Liability Rules under Evidentiary Uncertainty

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Abstract

I consider the efficiency of liability rules when courts obtain imperfect information about precautionary behavior. I ask what tort rules are consistent with socially efficient precautions, what informational requirements the evidence about the parties' behavior must satisfy, what decision rules courts should apply when faced with imperfectly informative evidence, whether these decision rules can be formulated in terms of the legal concept of standard of proof, and whether some general characterization of the efficient standard can be given. I show that court judgments provide appropriate incentives to exert care if they signal that the party prevailing at trial most likely exerted due care, neither more nor less. [Jel. D8, K4]

Keywords: Tort, negligence, moral hazard, imperfect information, standard of proof.

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1 Introduction

This paper considers the role of the legal concept of standard of proof in extending the economic model of tort law to situations where courts make errors in assessing care. The basic model without court error is well known to yield clear-cut predictions on how legal liability for accidents affects precautionary behavior. When only unilateral care is involved, potential injurers are induced to take efficient precautions under the strict liability rule or the negligence rule if courts set due care at the socially optimal level. With bilateral or joint-care, when potential victims as well as injurers affect the risk of harm, the first-best allocation of care is implemented under a variety of negligence-based rules, including simple negligence, negligence with the defense of contributory negligence, strict liability with the same defense, and comparative negligence.[1]

By contrast, no simple conclusion seems to emerge when the parties' behavior is imperfectly observable. The standard result is that the risk of court error may lead to either under or overcompliance with due care. If the courts' information is imperfect but not too noisy, a negligence rule would induce excessive precautions. In joint-care situations, equilibrium outcomes are said to be second-best under any liability rule. How the different rules compare would depend on the likelihood of victim versus injurer negligence, although it is also argued that court error is likely to matter less with comparative negligence. It has also been observed that courts could restore efficient incentives by letting the legal standard of care differ from the socially efficient level, but no general principle is offered as to how they can proceed to do so.[2]

Ad hoc offsetting adjustments in the legal standard of precautions are awkward considering that the interpretation of due care as socially efficient care was a seminal assumption of the economic approach to tort law. Once this is discarded, it is not clear what the model has to say about actual tort rules. The trade-off seems to be that, if the interpretation is maintained, negligence-based liability must lead to undesirable outcomes whenever courts may err in assessing care. This paper makes the point that such inconclusive results are unwarranted and stem from two shortcomings of the earlier

[1] The basic model is due to Brown (1973) and is developed in Landes and Posner (1987) and Shavell (1987). See also Kaplow and Shavell (2002) for a compact survey.

[2] See Diamond (1974), Calfee and Craswell (1984, 1986), Cooter and Ulen (1986, 2000), Shavell (1987), Kolstad, Ulen and Johnson (1990) and Edlin (1994).

literature on legal error.

The first is that court decisions were usually modeled as if courts were unaware that they possess imperfect information or attached no importance to the risk of error. This is surprising considering the importance in law, notably in common law, of concepts such as the standard of proof (the required weight of evidence) for court decisions. Another shortcoming is that the informational prerequisites for the provision of efficient incentives under a negligence-based rule were not clearly specified. Obviously, if the evidence about a party's behavior is very noisy, the finding of negligence must be uninformed and therefore cannot induce efficient care. One would therefore want to characterize the informational conditions under which negligence-based rules are at all consistent with implementation of first-best precautions. A related issue is the extent to which the informational requirements interact with the standard of proof.

Similar questions have been tackled in a more recent strand of literature but from a different perspective focusing on the relation between legal error, litigation expenditures, incentives to sue, ex ante incentives to exert care, the social cost of legal error, etc.[3] In this paper, I abstract from most of these considerations and revert to the issues raised in the earlier literature. I consider the basic model of liability rules and ask whether and under what conditions the efficient precaution levels are implemented when courts obtain imperfect information about the parties' behavior. Specifically, I ask what tort rules are consistent with implementation of the first best, what informational requirements the evidence about the parties' behavior must satisfy, what decision rules courts should apply when faced with imperfectly informative evidence, whether these decision rules can be formulated in terms of the legal concept of standard of proof, and whether some general characterization of the efficient standard can be given. In this analysis, I assume that courts are unsure only about the parties' actual precautions, i.e., courts are able to determine the efficient levels which they take as due care.[4]

I show that, if the risk of error is inevitable, efficient care in the bilateral case can only be obtained with rules that take into consideration the precautionary behavior of both parties (e.g., strict liability with contributory

[3] See for instance Rubinfeld and Sappington (1987), Polinsky and Shavell (1989), Hylton (1990), Kaplow and Shavell (1994), Hay and Spier (1997), Sanchirico (1997), Bernardo, Talley and Welch (2000).

[4] The model is closely related to Fluet (1999) although that paper dealt with the negligence rule in unilateral care problems under limited liability constraints.

negligence is inefficient). Regarding informational requirements, a necessary but not quite sufficient condition is that there be potential realizations of the evidence such that, following the occurrence of harm, efficient care by both parties would appear most likely. Finally, with zero-one liability rules (i.e., rules where either the victim or the injurer bears 100 percent of the loss), the underlying standard of proof must be such that court rulings, viewed as signals, convey that the prevailing party barely exerted due care, neither more nor less. In other words, a decision in favor of a party must signal to outsiders that bare compliance with due care was the party's most likely action. I show that this implies a form of "preponderance of evidence"—the standard of proof in common law for civil disputes—in the sense that a claim is established only if it appears more likely than not to the court.

Section 2 presents the framework. The main results are derived in section 3 for unilateral and bilateral care. Section 4 analyses the effect of changes in the informational quality of the evidence, extends the analysis to comparative negligence, and discusses the extent to which punitive damages reduce informational requirements. Section 5 concludes.

2 The model

The starting point is the simple accident model with risk neutral agents and zero litigation costs. An activity imposes a risk of loss L on third parties and the only concern is the extent of precautions to reduce this risk—exercising the activity is taken as given. The probability of accident is $p(u, v)$, a twice differentiable and strictly convex function with negative partial derivatives p_u and p_v, where u, $v \geq 0$ are the expenditures on precautions by injurer and victim respectively. The socially efficient levels minimize $p(u, v)L + u + v$, the sum of precaution and accident costs. Assuming an interior solution, they satisfy

$$-\,p_u(u^*, v^*)L = -\,p_v(u^*, v^*)L = 1. \tag{1}$$

As noted, different liability rules implement efficient care if courts can perfectly determine the parties' behavior and if legal standards of precaution are set at the socially efficient levels. To illustrate, under "simple negligence" the injurer pays full compensatory damages to the victim if he is found negligent, irrespective of the victim's behavior. The expected cost facing a potential injurer is then $U = p(u, v)\delta(u)L + u$ where $\delta(u) = 1$ if $u < u^*$ and is zero otherwise; a potential victim's expected cost is $V = p(u, v)[1-\delta(u)]L+v$.

