Preponderance of Evidence

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Abstract

This paper analyzes the incentive properties of the standard and burden of proof for a finding of negligence, when evidence about injurers' behavior is imperfect and rests with the parties. We show that the 'preponderance of evidence' standard used in common law, together with ordinary exclusion rules defining legally admissible evidence, provides maximal incentives for potential tort-feasors to exert care. This holds even though, following the occurrence of harm, litigants have unequal access to evidence and may distort information in adversarial procedures. Abstracting from litigation costs, the optimal assignment of the burden of proof is shown to follow from the principle underlying the standard of proof. Our main results are derived in a mechanism design framework, but we also consider implementation as a sequential equilibrium with the court as a player in the game. [Jel. D8, K4]

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1 Introduction

A fundamental rule in common law is for courts to reach a decision on the basis of a preponderance of evidence. For instance, in tort disputes under the negligence rule, the plaintiff must usually persuade the court that the defendant did not exercise due care. The court decides on a so-called 'balance of probabilities' or 'preponderance of evidence':

> To establish by a preponderance of evidence means to prove that something is more likely so than not so. (Devitt and Blackman, *Federal Jury Practice and Instructions*, 1977)

Thus, the defendant will be held liable if, upon the evidence, it appears "more likely than not" that he did not exercise due care.

This is generally understood as implying a threshold degree of certainty just above 50 percent for a ruling in favor of the party with the burden of proof:[1]

> The slightest preponderance of the evidence in his favor entitle[s] the plaintiff to a verdict. All that is required in a civil case of one who has the burden of proof is that he establish his claim by a preponderance of the evidence. When the equilibrium of proof is destroyed, and the beam inclines toward him who has the burden, however slightly, he has satisfied the requirement of the law, and is entitled to the verdict. A bare preponderance is sufficient, though the scales drop but a feather's weight. (Livanovitch v. Livanovitch, 99Vt. 327 131A. 799, 1926)

Preponderance of evidence stands in sharp contrast to the other main legal standard of "proof beyond a reasonable doubt" found in criminal proceedings. It also differs from the intermediate standard of "clear and convincing evidence" used by US courts on some matters. In the context of ordinary civil disputes, the most striking divergence by far is between the common law and the civilian tradition. In most civil-law countries, mere preponderance is not considered sufficient.[2] To take but one example, according to Zöller, an authority on German civil procedure:

[1] See Carlson et al. (1997) and Cross and Tapper (1985) among others, and the references therein.

[2] There are exceptions, for example in Quebec: "Evidence is sufficient if it renders the existence of a fact more probable than its non-existence, unless the law requires more convincing proof" (Civil Code of Quebec, Book VII, § 2804).

> Less than the conviction of the truth is not sufficient for a proof ... Standards that are based on a measure of likelihood do not find any support in the law. (Zöller, *Zivilprozeßordnung,* 1999)

In French law, the same meaning is conveyed by the requirement that parties bearing the burden of proof satisfy the judges to the point of *intime conviction*. In so far as it has been articulated, the civilian standard is often said to be tantamount to reasonable-doubt:[3]

> In continental European law, no distinction is made between civil and criminal cases with regard to the standard of proof. In both, such a high degree of probability is required that, to the degree that this is possible in the ordinary experience of life itself, doubts are excluded and probability approaches certitude. (Nagel, *Evidence*, in *Encyclopedia Britannica: Macropaedia*, 1974)

Are some civil standards better than others? In what sense do they matter? We address this question with respect to the issue of establishing negligence (other issues could be examined such as causation or identification). We do this from the usual perspective in the economic analysis of liability rules, considered as institutions for deterring socially inefficient behavior.

A class of situations is examined, within the so-called unilateral care problem, where negligence has a useful role as opposed to a simpler rule such as strict liability. Under the latter, an injurer must pay for all harm caused to third parties. As is well known, this provides inadequate incentives to exercise care when potential injurers have insufficient wealth to pay damages in full. By contrast, the negligence rule conditions liability both on the occurrence of damages and on additional ex post information about the tort-feasor's level of care. If care is observed without error, the rule can deter careless behavior even though potential injurers are partially judgment-proof (see for instance Shavell 1986, 1987).

We extend this analysis to the case of imperfect ex post information. Inducing care for as many potential tort-feasors as possible, when they differ in wealth and some may be judgment-proof, raises the issue of the efficient use of information. Three scenarios with increasing complexity are examined. In the first one, once an accident has occurred, society (as benevolent principal) directly observes evidence about the injurer's action. We show that society's

[3] See the references in Sherwin and Clermont (2001).

mechanism design problem is solved by assigning liability for damages on the basis of a more likely than not criterion. In the second scenario, society does not directly observe the evidence and must rely on victim and injurer, who may themselves have unequal access to evidence. Taking into account ex post incentives to disclose (or conceal) evidence in adversarial procedures, allocating damages on the basis of more likely than not is still shown to provide efficient ex ante incentives to take care. Finally, the third scenario shows that in either case the optimal mechanism can be implemented by delegating decisions to a court, through the use of the general rule of "preponderance of evidence".

The legal standard of proof is interpreted here squarely as "more likely than not" in the usual mathematical sense. A well known attempt to make sense of preponderance has been in terms of Bayesian updating.[4] Suppose A stands for the claim that the defendant was careless and $\overline{A}$ for the contrary. When E is the evidence submitted, the posterior odds on the defendant being at fault are

$$\frac{\Pr(A\,|\,E)}{\Pr(\overline{A}\,|\,E)} = \frac{\Pr(E\,|\,A)}{\Pr(E\,|\,\overline{A})} \times \frac{\Pr(A)}{\Pr(\overline{A})}$$

where $\Pr(A)$ is the court's prior that the defendant was careless and $\Pr(E\,|\,A)$ the probability of the evidence conditional on inadequate care (equivalently it is the likelihood of inadequate care given the evidence). According to the Bayesian interpretation, there is a preponderance of evidence against the defendant if $\Pr(A\,|\,E) > \Pr(\overline{A}\,|\,E)$. By contrast, we interpret preponderance as $\Pr(E\,|\,A) > \Pr(E\,|\,\overline{A})$, which means that inadequate care appears more likely upon the evidence submitted.

