can find a t that meets both (23) and (25). This is the case if, and only if, $\bar{t}^H \geq \underline{t}$ and $\underline{t}^H \leq \bar{t}$, that is, if and only if:

$$\begin{cases} c(x^n) + p_H(x^n) h \geq c(x^s) + p_I(x^s) d^* + p_H(x^s)(h - d^*), \\ c(x^n) + p_V(x^n) h \geq c(x^s) + p_H(x^s) d^* + p_V(x^s)(h - d^*). \end{cases} \tag{27}$$

If we fix $p_H(x^s) = p_I(x^s)$, the second inequality is met thanks to (24).

First, let us consider the simpler case in which $d = h$. If we let $p_H(x^n) = p_I(x^n)$, the first inequality becomes:

$$c(x^n) + p_I(x^n)\,h \geq c(x^s) + p_I(x^s)\,h,$$

which is met because x^s minimizes the injurer's loss at $d = h$. So, $p_I(x)$ is the common belief that supports $NDPD$.

Let us turn again to the general case (with $d^* \neq h$). For the case with $x^s < x^n$, let us consider the hypothetical belief: $p_H(x^n) = p_H(x^s) = p_I(x^s)$. The first inequality becomes

$$c(x^n) \geq c(x^s),$$

which is met. The necessary condition (26) is also met.

For the case with $x^s > x^n$, let us consider the hypothetical belief: $p_H(x^n) = 1$. The first inequality becomes

$$c(x^s) - c(x^n) \leq [1 - p_I(x^s)]\,h. \tag{28}$$

If condition (28) is met, also the necessary condition (26) is met. So, the move from negligence to strict liability satisfies NBPD if condition (28) is met.

A4. Other remarks

The model developed above allows the parties to evaluate in different ways the same risk prospect. As such, it has much in common with the case in which parties share the same beliefs but have different attitudes towards risk (Shavell (1982)). The main difference between the two approaches is that, in the differential beliefs model, risk aversion is essentially of first order (it increases linearly with the magnitude of the loss), while in the classic EU model, risk aversion is of second order (it increases exponentially with the magnitude of the loss). This difference becomes relevant when the injurer can harm many potential victims and losses add up. Here, the "risk structure" matters. Specifically, negligence tends to outperform strict liability if harms are positively correlated, and the other way around if harms are negatively correlated (Franzoni (2016)). This feature would be replicated by the divergent beliefs model if parties were assumed to be risk averse.

A further difference between the divergent beliefs model and the classic EU model concerns the way in which small risks are treated. Under risk aversion, when the loss is small, the cost of risk becomes negligible. This implies that a small share of the loss must be placed on the victim and that, therefore, optimal damages cannot be perfectly compensatory (Shavell (1982)). Under the divergent beliefs model, small risks entail different costs for the parties. So, full compensation can be optimal. In fact, optimal compensation can even exceed harm. This is not possible in the risk aversion model: a random reward for the victim would entail a risk cost both for the victim and the injurer.

Since beliefs can take any shape, the differential beliefs model is extremely versatile. In fact, it can replicate the basis features of most non-EU models that display first-order risk and ambiguity aversion, including the neo-additive model, Rank Dependent Expected Utility and, on the condition that losses and gains are treated symmetrically, Prospect Theory. Under this interpretation, the injurer and the victim share the same belief about the probability of harm, but they attach a different "weight" to this probability. So, if the injurer attaches a greater weight to the probability of harm than the victim does, then the injurer behaves as the "risk-pessimistic" party, and vice-versa.

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