Efficient care is the Nash equilibrium, that is,

$$U(u^*, v^*) \leq U(u, v^*) \text{ and } V(u^*, v^*) \leq V(u^*, v). \tag{2}$$

A single change is introduced. Rather than observing u and v, courts must rely on imperfectly informative evidence about the levels of care. The content of the evidence—testimonies by witnesses, expert opinions, various documents—is stochastic with probabilities that depend on the parties' care levels. Evidentiary outcomes are assumed to be comparable in terms of the "more favorable than" relation defined in Milgrom (1981), i.e., they can be ranked in terms of how damaging they are for the purpose of assessing a party's behavior. All relevant information can then be summarized by a random variable satisfying the monotone likelihood property—an "index" conveying how relatively unfavorable the underlying multidimensional evidence turns out to be.[5]

The signals about u and v are denoted $\widetilde{x}$ and $\widetilde{y}$ respectively, with cumulative distributions $F(x, u)$ and $G(y, v)$ and corresponding density functions $f(x, u)$ and $g(y, v)$ assumed twice continuously differentiable. Larger values correspond to more favorable evidence. The signals are independent for any levels of care and they take their values in the unit interval, which is without loss of generality since the range is arbitrary. This framework, with one additional condition, is summarized in the following assumptions.

Assumption 1: *For all u and v, $f(x, u) > 0$ and $g(y, v) > 0$ for x, $y \in [0, 1]$ and are zero otherwise.*

Assumption 2: *For all u and v, $f_u(x, u)/f(x, u)$ and $g_v(y, v)/g(y, v)$ are strictly increasing in x and y respectively.*

The first assumption means that error is inevitable because all possible realizations of the evidence are consistent with different levels of care. The second is the monotone likelihood ratio property (MLRP) and implies F_u, $G_v < 0$, except at the boundary of the support where the derivatives are nil.

The third and last assumption is a convexity condition. Consider the event "accident occurs and $\widetilde{x} < x$" for some $x \in (0, 1)$. Its probability is $p(u, v)F(u, x)$ and is strictly decreasing in u. Hence, the event represents

[5] Courts need not have direct access to the evidence. In an adversarial procedure, as evidence favors either the plaintiff or the defendant, it will be submitted if submission costs are negligible and both parties have access to the same verifiable evidence (Milgrom and Roberts, 1986).

unfavorable information about the injurer's level of care, i.e., it is "bad news". I assume that, as the injurer exerts less care, the probability of bad news about his behavior increases at an increasing rate relative to the probability of accident itself. The same holds with respect to evidence concerning the victim. To write this formally, let $u(p,v)$ and $v(p,u)$ be obtained by inverting the probability of accident function $p(u,v)$; that is, they represent a party's level of care as a function of the probability of accident, given the other party's care.

Assumption 3: *For* $x, y \in (0,1)$, $pF[x, u(p,v)]$ *and* $pG[y, v(p,u)]$ *are strictly convex in* p.

The assumption implies that pF and pG are strictly convex in u and v respectively, ensuring that the parties' optimization problems are well behaved.[6]

Courts are able to perfectly assess damages and the extent of the risk as a function of care. As in the basic accident model, they can therefore determine the efficient levels of precaution, which they take as due care. However, courts do not observe the true levels of care. They obtain evidence which they know to be imperfect and from which they draw likelihood assessments. On this basis, and given the tort rule that applies, they assign liability. When the rule requires a decision concerning a party's negligence, courts weigh whether the evidence about a party's behavior is sufficiently unfavorable. This amounts to using critical values x and y such that the injurer is found negligent if $\widetilde{x} < x$ and the victim is found negligent if $\widetilde{y} < y$. The evidentiary thresholds x and y reflect the courts' standard of proof. Lower thresholds mean that for finding negligence courts need more convincing evidence that care was insufficient. The parties know the court's decision rule and therefore anticipate the probability of being found negligent as a function of their level of care.

[6] Assumption 1 is known as invariant support. Assumption 3 is in lieu of the Convexity of the Distribution Function Condition. Given $p_{uu} > 0$, $F_u < 0$, $\partial u(p,v)/\partial p < 0$, it implies

$$\partial^2 p(u,v)F(u,x)/\partial u^2 = \left[\partial pF(x,u(p,v))/\partial p\right] p_{uu} + \left[\partial^2 pF(x,u(p,v))/\partial p^2\right] (p_u)^2 > 0.$$

3 Main results

It is useful to discuss first the case where the occurrence of harm depends only on the potential injurer's behavior. The relation between evidentiary thresholds and incentives to exert care is then straightforward. The properties extend to joint care.

Unilateral care

When only the injurer's precautions matter, the probability of accident is $p(u)$ with $p' < 0$ and $p'' > 0$. Socially efficient care minimizes $p(u)L + u$, satisfying

$$-p'(u^*)L = 1. \tag{3}$$

Strict liability induces efficient precautions. The issue is whether this is also feasible with the negligence rule.

If x is the threshold for finding negligence, a potential injurer minimizes the expected cost $p(u)F(x,u)L + u$. The equilibrium level of care satisfies the first-order condition[7]

$$-\left[p'(u)F(x,u) + p(u)F_u(x,u)\right]L = 1. \tag{4}$$

Comparing with (3), u^* is a solution if $x = 1$ since in that case $F = 1$ and $F_u = 0$, but this corresponds to the strict liability rule. The negligence rule requires that an injurer exerting due care avoids liability with positive probability, i.e., u^* must be a solution for some $x < 1$.

Substituting from (3) in (4) and setting care at the socially optimal level, the efficient threshold solves

$$\varphi(x) := -\left[p'(u^*)F(x,u^*) + p(u^*)F_u(x,u^*)\right] = -p'(u^*). \tag{5}$$

$\varphi(x)$ is the change in the probability of being found negligent when care varies marginally from the efficient level, given the evidentiary threshold. Condition (5) therefore requires that, when the injurer exerts due care, a marginal change in the level of care has the same effect on the probability of being found negligent as it has on the probability of accident.

– Figure 1 about here –

[7] The second-order condition is satisfied by assumption 3.

Obviously, $\varphi(0) = 0$ and $\varphi(1) = -p'(u^*)$. In figure 1, φ is drawn as a function of $F(x, u^*)$, a positive monotonic transformation of x. Taking the first and second-order derivatives,

$$\frac{d\varphi(x)}{dF(x,u^*)} = -\left[p'(u^*) + p(u^*)\frac{f_u(x,u^*)}{f(x,u^*)}\right], \tag{6}$$

$$\frac{d^2\varphi(x)}{dF(x,u^*)^2} = -\frac{p(u^*)}{f(x,u^*)}\frac{d}{dx}\left(\frac{f_u(x,u^*)}{f(x,u^*)}\right) < 0, \tag{7}$$

where the inequality follows from MLRP. Hence, the curve is strictly concave. The efficient evidentiary threshold is denoted $\widehat{x}$. $F(\widehat{x}, u^*)$ is the probability that an injurer exerting due care is erroneously found negligent and will be referred to as the type 1 error.

There are two requirements for the socially efficient precautions to be implemented with a negligence rule. First, the relevant curves must intersect, i.e., there must exist $\widehat{x} < 1$ as defined. This depends on how informative the evidence is likely to be with respect to the injurer's behavior. As discussed in section 4, insufficiently informative evidence entails a curve such as a in the figure. That curve remains below the horizontal line drawn from $-p'(u^*)$ except at the upper bound of the support. The consequence is that providing the desired incentives can then only be obtained with the strict liability rule.