Which interpretation better describes court decisions is debatable, since in legal discourse "more likely" or "more probable" have long been used interchangeably.[5] A commonly encountered argument, borrowed from statistical

[4] Extensive references on the legal or related literature discussing this approach are given in Brook (1982) and Fienberg (1988).

[5] This follows a respectable tradition: "If besides the arguments that count in favour of the thing, other pure arguments present themselves, which indicate the opposite of the thing, the arguments of both kinds must be weighted separately ... in order that one may obtain a ratio between the probability of the thing and the probability of the opposite of the thing. Here it must be noted that if the arguments for each side are strong enough, it can happen that the absolute probability of each side notably exceeds half of certainty. Thus each of the alternative is made probable, although speaking relatively one may be less than the other. So it can happen that a thing possesses 2/3 of certainty and its opposite possesses 3/4 of certainty. In this way, each of the alternative will be probable,

decision theory and often used to demonstrate the superiority of the common law over the civilian standard, is that preponderance in terms of Bayesian posteriors would minimize the overall frequency of error. This accords with the idea that triers of facts should seek truth in the long run, which seems appropriate if court decisions in civil trials impose symmetrical gains and losses on the parties.[6]

One well known difficulty with this argument is that courts are typically reluctant to consider "real" priors about facts involving a significant element of decision or voluntariness. Evidentiary rules determine what evidence is legally admissible. In a negligence case, they would exclude consideration that some known proportion of individuals act carelessly in situations similar to the case at hand. Evidence of character or of similar facts, alluding that the defendant has been negligent (or diligent) on other similar occasions, would also in general be inadmissible (e.g. Federal Rules of Evidence 404). This has led some commentators using a Bayesian terminology to suggest that priors be interpreted normatively.[7] With a neutral *pseudo* prior $\Pr(A) = 1/2$, Bayesian preponderance is of course equivalent to "more likely than not".[8]

What meaning can be attached to error minimization when normative priors are used is unclear. On the other hand, Bayesian preponderance, with situation consistent priors about defendants' behavior, is incompatible with liability rules being structured towards efficient deterrence. Seeking the truth is not the same as providing incentives. This is well known from the principal-agent literature (e.g. Holmström, 1979), but the point easily extends to liability rules. Suppose insolvency is not a problem, so that strict liability implements the first-best, and consider the negligence rule when evidence provides only imperfect information about care. With Bayesian preponderance, rational "priors" about a defendant having exerted due care can be neither zero nor unity: under the former, injurers are always held

but nevertheless the thing is less probable than its opposite, in the ratio of 2/3 to 3/4, or 8 to 9." (J. Bernoulli, *Ars conjectandi*, 1713, quoted from Hacking, 1975).

[6] Minimizing the expected costs of error (possibly together with litigation or prosecution costs) is also considered in much of the economic literature on standards of proof, as in Rubinfeld and Sappington (1987), Micelli (1990), Davis (1994) and Sanchirico (1997).

[7] For instance Posner (1999): "Ideally we want the trier of fact to work from prior odds of 1 to 1 that the plaintiff ... has a meritorious case".

[8] Even in the economics literature, priors differing from one half are sometimes described as "biased" (e.g. Froeb and Kobayashi, 1996). Daughety and Reinganum (2000a, 2000b) present an explicit modeling of non-Bayesian courts, motivated by the constraints imposed by evidentiary rules.

liable, which amounts to strict liability and therefore induces due care; under the latter, injurers are never held liable, which provides no incentives. In a sequential equilibrium, injurers therefore randomize between due care and carelessness (or some choose due care while others are careless), which implies less deterrence than under strict liability. By contrast, as will be shown in the paper, preponderance as "more likely than not" induces due care.

Under a "more likely than not" standard, triers of facts are simply arbiters in a contest of proof-strength: they do not seek to establish the absolute merit of a claim, but only assess the comparative evidential support for or against it.[9] Emphasizing deterrence therefore provides a justification, based on efficiency considerations, for rules of exclusion confining the facts and assumptions which courts are entitled to take into account. Such rules can be seen as a commitment device, whereby the judicial process prevents liability assessments from being based on information that would mitigate deterrence. Evidence is then relevant only if it relates to the particular defendant's behavior in the case under consideration. This is consistent with most of the legal commentary, as well as with civil jury instructions defining legally admissible evidence.

Court error nevertheless also matters for deterrence – see in particular Posner (1973, 1999), Craswell and Calfee (1986), Polinsky and Shavell (1989), Kaplow (1994), Kaplow and Shavell (1994) and Bernardo et al. (2000). In this literature, the probability of false positives or false negatives as to whether the defendant exerted due care is either exogenous or exogenously related to court expenditure on accuracy or parties' litigation costs, with no particular reference to the common law standard of proof or to the problem of interpreting evidence. The point made in the present paper is that, under the preponderance standard, the resulting type I and type II errors are such as to provide maximum incentives to exercise care, given the informativeness of the evidence.

The foregoing discussion is not meant to imply that all priors are irrelevant from a deterrence point of view. For instance, when the evidence rests with the parties, it may be that, based on some priors, the burden of proof should be assigned to one party rather the other. In some situations, courts may also discount a litigant's submission because it is conceivably partial and biased. In either cases this may look as if the court had priors with

[9] "The judge does not ascertain the truth in any real sense. What he does is to give a decision on the evidence presented to him...which is incomplete." (Eggleston, 1983)

respect to the injurer's behavior, but what is really at stake is the court's attempt to interpret the evidence. Our analysis in this respect borrows from the literature on adversarial persuasion games, as in Sobel (1985), Milgrom and Roberts (1986), Shin (1994, 1998) and Dewatripont and Tirole (1999). One difference is that we address the disclosure problem with the objective of aligning incentives to take care. Any "sophisticated skepticism" on the part of the court is then on the basis of the more likely than not criterion with respect to the defendant's care, given the court's beliefs about the information available to the parties.