Assuming the evidence is sufficiently informative, the second requirement is that courts use the appropriate evidentiary threshold. This has to do with the standard of proof for establishing negligence. Before discussing the standard, I give a condition ensuring that the evidence is sufficiently informative.

Condition 1: *u^* maximizes $p(u)f(x_0, u)$ for some $x_0 < 1$.*

The expression $p(u)f(x, u)$ is the probability that harm occurs together with the realized evidence being x, conditional on the level of care. In statistical terminology, it is the likelihood of the unknown care level u, given the "data" which comprise the occurrence of harm and the evidence x. Condition 1 requires that, for some realization of the evidence, due care is the most likely level of care. When the court is presented with x_0, its "maximum likelihood estimate" of the injurer's care is precisely u^*.

Note the difference with a Bayesian formulation. If priors about u are described by the density $\lambda(u)$ and posteriors by $\lambda(u \mid x)$, then by Bayes' rule the relative posterior *probability* of u versus u' is

$$\frac{\lambda(u \mid x)}{\lambda(u' \mid x)} = \left[\frac{p(u)f(x,u)}{p(u')f(x,u')}\right]\frac{\lambda(u)}{\lambda(u')},$$

where the term in brackets is the *likelihood* ratio of u versus u' given the "data". In what follows, court decision-making disregards priors about the injurer's conduct and is solely in terms of relative likelihood. This captures the idea that the court's decision rests only on the "particular facts" whose probability depends on what the defendant might have done. The issue of priors is discussed further in section 5.

From the necessary condition for a maximum in condition 1, x_0 solves

$$-\frac{p'(u^*)}{p(u^*)} = \frac{f_u(x,u^*)}{f(x,u^*)}. \tag{8}$$

The right-hand side is strictly increasing in x, hence x_0 is unique.[8] The critical x_0 has another interpretation as well. Recalling (6) and (7), $\varphi(x)$ reaches a strict interior maximum at x_0 as represented in figure 1. The next result follows immediately.

LEMMA 1: *Under condition 1, there is a unique* $\widehat{x} < x_0$ *such that* $\varphi(\widehat{x}) = -p'(u^*)$. $\varphi(x)$ *is increasing if* $x < x_0$, *decreasing if* $x > x_0$.

A threshold $x' < \widehat{x}$ leads to underprecaution, a threshold $x'' \in (\widehat{x}, 1)$ to overprecaution. A threshold lower than the efficient $\widehat{x}$ corresponds to a higher standard of proof than would be required to provide efficient incentives. Conversely, a less demanding standard of proof provides too much incentives.[9]

LEMMA 2: *If* $x \lesseqgtr x_0$, *then* $\arg\max_u p(u)f(x,u) \lesseqgtr u^*$.

PROOF: See Appendix.

Lemma 2 partitions possible realizations of the evidence in terms of whether inadequate ($u < u^*$) or sufficient care ($u \geq u^*$) is most likely. Its interpretive role is discussed after the next proposition.

[8] As a function of x, f_u/f increases from negative to positive. It needs to become sufficiently large for there to exist x_0 as defined. Loosely speaking, poor information corresponds to a flat f_u/f function.

[9] In the limit, as x'' tends to unity, the negligence rule becomes indistinguishable from strict liability. A threshold greater than x_0 can be interpreted as putting on the injurer the "burden of persuasion" (see footnote 18).

Proposition 1: *If $\widehat{x}$ is the efficient evidentiary threshold for negligence in the unilateral case, then* $\arg\max_u p(u)f(x,u) < u^*$ *for all* $x < \widehat{x}$. *Moreover,* $\widehat{x}$ *is efficient if and only if* u^* *maximizes* $p(u)\,(1 - F(\widehat{x}, u))$.

Proof: See Appendix.

The court finds negligence only if $x < \widehat{x}$, when the most likely level of care is below due care. The underlying standard of proof therefore entails a form of "preponderance of evidence", i.e., negligence is deemed proved only if inadequate care is more likely than due care given the evidence at trial. However, the condition is not sufficient. By lemma 2, for any $x \in [\widehat{x}, x_0)$, inadequate care is also more likely than due care but the defendant is nevertheless not found negligent. The interpretation is therefore that, to establish negligence, inadequate care must be sufficiently more likely than due care, i.e., there must be a *sufficient* "preponderance of evidence". How much so is characterized in the second part of proposition 1.

The characterization is in terms of court rulings viewed as signals about defendants' behavior. I now consider the case of outsiders who understand the situation and the courts' decision rule, but do not have access to the detailed evidence presented at trial. What should they infer about a defendant's likely level of care when the court decides in his favor? For instance, in a criminal trial guilt must be proved beyond a reasonable doubt, hence acquittal need not be a strong signal that the accused is innocent. A much lower standard of proof—preponderance of evidence—is used for civil trials in common law. A decision in favor of the defendant is then a stronger signal that he exerted due care.

One way to approach these questions is to ask what estimate outsiders would form of the injurer's care, upon knowing only that harm occurred and that the injurer was found non negligent. As a function of the care level, the probability of this event is $p(u)(1 - F(\widehat{x}, u))$. Borrowing from statistical terminology once more, the expression is the likelihood of the unknown u given that harm occurred and that the defendant escaped liability. Thus, the second part of the proposition states that, from the outsiders' point of view, the most likely level of care, when the injurer prevails, is due care, i.e., u^* is the outsiders' maximum likelihood estimate of the injurer's care. Noting that

$$\arg\max_u p(u)[1 - F(x, u)]$$

is increasing in x, the interpretation is therefore that the courts' underlying standard of proof should not be weak to the point that a defendant escaping liability suggests more than due care—as would be the case with a threshold to the right of $\widehat{x}$. Neither should the standard be stringent to the point that escaping liability suggests less than due care, as would follow from a threshold to the left of $\widehat{x}$.

Observe also that $p(u)(1 - F(\widehat{x}, u))$ is the probability that victims will bear a loss, as a function of the injurer's care level. Therefore, the evidentiary threshold is efficient if any deviation from due care by the injurer benefits potential victims. This generalizes a property of the negligence rule when care is observable without error.[10]

To conclude the section, I relate the results to the existing literature. The most common approach has been to assume that courts observe a signal $\widetilde{x} = u + \widetilde{\varepsilon}$, where $\widetilde{\varepsilon}$ is an error term, and that they find negligence if $\widetilde{x} < u^*$. Several authors (e.g., Shavell, 1987, Kolstad et al., 1990) have noted that this induces insufficient care if the variance of $\widetilde{\varepsilon}$ is large and excessive care if it is small. By itself, $\widetilde{x} = u + \widetilde{\varepsilon}$ is consistent with and is in fact a particular case of the present model provided $\widetilde{x}$ satisfies MLRP.[11] However, two points were made. First, if the evidence is sufficiently poor (e.g., if the variance of $\widetilde{\varepsilon}$ is large), there may be no threshold for negligence that induces efficient care. Secondly, as an evidentiary threshold, u^* is perfectly arbitrary.

To see this, observe that the rule "find negligence if $\widetilde{x} < u^*$" takes no account of how informative $\widetilde{x}$ is. Furthermore, it disregards part of the relevant evidence, namely the information from the occurrence of harm itself. To take an extreme case, suppose care can be either low or high with, say, $u_l = 0$ and $u_h = 1$. Suppose further that $p_l = 0.99$ while $p_h = 0.01$. The mere occurrence of harm then constitutes rather strong evidence that care was low. For a decision in favor of the injurer to convey that high care is at least as likely as low care, the threshold for $\widetilde{x}$ needs to be higher than u^*.

Proposition 1 nevertheless suggests that the common law standard of proof may be too weak. According to the usual interpretation, a claim is

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[10] Using the notation of section 2, the probability of loss by victims is then $p(u)[1-\delta(u)]$. This is zero if $u < u^*$ and it equals $p(u)$ if $u \geq u^*$. Hence, it is maximized at $u = u^*$.

[11] Let $H(\varepsilon)$ be the cumulative distribution function of $\widetilde{\varepsilon}$ with density $h(\varepsilon)$. Then $F(x, u) = H(x - u)$ and MLRP is satisfied if $(h')^2 - hh'' > 0$. With this specification, one would want to discard the convention that $\widetilde{x}$ takes its values in the unit interval. Alternatively, the signal $\widetilde{z} := H(\widetilde{x} - u_1)$ could be introduced where $u_1 > 0$ is an arbitrary fixed level of care. $\widetilde{z} \in [0, 1]$ then conveys the same information as $\widetilde{x}$ and it satisfies MLRP if $\widetilde{x}$ does.

established by a "preponderance of evidence" if it is shown to be more likely true than not true.[12] Negligence would therefore be found whenever inadequate care is more likely than due care. By lemma 2, this amounts to using x_0 as evidentiary threshold, resulting in overcompliance. The issue of excessive care has been much debated in malpractice liability. A common argument is that incentives to practice medicine defensively are increased by the possibility of court error, given that precautionary behavior is particularly difficult to verify ex post.[13] The above suggests that excessive care results not so much from the risk of court error per se as from too weak a standard of proof.

Bilateral care

When both injurer and victim can take precautions, the efficient levels minimize $p(u, v)L + u + v$ and satisfy the first-order conditions (1).

Liability rules for joint care belong to two categories. One class of rules assigns liability on the basis of the behavior of only one party. This includes "simple negligence", where only the injurer's behavior is taken into account, and "strict liability with the defense of contributory negligence" where only the victim's behavior is considered. In the other class of rules, the behavior of both parties is taken into account, as in "negligence with the defense of contributory negligence" and "comparative negligence".

Rules in the first category are inefficient if behavior is imperfectly observable. Consider the simple negligence rule. With the threshold x, u^* and v^* constitute a Nash equilibrium if u^* minimizes $p(u, v^*)F(x, u)L + u$ and v^* minimizes $p(u^*, v)[1 - F(x, u^*)]L + v$. The efficient v^* solves the second problem only if $F(x, u^*) = 0$. By assumption 1, this implies $F(x, u) = 0$ for all u. Hence, the injurer has no incentive to take care and u^* cannot be part of the equilibrium. A similar argument applies to strict liability with the defense of contributory negligence.[14]

Proposition 2: *With bilateral care, the rules of negligence and of strict liability with the defense of contributory negligence are inconsistent with the first-best allocation of care.*

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[12] "A bare preponderance is sufficient, though the scales drop but a feather's weight" (Livanovitch vs Livanovitch, 99Vt. 327 131A. 799, 1926).

[13] The debate is surveyed in Kessler and McClellan (1995) who present evidence of excess precautions.

[14] This is true if "punitive damages" are ruled out. These are discussed in section 4.

The point is that, so long as courts may err in determining care, there are no evidentiary thresholds under the above rules that implement the efficient precautions as a noncooperative equilibrium.

Among the second class of tort rules, the traditional one in common law is negligence with the defense of contributory negligence, "contributory negligence" hereafter.[15] The injurer is then liable for the victim's loss if he is found negligent and the victim is not found negligent. With the thresholds x and y for injurer and victim, the injurer is therefore liable only if the evidence satisfies $\widetilde{x} < x$ and $\widetilde{y} \geq y$. The injurer's expected cost is then

$$U = p(u,v)F(x,u)\left(1 - G(y,v)\right)L + u,$$

while that of the victim is

$$V = p(u,v)\left[1 - F(x,u)\left(1 - G(y,v)\right)\right]L + v.$$

At a Nash equilibrium with positive care levels, u and v satisfy the first-order conditions[16]:

$$-\left[p_u(u,v)F(x,u) + p(u,v)F_u(x,u)\right]\left(1 - G(y,v)\right)L = 1,$$

$$-\left\{p_v(u,v)\left[1 - F(x,u)(1 - G(y,v))\right] + p(u,v)F(x,u)G_v(y,v)\right\}L = 1.$$

Setting care at the efficient levels and substituting from (1), the efficient thresholds $\widehat{x}$ and $\widehat{y}$ solve:

$$-\left[p_u(u^*,v^*)F(x,u^*) + p(u^*,v^*)F_u(x,u^*)\right]\left(1 - G(y,v^*)\right) = -p_u(u^*,v^*), \quad (9)$$

$$-\left[p_v(u^*,v^*)G(y,v^*) + p(u^*,v^*)G_v(y,v^*)\right] = -p_v(u^*,v^*). \quad (10)$$

The last condition has the same form as (5) in the preceding section. Thus, $y = 1$ is a solution but clearly only $y < 1$ is consistent with (9). In the figures 2 and 3, all functions are evaluated at the efficient care levels. The efficient thresholds are shown in terms of the type 1 errors $\alpha = F(\widehat{x}, u^*)$

[15] Interchanging the role of the parties, what follows also applies to the theoretical rule of "dual contributory negligence" defined in Brown (1973). Under this rule the injurer is always liable except when the victim is found negligent and the injurer nonnegligent. Comparative negligence is considered in section 4.

[16] The conditions for an equilibrium are the same as in (2), but with the parties' expected cost U and V defined as above. By assumption 3 these functions are strictly convex in u and v respectively.

and $\beta = G(\widehat{y}, v^*)$. I introduce a condition which parallels condition 1 for unilateral care.

Condition 2: *For some x_0, $y_0 < 1$,*

$$(u^*, v^*) = \arg\max_{u,v} p(u,v) g(y_0, v) f(x_0, u).$$

Again, the expression is the likelihood of the pair of care levels (u, v) given the occurrence of harm and the evidence x_0 and y_0. The condition requires that there be realizations of the evidence for which due care by both parties is most likely.

– Figures 2 and 3 about here –

Extending previous results, condition 2 implies the existence of $\widehat{y} < y_0$ solving (10). However, the condition is not sufficient with respect to the injurer as there is an asymmetry in the determination of the efficient thresholds. The one concerning the victim is obtained directly from (10) independently of the injurer's threshold, but the latter depends on the type 1 error with respect to the victim.

Lemma 3: *Under condition 2, there exists $\widehat{y} < y_0$ solving (10); there exists $\widehat{x} \leq x_0$ solving (9) if*

$$-\left[p_u(u^*, v^*) F(x_0, u^*) + p(u^*, v^*) F_u(x_0, u^*)\right] \geq \frac{-p_u(u^*, v^*)}{1 - G(\widehat{y}, v^*)}.$$

If the above inequality is strict, there are in fact two solutions to (9), as shown in figure 3. I retain only the one corresponding to the smallest type 1 error.[17] As discussed below, this is appropriate if the victim bears the burden of persuasion regarding the injurer's negligence and if the standard of proof involves a form of "preponderance of evidence". The following is the analog to proposition 1.