We take it that the purpose of liability rules is to minimize the sum of care costs and expected accident losses. Our results need to be qualified if, in addition to these "primary costs", there are non negligible private and public costs of presenting and hearing evidence – or if the cost imposed on the injurer by a ruling of negligence is not a pure transfer to the victim. Such secondary costs introduce a trade-off between the deterrence provided by liability rules and the costs of the tort mechanism itself. A possible implication is that true priors about the defendants' care may now matter. In particular, they provide an additional determinant for the optimal assignment of the burden of proof, along the lines of Sobel (1985) or Hay and Spier (1997).

The paper is organized as follows. In section 2 we present the basic framework and define liability rules. Section 3 analyses the mechanism design problem when society has direct access to evidence. Section 4 discusses the standard of proof. In sections 5 and 6 we deal with the mechanism design problem when only the parties have direct access to evidence and derive the implications for the allocation of the burden of proof. In section 7 we show how the optimal mechanism is implemented through the preponderance rule, with courts modeled as players in the game. Finally, extensions such as litigation costs are discussed in the concluding section.

2 The model

In the course of their activities, individuals may impose an accidental loss of amount L on a third party. The probability of causing harm depends only on the potential injurers' level of care, which can take two values referred to as high and low care with opportunity cost $c_h > c_l$ and probability of accident $p_h < p_l$ respectively. All individuals are risk neutral and high care is the

socially efficient action, that is

$$p_h L + c_h < p_l L + c_l \,. \tag{1}$$

Under the *strict liability rule*, individuals are held liable for any harm they may cause. Assuming causality is always established without error, injurers then pay L or up to their wealth or liability limit w, if the latter is smaller. Thus, an agent with wealth w has his private incentives aligned with those of society if

$$p_h \min[w, L] + c_h \leqslant p_l \min[w, L] + c_l \,. \tag{2}$$

The wealth threshold at which a potential injurer is just indifferent between either level of care is

$$w_S = \frac{c_h - c_l}{p_l - p_h} \,. \tag{3}$$

Individuals with wealth smaller than w_S therefore undertake inadequate care, while others produce first-best care.

Under the *negligence rule*, in addition to ascertaining the occurrence of harm and the causal relation with the defendant's actions, courts consider additional information about the specific circumstances of the accident. An injurer is then held liable for harm if the court is satisfied, on the basis of the evidence produced at trial, that he did not exert due care (courts are assumed to equate due care with the socially efficient action). What kind of evidence is admissible in court, which side bears the burden of producing the evidence, how the submitted evidence is evaluated and other procedural issues are all characteristics of a negligence rule.

Under a specific rule, individuals anticipate the probability of being found negligent following the occurrence of harm and given their level of care. We denote with α_h and α_l the respective probabilities: α_h may be interpreted as the probability of type I error – the injurer is found negligent even though he produced high care; similarly, $1 - \alpha_l$ is the probability of a type II error – the injurer is not held liable even though he underproduced care. Agents with wealth w therefore have incentives to exercise due care if

$$p_h \alpha_h \min[w, L] + c_h \leqslant p_l \alpha_l \min[w, L] + c_l \,, \tag{4}$$

implying the wealth threshold

$$w_N = \frac{c_h - c_l}{p_l \alpha_l - p_h \alpha_h} \,. \tag{5}$$

In choosing between liability rules, society would want to take into account incentives to exercise care, together with the private and public costs associated with the rules themselves. In the present context, compared to strict liability, the negligence rule can induce more individuals to exert due care only if $w_N < w_S$ or equivalently

$$p_l\alpha_l - p_h\alpha_h > p_l - p_h.$$

Whether this condition holds obviously depends on the characteristics of the negligence rule under consideration and presumably also on the informational content of the evidence.

More generally, society's problem is to choose and design rules with respect to a whole array of possible situations or environments such as the one described above. Each situation corresponds to particular values w, L, c_h, p_h, c_l, p_l and to a specification of the distribution functions of evidence. Let each such situation be identified by $s \in S$, where S is some index set with measure P reflecting relative frequency. At this point, we need not further specify the structure of S, but assume that (1) holds for all $s \in S$ (i.e. in every situation there is the possibility that individuals undertake less than due care). Also, we take it that there is at least a subset of situations in which individuals would not be careful under strict liability.

For each situation s, given the level of care, "primary costs" are

$$C(j,s) = p_j(s)L(s) + c_j(s), \quad j = h,l. \tag{6}$$

Depending on incentives, individuals in each particular environment undertake some level of care. Denoting the chosen level by $j(s)$, the aggregate cost to society is

$$C_A = \int_S C(j(s),s)\, d\mathrm{P}. \tag{7}$$

In what follows, we disregard the costs of the tort mechanism itself and consider what rules minimize aggregate primary costs, defined as the sum of care costs and accident losses.

3 Hidden action

We initially ignore any of the difficulties associated with legal procedures and reduce the issue to a simple principal-agent problem with hidden action.

Society (as the principal) is assumed to observe the occurrence of harm, upon which it is able to identify the injurer involved and the situation s in which harm occurs. In addition, the principal then also observes a signal correlated with the injurer's care level. This is represented by a random vector $X \in \mathbb{R}^n$ with conditional density functions $f_h(x,s)$ and $f_l(x,s)$, depending on the level of care exerted by the injurer. The signal may be interpreted as information about the circumstances of the particular accident, which may bear some relation to the injurer's behavior.

The principal's problem is to design an incentive scheme given information revealed only upon the occurrence of harm. This captures one characteristic of the tort mechanism. An additional characteristic is that incentives are to be provided only through monetary penalties. These are bounded by the amount of the victim's loss or the injurer's liability limit.[10] Given these restrictions, the incentive scheme under consideration is a penalty function $t(x,s)$ imposed only in the case of accident and satisfying

$$0 \leq t(x,s) \leq \min[w(s), L(s)]\,. \tag{8}$$

There are no participation constraints as everyone is subject to the law. The principal therefore chooses $t(x,s)$ given the above constraint so as to minimize C_A.