Proposition 3: *$\widehat{x}$ and $\widehat{y}$ are efficient evidentiary thresholds under contributory negligence if and only if*

$$u^* = \arg\max_u p(u, v^*) \left[1 - F(\widehat{x}, u) \left(1 - G(\widehat{y}, v^*)\right)\right], \tag{11}$$

$$v^* = \arg\max_v p(u^*, v) \left(1 - G(\widehat{y}, v)\right) F(\widehat{x}, u^*). \tag{12}$$

[17] In the figures, $\alpha_0 = F(x_0, u^*)$ and $\beta_0 = G(y_0, v^*)$. The solutions α and α' to (9) satisfy $\alpha < \alpha_0 < \alpha'$.

$\arg\max_v p(u^*, v)g(y, v) < v^*$ *if* $y < \widehat{y}$, $\arg\max_u p(u, v^*)f(x, u) < u^*$*if* $x < \widehat{x}$ *with* $\widehat{x} \leq x_0$.

PROOF: See Appendix.

As in the unilateral case, negligence is found only if inadequate care is more likely than due care. This is consistent with the injurer bearing the burden of proving the victim's negligence, by a sufficient preponderance of evidence, in order to benefit from the defense of contributory negligence. It is also consistent with the victim bearing the burden of proving the injurer's negligence, provided we choose the solution $\widehat{x} \leq x_0$ to condition (9) rather than the one corresponding to α' in figure 3. With the latter, it would be as if the injurer had the burden of proving that he was not negligent.[18]

Consider now the interpretation of court decisions as signals about the parties' behavior. The expression in (11) is the likelihood of the injurer's care level u upon knowing that harm occurred and that the injurer won the trial. A suit won by the injurer must convey that he barely undertook due care, neither more nor less. The maximum likelihood u^* takes into account the fact that the injurer avoids liability if found non-negligent or if the victim is found negligent. The expression in (12) is the likelihood of the victim's care level v given that the victim won the case. The maximum likelihood v^* is then the same as would be obtained by asking what level of care is most likely, given that the victim was not found negligent.

The result implies that courts should apply a weaker standard of proof for finding injurer negligence than for victim negligence. Indeed, at the efficient threshold[19],

$$\arg\max_u \; p(u, v^*) \left[1 - F(\widehat{x}, u)\right] > u^*.$$

The outsiders' maximum likelihood u, upon learning that the injurer was found non-negligent (and not simply that he won the case), is greater than due care. Intuitively, a ruling of non negligence with respect to the injurer represents more favorable information about the injurer's behavior than a

[18]Let $\alpha' = F(x', u^*)$ so that $x' > x_0$. With the threshold x', the injurer avoids being found negligent only if $x \geq x'$. By lemma 2, this implies $\arg\max_u p(u, v^*)f(x, u) \geq u^*$, i.e., a finding of negligence is avoided only if sufficient care appears most likely. To keep the exposition simple, I henceforth disregard this possible allocation of the burden of persuasion.

[19]By proposition 3, u^* maximizes $p(1-F) + GpF$. Since pF is decreasing in u, it must be that $p(1-F)$ is increasing at u^*.

similar ruling about the victim. Accordingly, it must be that courts require less convincing evidence to find an injurer negligent.

Finally, observe that the expression in (11) is the probability that the victim bears a loss, as a function of the injurer's precautions and assuming the victim undertook due care. A potential victim benefits from any deviation by the injurer from his efficient care level. Similarly, the right-hand side of (12) is the probability that the injurer will have to pay damages. Any deviation by the victim from his efficient care level benefits potential injurers. Thus, under the efficient thresholds, the liability rule exhibits a "saddle point" property. Schweizer (2005) has shown that this property is shared by efficient liability rules in many different contexts.

4 Extensions

Information

Inducing efficient precautions is feasible only with sufficiently informative evidence. I now discuss the effect of changes in the quality of the evidence.

Intuitively, more informative evidence should reduce the risk of error. Consider two situations differing only in the quality of the evidence about the injurer's behavior. One is characterized by $F(x, u)$, the other by the distribution $H(x, u)$ also satisfying assumptions 1 to 3. A general criterion for ranking information structures is the following.

DEFINITION: *H is more informative than F with respect to u if, for all u, $H_u(x_1, u) < F_u(x_2, u)$ for $x_1, x_2 \in (0, 1)$ such that $F(x_1, u) = H(x_2, u)$.*

The more informative the evidence, the more the probability of unfavorable evidence is sensitive to changes in the level of care. The condition is equivalent to other well known criteria.[20]

To see the implications, consider again the negligence rule in the case of unilateral care. Choose the evidentiary thresholds so that the type 1 error is the same in both situations, i.e., $F(x_1, u^*) = H(x_2, u^*)$. Then, if H is more informative than F,

$$\begin{aligned} &- \left[p'(u^*)H(x_2, u^*) + p(u^*)H_u(x_2, u^*)\right] > \\ &\qquad - \left[p'(u^*)F(x_1, u^*) + p(u^*)F_u(x_1, u^*)\right]. \end{aligned}$$

[20] Demougin and Fluet (2001) show the equivalence with Kim's (1995) criterion defined in terms of mean preserving spreads of the likelihood ratio f_u/f.

Marginal incentives are greater with H and this is true for any pair of thresholds with the same type 1 error. In figure 1, the φ-curve for H is therefore above the one for F, for example curve b. Conversely, if H were less informative, the curve would be below the one for F. A particular case is curve a where implementing the efficient level of care is no longer feasible under a negligence rule.[21] Otherwise, the less informative the evidence, the greater the type 1 error under the efficient standard of proof. This benefits potential victims since injurers are held liable more often.

Similar results obtain under joint care with the rule of contributory negligence. In the figures 2 and 3, less informative evidence shifts the incentive curves downward. With sufficiently poorer evidence about either the victim or the injurer, at least one set of curves will not intersect and the first best will no longer be feasible.

The effect on court error is similarly straightforward. Less informative evidence about the victim's behavior leads to a higher type 1 error β. In turn, this induces a downward shift in the relevant curve of figure 3, yielding an increase in the type 1 error α as well. The redistributive effects on the parties' well-being is not a priori obvious, but I show below that the change is beneficial to potential victims (i.e., α increases more than β). Finally, less informative evidence about the injurer's behavior only affects the curve in figure 3 and is obviously beneficial to victims.

Proposition 4: *Under contributory negligence with the efficient standards of proof, potential victims benefit from poorer evidence about either the victims' or the injurers' precautions.*

(i) Poorer evidence about the victim's care increases the type 1 errors for both victim and injurer;

(ii) poorer evidence about the injurer's care increases the injurer type 1 error with no effect on victim type 1 error.

Proof: See Appendix.

When courts obtain perfect information about the parties' behavior, victims bear 100 per cent of expected accident costs under contributory negligence. The possibility of error shifts part of these costs to injurers. It should be emphasized that the informational quality of the evidence affects the risk of erroneously finding negligence, although the underlying standard of proof

[21] In particular, condition 1 is then not satisfied. Thus, the conditions 1 and 2 refer to how informative the evidence is.

is invariant and satisfies the conditions of proposition 3. Irrespective of the quality of the evidence, a ruling in favor of a party signals that bare compliance with due care is most likely. Given the standard of proof, the type 1 errors then follow from the quality of the evidence.

Comparative negligence

Between the mid 1960s and early 1980s, most US jurisdictions replaced the principle of contributory negligence with comparative negligence. The latter differs by apportioning the loss between injurer and victim when both parties are found negligent, which is seen as less harsh than the complete bar to recovery by a negligent victim under contributory negligence.[22] Comparative or relative negligence is also the main liability rule in England and in civil law countries.

I consider a simple form where the victim bears a given fraction θ of the loss when both parties are found negligent.[23] With the evidentiary thresholds x and y, the injurer is liable for the whole loss if $\widetilde{x} < x$ and $\widetilde{y} \geq y$ and for a fraction $1-\theta$ if $\widetilde{x} < x$ and $\widetilde{y} < y$. The injurer's expected cost is

$$\begin{aligned} U &= p(u,v)F(x,u)\left[1 - G(y,v) + (1-\theta)G(y,v)\right] \\ &= p(u,v)F(x,u)\left(1 - \theta G(y,v)\right)L + u \end{aligned}$$

and the victim's is

$$V = p(u,v)\left[1 - F(x,u)\left(1 - \theta G(y,v)\right)\right]L + v.$$

Proceeding as before, the efficient thresholds x' and y' solve

$$-\left[p_u(u^*,v^*)F(x,u^*) + p(u^*,v^*)F_u(x,u^*)\right]\left(1 - \theta G(y,v^*)\right) = -p_u(u^*,v^*), \quad (13)$$

$$-\left[p_v(u^*,v^*)G(y,v^*) + p(u^*,v^*)G_v(y,v^*)\right]\theta = -p_v(u^*,v^*). \quad (14)$$

Again there may be several solutions but I retain only the ones with the smallest type 1 errors.[24]

[22] The "fairness" argument played an important role in the spread of comparative negligence. See Landes and Posner (1987), but also Curran (1992) who argues that the adoption of strict product liability in the 1960s reduced manufacturers' opposition to comparative negligence.

[23] There are many variants of comparative negligence. Actual rules usually apportion the loss in proportion to the parties' degree of negligence.

[24] That is, $x' < x_0$ and $y' < y_0$.

Comparing (14) and (10), it is readily seen that $\theta < 1$ amounts to a proportional downward shift in the incentive curve of figure 2. Hence, we must have $y' > \widehat{y}$, where the latter is the efficient threshold under contributory negligence. Since the injurer now sometimes shares part of the loss, the standard of proof for victim negligence must be less demanding in order to provide potential victims with the appropriate incentives. Comparing (13) and (9), the implications regarding the injurer's threshold are at first sight ambiguous: $\theta < 1$ increases the injurers' incentives but a larger y reduces them.

PROPOSITION 5: *Let $\widehat{x}$ and $\widehat{y}$ be the efficient thresholds under contributory negligence, x' and y' the efficient thresholds under comparative negligence. Then $x' > \widehat{x}$, $y' > \widehat{y}$ and potential victims are better off under comparative negligence than under contributory negligence.*

PROOF: See Appendix.

The standard of proof for finding negligence must now be weaker for both parties, although inadequate care is still required to be more likely than due care. Victims are found negligent more often but nevertheless face a lower expected cost than under contributory negligence.[25] Thus, the switch to comparative negligence may indeed benefit victims while still maintaining efficient incentives.

Proposition 5 also shows that comparative negligence does not improve things regarding the feasibility of implementing the first best compared to contributory negligence. If the first best is feasible with some $\theta < 1$, it is also feasible with $\theta = 1$ but the converse does not hold. When the evidence about the parties' behavior is poor, contributory negligence may therefore be the better rule since comparative negligence dilutes incentives.[26] On the other hand, if common law courts apply too weak a standard of proof (corresponding, say, to the thresholds x_0 and y_0) and if the evidence is relatively informative, comparative negligence may well yield less distortion from the first best.[27]

[25] Similar results were found by Edlin (1994), but with the interpretation that due care standards should be set higher under comparative negligence.

[26] There is evidence that the switch to comparative negligence from contributory negligence has resulted in reduced incentives to exert care (e.g., White, 1989, and Flanagan et al., 1989).

[27] This is reminiscent of the claim by Cooter and Ulen (1986) and Edlin (1994) that comparative negligence would generally fare better.

Punitive damages

Punitive in addition to compensatory damages are sometimes awarded, usually because the defendant's conduct has been particularly reprehensible. The economics literature has stressed the deterrence rationale for situations where an injurer may escape liability for the harm he caused, e.g., because he cannot always be identified.[28] I briefly examine the extent to which punitive damages reduce informational requirements in the joint care problem.

From the principal-agent literature, it is well known that sufficiently large money incentives solve the moral hazard problem when the agent is risk neutral, even though information is poor. In the bilateral care situation, one therefore expects that appropriate punitive damages can always induce injurers to undertake efficient precautions. I examine whether, under contributory negligence, the fear of not being paid punitive damages (assuming these do not go to the state) might also induce potential victims to exert care, even though the evidence about their behavior is poor. I show that the answer is negative, i.e., the prospect of more than compensatory damages has no effect on informational requirements with respect to the victim nor on the standard of proof for deciding victim negligence.

Let $D \geq L$ be the total damages awarded (the punitive part is then $D-L$) under the contributory negligence rule with evidentiary threshold x and y. The injurer's expected cost is

$$U = p(u,v)F(x,u)\,(1-G(y,v))\,D + u \tag{15}$$

and the victim's is

$$V = p(u,v)\,[L - F(x,u)\,(1-G(y,v))\,D] + v. \tag{16}$$

The victim bears the loss L but is paid D when he wins the case.

Obviously, $x > 0$ is needed to provide the injurer with incentives. From (16), it follows that v^* is the best reply to u^* if the victim's threshold satisfies

$$\left.\frac{\partial p(u^*,v)\,(1-G(\widehat{y},v))}{\partial v}\right|_{v=v^*} = 0.$$

This is the same condition as in proposition 3. Informational requirements concerning the victim are therefore not improved and the standard of proof

[28] See for instance Polinsky and Shavell (1998).

is the same as before. Given $\widehat{y}$, it is clear from (15) that u^* can be made to be the best reply to v^* with different combinations of x and D. One possibility is to disregard the injurer's conduct altogether and to set $x = 1$ with the damage multiplier equal to

$$\frac{D}{L} = \frac{1}{1 - G(\widehat{y}, v^*)},$$

i.e., the reciprocal of the probability that the injurer avoids liability due to the victim being found negligent. Overall, except for the punitive part, the rule corresponds to strict liability with the defense of contributory negligence. The implication is that information about the injurer's conduct is not needed with appropriate punitive damages, although the need to obtain sufficiently informative evidence about the victim's care remains unchanged. The next proposition summarizes the results.