In any situation the first best level of care is undertaken if (to simplify notation we omit explicit reference to s when there is no ambiguity)

$$c_h + p_h \int t(x) f_h(x)\,dx \leq c_l + p_l \int t(x) f_l(x)\,dx\,. \tag{9}$$

Factorizing terms, the condition is equivalent to

$$\int t(x)[p_l f_l(x) - p_h f_h(x)]\,dx \geq c_h - c_l\,. \tag{10}$$

An optimal scheme maximizes the number of situations where due care is undertaken. Such a scheme is not unique, but one obvious solution is to choose the penalty function so that, in every situation, the integral on the left hand side of (10) is maximized. When the square bracket in the integral is positive, this requires setting the penalty as high as possible; when it

[10] Excluding monetary "punitive damages" implies no real restrictions here, since inefficiencies exist only because of the limited liability constraints.

is negative, the penalty should be as small as possible. Finally, when the square bracket just vanishes the size of the penalty is inconsequential for setting incentives. Thus, one best scheme is

$$t^*(x) = \begin{cases} \min[w, L] & \text{when} \quad p_l f_l(x) > p_h f_h(x) \\ 0 & \text{when} \quad p_l f_l(x) < p_h f_h(x) \end{cases} \tag{11}$$

This scheme may not be unique even in a measure theoretical sense, because the set of realizations of the signal satisfying $p_l f_l(x) = p_h f_h(x)$ could well be large. Moreover, as already noted, there may be other penalty schemes that do not satisfy (11), but induce the same behavior of all individuals.[11]

However, focusing on t^* allows a straightforward interpretation in terms of a negligence rule applying a more likely than not standard of proof. Observe that any penalty function satisfying (8) can be written as

$$t(x, s) = \psi(x, s) \min[w(s), L(s)], \quad \psi(x, s) \in [0, 1]. \tag{12}$$

The previous result can then be reformulated as follows.

Proposition 1 *Primary costs are minimized by any penalty scheme* $t^*(x, s) = \psi^*(x, s) \min[w(s), L(s)]$ *with* $\psi^*(x, s) \in \{0, 1\}$ *and*

$$\psi^*(x, s) = \begin{cases} 1 & \textit{when} \quad p_l(s) f_l(x, s) > p_h(s) f_h(x, s) \\ 0 & \textit{when} \quad p_l(s) f_l(x, s) < p_h(s) f_h(x, s) \end{cases} \tag{13}$$

An essential characteristic of this solution is that the principal's decision to penalize and the size of the penalty are separable. In this two-step scheme, ψ^* can be understood as society's decision criterion to determine whether an injurer should be held liable or not. If held liable, injurers pay damages either in full or up to their wealth limit. In the first step, the yes or no decision regarding liability depends on the situation s only through the likelihood functions $p_h f_h$ and $p_l f_l$ of due care versus inadequate care. Liability is then determined on the basis of a more-likely-than-not criterion, given the occurrence of harm and the realization of the additional evidence represented by X. Thus, an individual causing harm is penalized if carelessness is ex post

[11] For instance,

$$t(x, s) = \begin{cases} L(s) & \text{if } L(s) \leq w(s) \\ t^*(x, s) & \text{otherwise} \end{cases}$$

more likely; conversely, he is not to be penalized when adequate care appears more likely. When both actions are equally likely the allocation of damages is irrelevant.

In some situations there might be realizations of the evidence for which there is perfect information about the injurer's behavior. For instance, when $f_h(x) = 0$ and $f_l(x) > 0$, a principal seeing x would know for sure that the injurer was careless. To align incentives, injurers should then be penalized. Similarly, if $f_h(x) > 0$ and $f_l(x) = 0$, the principal knows that the individual took adequate care and, as a consequence, should not be penalized. The proposition shows that it is optimal to use a more-likely-than-not criterion to extend these common sense penalty assignment rules to circumstances where post-accident information does not perfectly reveal the injurer's behavior. Of course, as is standard in principal-agent models, there is no actual ex post uncertainty since, under the scheme, a principal observing s would understand the injurer's incentives and would therefore "know" whether he exerted due care or not.

4 The standard of proof

Other incentive schemes also minimize aggregate primary costs, but there is a sense in which the two-step scheme described above is unique. Consider the problem of implementing an incentive scheme by delegating decisions to courts through a liability rule. Any such rule will be characterized by its informational requirements and its decision criterion. Our two-step scheme corresponds to a negligence rule where liability is determined only on the basis of information about the injurer's behavior and where the decision criterion takes the form of a standard of proof. Such a scheme is broadly consistent with how tort law operates. For instance, in the US responsibility for assessing negligence (the yes or no decision) is often attributed to a lay jury who will be instructed on what evidence is admissible and on the required standard of proof. Even when there is no jury, the same two-step approach generally holds as a matter of principle in civil trials.[12]

From the point of view of implementation, a natural question to be ad-

[12] Under Federal Rule of Civil Procedure 42(b), in order to "avoid prejudice", courts sometimes have the option of conducting a separate trial to first determine whether the injurer is liable (in this trial evidence about the extent of damages or the injurer's capacity to pay is inadmissible).

dressed is what minimal information should as a rule be communicated to courts for them to be able to make the appropriate binary decision regarding liability.. This question should be addressed from the standpoint of designing a *general rule* that is situation independent. That is, before knowing what situations will occur, it must be decided whether as a rule the whole of s will be communicated or only part of it and whether as a rule the realization of X will also be communicated. Moreover, society must beforehand impose on courts some general decision criterion, telling them what to do with whatever information will be made available to them.[13]

The preceding results show that it is sufficient to communicate the likelihood functions $p_h f_h$ and $p_l f_l$, together with the realization of X. If the set S of possible situations is sufficiently varied, communicating this information is also necessary for implementing an optimal scheme. In other words, if as a rule $p_h f_h$, $p_l f_l$ and X were not communicated, court decisions would on average lead to strictly higher primary costs, irrespective of what other information is made available. Minimal informational requirements are related to the notion of the informational efficiency of a resource allocation system. According to the Hurwicz criterion (see for instance Milgrom and Roberts, 1992), informational efficiency depends on how much information it takes to determine whether a particular resource allocation is efficient. In the present case, we ask what minimal information an outside observer would require in order to check whether a particular allocation of "yes or no decisions" upon the occurrence of harm is consistent with minimizing aggregate primary costs.

If more information were made available in every situation, many decision rules could implement an optimal scheme. A relatively simple one, where assessing liability also requires knowledge of w and L, is the "deep-pocket rule"

$$\psi(x,s) = \begin{cases} 1 & \text{if } L(s) \leq w(s) \\ \psi^*(x,s) & \text{otherwise} \end{cases} \tag{14}$$

There are other still more complicated rules. We know that ψ^* is sufficient for optimal incentives under what has just been described as the minimum information set. Provided S is sufficiently rich, this decision criterion is also necessary. That is, if a general decision rule is one which must be used in all conceivable situations, the more likely than not criterion is the only one con-

[13] "General rules, genuine laws, as distinguished from specific orders, must ... be intended to operate in circumstances which cannot be foreseen in detail." (Hayek, 1944)

sistent with optimal incentives under minimal informational requirements.

Proposition 2 *The negligence rule together with the more likely than not standard is the only general rule for assessing liability that has minimum informational requirements consistent with minimizing aggregate primary costs.*

Optimality has already been shown. To prove necessity as a general rule, one need only exhibit a set S of situations that is sufficiently varied.

Given an arbitrary rule ψ, the conditional probability of being found liable upon the occurrence of harm is

$$\alpha_j(s) = \int \psi(x,s) f_j(x,s)\, dx \quad j = h, l. \tag{15}$$

Under the maximum likelihood rule ψ^*, these conditional probabilities are chosen so as to maximize incentives. Since $\alpha_h = \alpha_l = 1$ is always feasible (by setting $\psi \equiv 1$), it necessarily follows that in all situations

$$w_N = \frac{c_h - c_l}{p_l \alpha_l^* - p_h \alpha_h^*} \leq \frac{c_h - c_l}{p_l - p_h} = w_S\,. \tag{16}$$

The wealth threshold w_S on the right hand side is the one characterizing the strict liability rule, which only requires knowledge of the occurrence of harm. The threshold w_N characterizes the negligence rule with the more likely than not standard. The claim in the proposition is true if over a subset of situations with positive measure the following holds: (i) the inequality in (16) is strict; (ii) there are individuals with sufficiently small wealth; (iii) the more likely than not rule is necessary for maximizing "deterrence" defined as

$$\delta = p_l \alpha_l - p_h \alpha_h\,. \tag{17}$$

Condition (i) holds if X provides sufficient additional information, compared to simply knowing that an accident occurred. The information content of X depends on the variability of the likelihood ratio $f_l(x)/f_h(x)$. A totally uninformative X corresponds to a constant likelihood ratio equal to unity. Even if this ratio is not constant, the informational content of X may be too weak to ever overturn the likelihood of low care resulting from the occurrence of an accident.[14] We introduce the following definition:

[14] This could be the case for instance when the mere occurrence of harm speaks for itself, as when $p_h \simeq 0$. An arbitrarily small $f_l(x)/f_h(x)$ is then required for $p_l f_l(x) - p_h f_h(x) < 0$.

DEFINITION 1: *X is informative if $\int_E f_h(x)\,dx > 0$, where E is the set of realizations such that $p_l f_l(x) < p_h f_h(x)$.*

An informative X implies

$$p_h \int_E f_h(x)\,dx - p_l \int_E f_l(x)\,dx = p_h(1-\alpha_h^*) - p_l(1-\alpha_l^*) > 0, \qquad (18)$$

which amounts to $p_l\alpha_l^* - p_h\alpha_h^* > p_l - p_h$. Thus, a sufficient (and indeed necessary) condition for (i) to hold is that X be informative as defined above.

To formalize condition (ii), suppose there is a subset S' of situations that differ only with respect to the individuals' wealth. Assume also that $\mathrm{P}(w \leq \widehat{w} \mid S') > 0$ for all $\widehat{w}$ above some sufficiently small level and let this be a continuous function in $\widehat{w}$. Increasing deterrence then always increases the number of individuals in S' exerting due care. If condition (i) also holds in S', maximizing deterrence requires liability decisions to be conditioned on the information conveyed by X. Hence, as a rule, communicating the additional evidence (together with $p_l f_l$ and $p_h f_h$) is necessary to minimize aggregate primary costs.

Finally, consider the courts' decision rule. Maximizing deterrence is insured by ψ^*. However, in any situation, satisfying ψ^* almost everywhere is also necessary in order to maximize deterrence. Therefore, if there are subsets of situations such as S' where conditions (i) and (ii) hold, liability decisions should as a rule be determined according to the preponderance standard.

5 Disclosure

Until now we have assumed an extreme "inquisitorial" world where society has directly observed the occurrence of accidents and the associated evidence. In reality, the incidence of harm and any additional information rest with the parties involved. This introduces an auxiliary problem of hidden information. In order to motivate careful behavior on the part of potential injurers, liability rules must also provide incentives for the parties to disclose evidence. We revert to a pure mechanism design approach and proceed as in section 3, taking into account the parties' incentives to disclose or conceal evidence. Implementation, with decisions delegated to courts, is discussed in section 7.

To fix ideas, consider first the limiting case where it is common knowledge that both parties always observe all the potential evidence. As is well known,

when parties have diametrically opposed interests it is straightforward to induce revelation of all relevant information.[15] To see this, assume that in order to establish occurrence and causality the victim must communicate the characteristics of the situation, as captured by $s \in S$, together with a subvector X_1 of the additional evidence, where X_1 describes some of the circumstances of the accident and where the complete evidence is $X = (X_1, X_2)$. The interpretation is that the victim cannot but present both s and the realization of X_1 if he wishes to establish the occurrence of harm, but need not disclose the complete potential evidence.

Optimal mechanisms are then a simple extension of the ones examined in the preceding sections and they induce the same primary costs. One best scheme is for the victim to be indemnified only if the entire evidence $X = (X_1, X_2)$ is submitted to the principal and its realization satisfies $p_l f_l(x) > p_h f_h(x)$. When the evidence is favorable to the victim, he will submit it and the injurer will be found liable. In contrast, when it is unfavorable, the victim does not file suit and the injurer is not held liable. But of course, even if the evidence had been revealed, the injurer would still not have been held liable on the basis of the more likely than not criterion.