PROPOSITION 6: *Appropriate punitive damages implement the efficient levels of care, provided the threshold $\widehat{y}$ for victim negligence satisfies $v^* = \arg\max_v p(u^*, v)\,(1 - G(\widehat{y}, v))$.*

5 Concluding remarks

A simplifying assumption of the foregoing analysis is that verifiable information about precautionary behavior is exogenously made available to the parties and can be communicated to the court at negligible cost. Within the limits of this assumption, the basic economic model of liability rules easily extends to imperfect information about care.

When the situation involves bilateral precautions, efficient care is implemented through negligence-based rules assigning liability on the basis of both parties' behavior, provided the evidence is sufficiently informative and courts use the appropriate standard of proof. In all-or-nothing rules such as negligence with the defense of contributory negligence, the underlying standard of proof is efficient if the outcome of a trial conveys that the prevailing party most likely exerted neither more nor less than due care. In rules which involve sharing the loss such as comparative negligence, the efficient standards of proof are weaker and both the plaintiff and defendant will be found negligent more often. In all cases, efficiency requires that a claim is proved only if it appears more likely than not by some margin.

In this analysis, court decisions rest on the relative likelihood of negligent behavior versus due care. Relative likelihood is meant in the usual mathematical sense. Specifically, courts do not use Bayesian inference to update priors about how parties generally behave. It has been noted by several authors that the courts' decision process in this respect is typically not Bayesian and that there are efficiency-based rationales (i.e., the provision of incentives) for rules of evidence and rules of proof—e.g., Posner (1999), Daughety and Reinganum (2000a, 2000b), Fluet (2003), Demougin and Fluet (2006). In the above framework, this means that courts disregard any understanding they may have of equilibrium behavior and base their decisions on the weight of evidence about the parties' actions.

Appendix

PROOF OF LEMMA 2: I first show that $\arg\max_u p(u)f(x,u)$ is non decreasing in x. Let $p(u')f(x',u') \geq p(u)f(x',u)$ for all u. Then, for $u < u'$ and $x > x'$,

$$\frac{p(u)}{p(u')} \leq \frac{f(x',u')}{f(x',u)} < \frac{f(x,u')}{f(x,u)},$$

where the strict inequality follows from MLRP (i.e., $f(x,u')/f(x,u)$ is strictly increasing in x if $u' > u$). Hence u maximizes the likelihood at $x > x'$ only if $u \geq u'$. I now show that the latter inequality is strict, focusing on the case $u' = u^*$. By lemma 1 $\varphi'(x) \gtrless 0$ if $x \lesseqgtr x_0$. Now,

$$\partial[p(u)f(x,u)]/\partial u|_{u=u^*} = p'(u^*)f(x,u^*) + p(u^*)f_u(x,u^*) = -\varphi'(x).$$

Hence, for $x > x_0$ there is $u > u^*$ with strictly greater likelihood than u^*, implying $\arg\max_u p(u)f(x,u) > u^*$. A similar argument shows that $\arg\max_u p(u)f(x,u) < u^*$ for $x < x_0$.

PROOF OF PROPOSITION 1: The first claim follows directly from the lemmas. Concerning the second, the necessary condition for a maximum is

$$\frac{\partial p\,(1-F)}{\partial u} = p'\,(1-F) - pF_u = 0. \tag{17}$$

If the maximum is at u^* for the given $\widehat{x}$, condition (5) holds and sufficiency is proved. Necessity follows if

$$\frac{\partial^2 p\,(1-F)}{\partial u^2} = p''(1-F) - 2p'F_u - pF_{uu} < 0$$

whenever (17) holds, i.e., if $p\,(1-F)$ is pseudo-concave in u. Substituting from (17),

$$\frac{\partial^2 p\,(1-F)}{\partial u^2} = \left(\frac{p''p}{p'} - 2p'\right) F_u - pF_{uu}.$$

By assumption 3,

$$\frac{\partial^2 pF}{\partial p^2} = \frac{1}{(p')^2}\left[\left(2p' - \frac{p''p}{p'}\right) F_u + pF_{uu}\right] > 0. \tag{18}$$

Hence, $\partial^2 p\,(1-F)\,/\partial u^2 < 0$ at a stationary point, which is therefore a global maximum.

Proof of proposition 3: The proof is similar to that of proposition 1. I only show the necessity of condition (11). The first-order condition for a maximum is

$$\frac{\partial p[1-F(1-G)]}{\partial u} = p_u - (p_u F + pF_u)\,(1-G) = 0. \tag{19}$$

It remains to show that u^* satisfying (19) is a global maximum. This follows if $p[1-F(1-G)]$ is pseudo-concave in u, i.e., if for any solution satisfying (19)

$$\begin{aligned}\frac{\partial^2 p[1-F(1-G)]}{\partial u^2} &= p_{uu} - (p_{uu}F + 2\,p_u F_u + pF_{uu})\,(1-G) \\ &= p_{uu} - \left[\frac{p_{uu}F + 2\,p_u F_u + pF_{uu}}{p_u F + pF_u}\right] p_u < 0, \end{aligned} \tag{20}$$

where the second expression is obtained by substituting from (19). The inequality (20) is equivalent to

$$\left(2p_u - \frac{p_{uu}p}{p_u}\right) F_u + pF_{uu} > 0,$$

which follows from assumption 3 (see (18) in the proof of proposition 1).

Proof of proposition 4: The claims (i) and (ii) and the statement that poorer evidence about injurers benefits victims follow from the discussion. I prove that victims also benefit from poorer evidence about their own precautions. A less informative G implies an increase in the type 1 error β. From (9),

$$\frac{d\widehat{x}}{d\beta} = \frac{p_u F + pF_u}{(1-\beta)(p_u f + pf_u)} > 0$$

where the denominator is negative for $\widehat{x} < x_0$. The effect on injurers' expected liability costs is

$$\begin{aligned}\frac{dpF(1-\beta)}{d\beta} &= -pF + p(1-\beta)f\frac{d\widehat{x}}{d\beta} \\ &= p^2\left[\frac{fF_u - Ff_u}{p_u f + pf_u}\right] > 0,\end{aligned}$$

where the numerator is negative by MLRP.

Proof of proposition 5: $y' > \widehat{y}$ is obvious from (14) given $\theta < 1$. $x' > \widehat{x}$ follows from (13) if $\theta G(y', v^*)$ is decreasing in θ. From (14),

$$\begin{aligned}\frac{d\theta G(y', v^*)}{d\theta} &= G + \theta g\frac{dy'}{d\theta} \\ &= \left(\frac{g_v G - gG_v}{p_v g + pg_v}\right)p < 0. \qquad (21)\end{aligned}$$

The numerator is positive by MLRP and the denominator negative since $y' < y_0$. Potential victims are better off under comparative negligence if $p[1 - F(1-\theta G)]$ is increasing in θ. Now,

$$\frac{dF(1-\theta G)}{d\theta} = (1-\theta G)f\frac{dx'}{d\theta} - F\frac{d\theta G}{d\theta}. \qquad (22)$$

From (13),

$$\frac{dx'}{d\theta} = \frac{p_u F + pF_u}{(1-\theta G)(p_u f + pf_u)}\frac{d\theta G}{d\theta}.$$

Substituting in (22),

$$\frac{dF(1-\theta G]}{d\theta} = p\left(\frac{fF_u - f_u F}{p_u f + pf_u}\right)\frac{d\theta G}{d\theta} < 0.$$

The sign follows from (21), MLRP and $p_u f + pf_u < 0$ for $x' < x_0$.