An alternative scheme is one whereby the victim is indemnified if he submits X_1, except when X_2 is also disclosed and $p_l f_l(x) < p_h f_h(x)$. Consequently, when $p_l f_l(x) \geq p_h f_h(x)$ the victim files suit and the injurer is held liable. In all other cases the victim does not file suit (if he did, the injurer would just submit x_2 and escape liability). In the context of liability rules within an adversarial procedure, the distinction between the two schemes is simply which party carries the burden of proof with respect to the issue of negligence. Under either allocation of the burden, all relevant information is revealed and incentives to take care are the same as before.

The foregoing argument relies on the assumption that X is known to be observable by both parties. It does not generalize to situations where parties may be imperfectly informed and the principal does not know the extent of the information available to them. For instance, suppose the burden is on the injurer who does not always observe X_2. Not communicating the realization of X_2 then does not necessarily imply that the evidence would have been favorable to the victim, since the injurer may simply be uninformed. In what follows we examine the mechanism design problem for the case where

[15] See Milgrom and Roberts (1986), Lipman and Seppi (1995) and Seidman and Winter (1997).

society, in addition to being unable to observe the evidence directly, does not know how well informed the parties are.

We assume it is common knowledge that both parties know the situation s, that they observe X_1 upon the occurrence of harm but only observe X_2 with some probability: v for the victim and u for the injurer (u and v are now part of the specification of s). As parties may be uninformed, when only X_1 is disclosed the principal does not know whether this is because the parties did not observe all the potential evidence or whether an informed party chose not to disclose X_2. Note that we make the common assumption that evidence is verifiable, i.e. false evidence cannot be fabricated.[16] The principal's problem is to design a transfer scheme on the basis of the evidence $z \in \{x_1, (x_1, x_2)\}$ submitted to him. As before, we focus on mechanisms satisfying the constraint

$$0 \leq t(z, s) \leq \min[w(s), L(s)], \tag{19}$$

where $t(z, s)$ is now the transfer from the injurer to the victim. The principal's objective is to choose the transfer scheme which minimizes aggregate primary costs, subject to (19) and to additional disclosure constraints.

The disclosure game is as follows. When an accident occurs, both parties observe X_1 and possibly also X_2; the victim then decides whether or not to file suit. In order to establish the occurrence of harm and the identity of the injurer, a suit entails the submission of the realization of X_1 together with the characteristics of the situation s. Once a suit is filed, both parties decide whether to submit additional evidence. They act simultaneously and neither knows whether the other has seen the complete potential evidence. The following strategy pair for injurer and victim is easily seen to constitute an equilibrium for this game (we omit explicit reference to s):

(i) If the victim observes the complete evidence and if $t(x_1) < t(x_1, x_2)$, the victim files suit and discloses (x_1, x_2) ; when X_2 is not observed or when $t(x_1, x_2) \leq t(x_1)$, the victim files suit by submitting only x_1 provided $t(x_1) > 0$; in all other cases the victim does not file suit.

(ii) If a suit has been filed and $t(x_1, x_2) < t(x_1)$, the injurer discloses (x_1, x_2) if he can; otherwise he reveals nothing.

[16] In the current context, the assumption can be justified by the severe penalties for perjury.

In equilibrium each party discloses information only if this strictly benefits him under the transfer scheme. Observe that we have focused on an equilibrium where parties do not disclose when indifferent. This can be interpreted in terms of arbitrarily small costs of submitting evidence, with the disclosure of (x_1, x_2) being itself ε-more costly than submitting x_1 only. While this has no substantial effect on the principal's problem, the assumption has the advantage that the above strategies (now dominant strategies) can be transposed without modification to situations where presenting evidence is costly, provided of course costs are not too large. We briefly discuss this issue in the concluding section.

For any transfer scheme, the expected liability costs imposed on potential injurers depend on the parties' ability to disclose information and on their incentives to do so, where these follow from the transfer scheme itself. However, the disclosure problem for X_1 can be disregarded, as the outcome is always the same as if the principal directly observed that part of the potential evidence. The reason is that, in equilibrium, X_1 remains undisclosed only when the injurer's payment is the same whether or not there is disclosure.[17] Regarding X_1, the situation is therefore similar to the case of perfectly informed parties discussed earlier and we can proceed as if the principal needed only be concerned about the parties's ability or incentives to disclose X_2.

In order to derive the expected liability costs of potential injurers, it is useful to introduce the following notation. Let $t_1(x)$ denote the transfer when only x_1 is disclosed. Accordingly, as a function of the potential evidence, $t_1(x)$ is constrained to be constant in x_2. Let $t_2(x)$ denote the transfer when the whole evidence is disclosed. For a given transfer scheme, the set of possible realizations x is partitioned into three regions: one where the victim would strictly benefit from disclosure of the complete evidence (as opposed to the disclosure of x_1 only), one where the injurer would strictly benefit, and one where both parties would be indifferent. We characterize these regions by two indicator functions. As indicator for the first region, let $\varphi^v(x) = 1$ if $t_1(x) < t_2(x)$ and zero otherwise. Similarly, for the second region let $\varphi^u(x) = 1$ if $t_1(x) > t_2(x)$ and zero otherwise. The remaining region defined by $t_1(x) = t_2(x)$ has the indicator function $(1 - \varphi^v(x))(1 - \varphi^u(x))$.

Taking into account the parties' ability and incentives to disclose X_2, the

[17] When $t(x_1) > 0$, the victim submits x_1 and the injurer may or may not also reveal x_2. Either way the outcome is as if the principal had directly observed x_1. When $t(x_1) = 0$, either the victim discloses both x_1 and x_2 or no information is revealed and the injurer pays nothing. Again, the outcome is the same as under direct observation of x_1.

expected liability costs to a potential injurer exerting the care level $j = h, l$ is then

$$p_j \int \{\varphi^v [vt_2 + (1-v)t_1] + \varphi^u [ut_2 + (1-u)t_1] + (1-\varphi^v)(1-\varphi^u)t_1\} f_j \, dx \, .$$

The interpretation is straightforward. When $\varphi^v(x) = 1$ the victim will reveal whenever he observes x_2; this occurs with probability v and induces the transfer t_2. When the victim does not observe x_2 the transfer is t_1. The same logic applies for the injurer when $\varphi^u(x) = 1$. In the third region, x_2 is not revealed and transfers are t_1. Expected liability costs can be rewritten as

$$v \int \varphi^v (t_2 - t_1) p_j f_j \, dx + u \int \varphi^u (t_2 - t_1) p_j f_j \, dx + \int t_1 p_j f_j \, dx.$$

The optimal scheme maximizes the difference in the expected liability costs from exerting care level l as opposed to h. This is now

$$\begin{aligned} \Delta \;\; = \;\; & v \int \varphi^v (t_2 - t_1)(p_l f_l - p_h f_h) \, dx + u \int \varphi^u (t_2 - t_1)(p_l f_l - p_h f_h) \, dx \\ & + \int t_1 (p_l f_l - p_h f_h) \, dx. \end{aligned} \tag{20}$$

Writing $f_j(x_1, x_2) = g_j(x_1) f_j(x_2 \,|\, x_1)$, where $g_j(x_1)$ and $f_j(x_2 \,|\, x_1)$ are respectively the marginal and conditional distributions given care level j, we have the following result (the proof is in the appendix).

Proposition 3 *When only the parties have direct access to the evidence and may be imperfectly informed, society's primary costs are minimized by any scheme* $t(z) = \theta(z) \min[w, L]$, $z \in \{x_1, x\}$, *with* $\theta(x) = \psi^*(x)$ *as defined by (13) in proposition 1 and* $\theta(x_1) \in \{0, 1\}$ *satisfying*

$$\theta(x_1) = \begin{cases} 1 & \text{when } p_l g_l(x_1) P_l(x_1) > p_h g_h(x_1) P_h(x_1) \\ 0 & \text{when } p_l g_l(x_1) P_l(x_1) < p_h g_h(x_1) P_h(x_1) \end{cases} \tag{21}$$

where

$$P_j(x_1) = 1 - v \int \psi^*(x) f_j(x_2 \,|\, x_1) \, dx_2 - u \int [1 - \psi^*(x)] f_j(x_2 \,|\, x_1) \, dx_2. \tag{22}$$

The proposition extends the more likely than not criterion to situations where disclosure is an issue. $P_j(x_1)$ represents the conditional probability

of X_2 not being disclosed depending on the injurer's care level, given the occurrence of harm and $X_1 = x_1$. The rationale is that X_2 remains undisclosed, unless parties are informed and cannot be harmed from disclosing. Alternatively, the expression can be rewritten as

$$\begin{aligned} P_j(x_1) &= (1-v)(1-u) + (1-u)v \int [1-\psi^*(x)] f_j(x_2 \,|\, x_1)\, dx_2 \\ &\quad + (1-v)u \int \psi^*(x) f_j(x_2 \,|\, x_1)\, dx_2. \end{aligned} \tag{23}$$

That is, X_2 remains undisclosed either because both parties are uninformed or only one is informed but would not disclose unfavorable evidence. Thus, $p_j g_j(x_1) P_j(x_1)$ is the probability of the event "x_1 and X_2 not disclosed" given the injurer's care level. Equivalently, it is the likelihood of care level j given the observation of "x_1 and X_2 not disclosed". With respect to assessing negligence, the criterion defined by (21) is therefore "more likely than not" taking into account incentives to disclose evidence.[18]

6 The burden of proof

The mechanism described in proposition 3 has been interpreted as defining the standard of proof for assessing negligence. It can also be interpreted in terms of the allocation of the burden of proof. In legal practice, the victim has the burden of proof if he bears the loss unless evidence is produced showing with a preponderance that the injurer was careless. Conversely, the burden rests on the injurer if he is held liable unless evidence is submitted showing with a preponderance that he exerted due care. Nevertheless, in all cases the process is initiated by the victim who bears the "primary burden" of establishing the occurrence of harm and causality with respect to the injurer's activity.

In the context of the model, a necessary though generally not sufficient condition for the victim to obtain damages is for the realization of X_1 to be submitted. Note that only the victim could possibly have an interest in disclosing X_1 alone. Accordingly, the injurer may be said to bear the

[18] The likelihood of h versus l is computed here as if parties disclosed evidence when indifferent between disclosing or not. In section 7, where implementation is discussed, the court is modeled as a player in the game. "More likely than not" is then in terms of the actual equilibrium probabilities of disclosure.

burden of proof with respect to negligence (or diligence) if any realization x_1 submitted by the victim would be sufficient by itself for the injurer to be held liable. The victim then never has an incentive to submit X_2 and the injurer can escape liability only by coming forward with sufficient counter-evidence, i.e. submitting x_2 such that $\psi^*(x_1, x_2) = 0$. In all other cases where X_1 is not always sufficient by itself for a decision against the injurer, the victim may be said to bear the burden of proof. The victim will then sometimes not file suit or, when informed of the complete evidence, will also sometimes want to submit X_2 when the realization of X_1 is not sufficient by itself to win the suit. This captures part of the meaning of the burden of proof, at least regarding the so-called "burden of production", since it apportions between parties the task of producing evidence.[19]

DEFINITION 2: *In a given situation, a scheme assigns the burden of proof to the injurer if $\theta(X_1) = 1$ with probability one. Otherwise the burden is on the victim.*

The allocation of the burden depends on the parties' access to information and on the informational content of the potential evidence. It may also be a matter of indifference, since the schemes defined in proposition 3 do not prescribe a decision when the evidence is in equipoise. The conditions determining $\theta(x_1)$ are in terms of the sign of the likelihood difference

$$\begin{aligned} \eta(x_1) &\equiv p_l g_l(x_1) P_l(x_1) - p_h g_h(x_1) P_h(x_1) \\ &= (1-u)\left[p_l g_l(x_1) - p_h g_h(x_1)\right] \\ &\quad + (u-v)\int \psi^*(x_1, x_2)\left[p_l f_l(x_1, x_2) - p_h f_h(x_1, x_2)\right] dx_2. \end{aligned} \tag{24}$$

When $\eta(x_1) > 0$ for all x_1, any scheme satisfying proposition 3 assigns the burden to the injurer. When $\eta(x_1) \geq 0$ for all x_1 but $\eta(x_1) = 0$ occurs with positive probability, either assignment of the burden is consistent with the proposition. Finally, when $\eta(x_1) < 0$ over a set of positive measure the burden must be on the victim.