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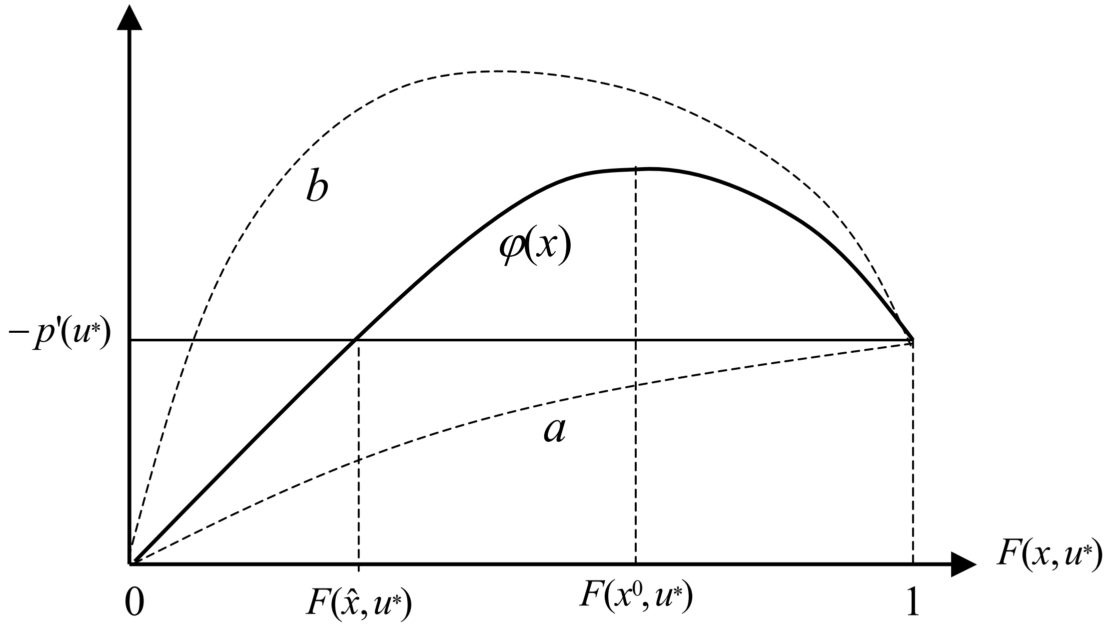

Figure 1: Threshold under unilateral care

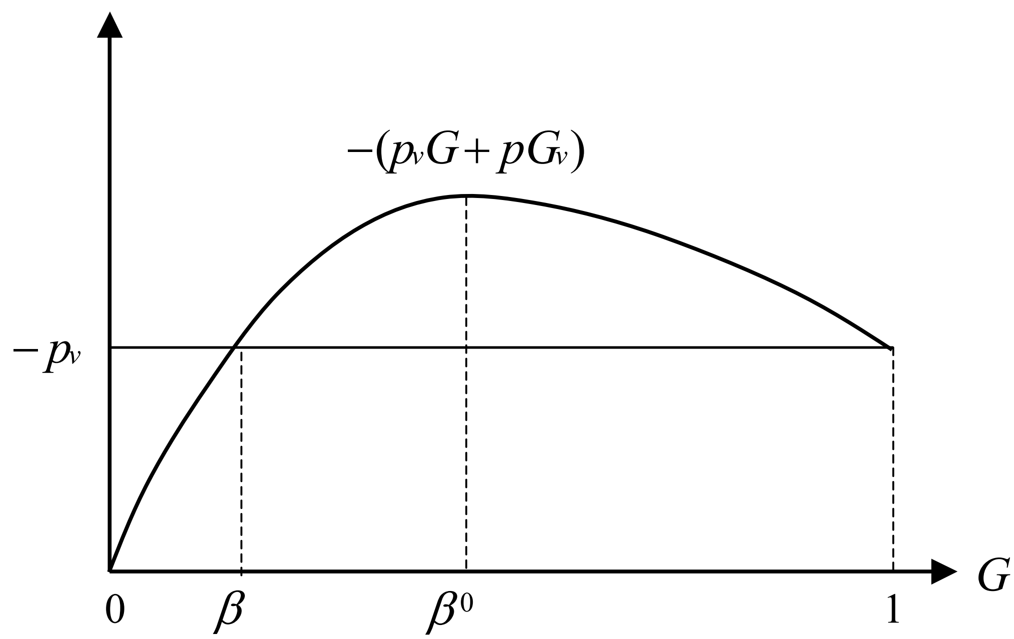

Figure 2: Threshold for victim

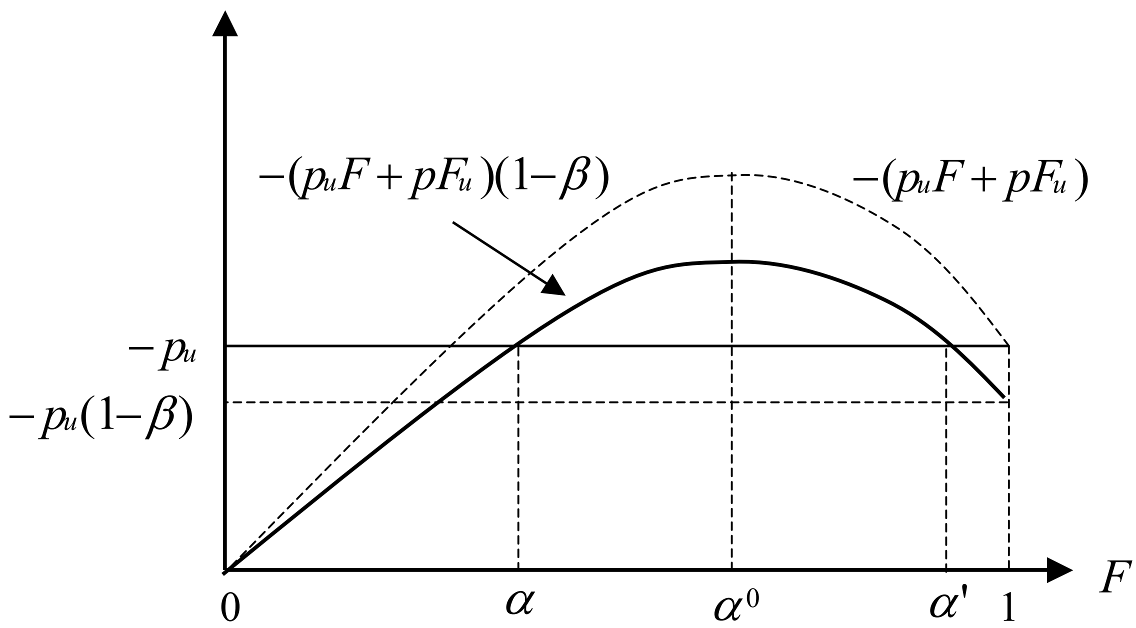

Figure 3: Threshold for injurer