We now examine how these possibilities are related to the informational content of the evidence. Recall from definition 1 that X is "informative" if it provides useful additional information for deterrence purposes, compared to simply observing the occurrence of harm. This arises when the more likely

[19] See Hay and Spier (1997) for a related analysis.

than not criterion requires injurers exerting due care to face a strictly positive probability of escaping liability. To analyze the assignment of the burden of proof, we need to extend this definition.

DEFINITION 3: *X is strictly uninformative if $\int_F f_h(x)\,dx = 1$, where F is the set of realizations such that $p_l f_l(x) > p_h f_h(x)$. When X is neither informative in the sense of definition 1 nor strictly uninformative, it is said to be weakly informative.*

The motivation for these definitions is as follows. If X is informative, there are realizations of the evidence where under the more likely than not criterion the injurer *should not* be held liable. If X is strictly uninformative, he *must* be held liable under any realization of the evidence. Finally, a weakly informative X means that $p_l f_l(X) \geq p_h f_h(X)$ with probability one, but $p_l f_l(X) = p_h f_h(X)$ also occurs with strictly positive probability. Over the latter realizations of the evidence, it is irrelevant for deterrence purposes whether the injurer is held liable or not.

The evidence X is at least weakly informative in all situations where harm, although related to the injurer's activity, can also be caused by events unrelated to his level of care. For instance, suppose harm can be caused either by the event A occurring with probability π or by a mistake on the part of the injurer, which occurs with probability q_j where $q_l > q_h$. Assuming independence, the probability of harm is then $p_j = \pi + (1 - \pi)q_j$. The possibility of observing whether A occurred or not is "weakly informative": when A is observed, care levels h and l are equally likely; when A is known not to have occurred, l is strictly more likely. If both parties are known to observe whether A has occurred and if this is the only potential evidence, allocating the burden of proof on the injurer or the victim does not matter from a deterrence point of view (the burden would be on the victim if to win the case he were required to show that A did not occur).

The same definitions apply to X_1 for situations where only that part of the evidence is observable. Thus, we say that X_1 is "informative" if $\int_{E_1} g_h(x_1)\,dx_1 > 0$, where E_1 is the set of realizations such that $p_l g_l(x_1) < p_h g_h(x_1)$, etc. For instance, in the foregoing example X_1 is weakly informative if it corresponds to the possibility of observing whether the event A occurred or not.

Consider first the case where X is strictly uninformative, which obviously implies that X_1 is also strictly uninformative. It is easily verified that we then

have $\eta(x_1) > 0$ for all realizations (implying $\theta(x_1) = 1$ for all x_1).

Corollary 1 [STRICT LIABILITY] *In situations where X is strictly uninformative, $\theta(x_1) = 1$ for all x_1. The victim always files suit, submitting X_1, and the injurer is always held liable (X_2 is never submitted).*

The interpretation is that the optimal scheme implies the equivalent of the strict liability criterion, without the necessity of establishing negligence as such. An alternative interpretation is that a strictly uninformative X refers to situations where the mere occurrence of harm is sufficient to prove negligence.

In the sequel we consider situations where X is informative. The following result identifies situations for which proposition 3 prescribes an unambiguous assignment of the burden of proof.[20]

Corollary 2 [NEGLIGENCE] *When X is informative, the allocation of the burden of proof is inconsequential if $u = v = 1$. Otherwise, it is as follows:*

(i) When X_1 is informative, the burden is on the victim unless u is sufficiently larger than v.

(ii) When X_1 is only weakly informative, the burden is on the victim if $v > u$ (and is inconsequential if $v = u$).

(iii) When X_1 is strictly uninformative, the burden is on the injurer unless v is sufficiently larger than u.

The proof is in the appendix, but we will now discuss a few simple cases. Consider first situations where $v < u = 1$. Intuitively, since he is perfectly informed of the evidence, the injurer should be held liable when only X_1 is revealed in order to induce disclosure of the complete evidence. In other words, recalling definition 2, the burden of proof should be on the injurer. This also follows from (24) since the integral is non negative by definition of ψ^*, so that $\eta(x_1) \geq 0$ for all realizations and is consistent with assigning the burden to the injurer. Conversely, when $u < v = 1$, it can be shown from (24) that $\eta(x_1) \leq 0$ for all realization, which is consistent with the burden resting on the victim. Finally, when both parties are perfectly informed, $\eta(x_1) = 0$ for all realizations. Which party has the burden of proof is then irrelevant, as discussed at the beginning of section 5.

[20] In cases that are not explicitly characterized, the informational properties of the evidence would need to be further specified for an unambiguous assignment.

In all these situations at least one of the parties is known to observe the complete potential evidence. One then expects the level of deterrence achieved to be the same as if society directly observed the whole evidence. To see that this follows from an optimal assignment of the burden, consider the conditional probability of being found liable upon the occurrence of harm. This can be shown to equal

$$\alpha_j = \int \theta(x_1) g_j(x_1)\, P_j(x_1)\, dx_1 + v \int \psi^*(x) f_j(x)\, dx, \quad j = h, l. \tag{25}$$

The first integral is the probability of a finding of negligence on the basis of "x_1 and X_2 not disclosed". The second term is the added probability for a finding negligence on the basis of the complete evidence. Observe that the complete evidence is only submitted by the victim when fully informed, which occurs with probability v, and when $\psi^*(x) = 1$. Deterrence is therefore

$$\begin{aligned} \delta &= p_l \alpha_l - p_h \alpha_h \\ &= \int \theta(x_1) \eta(x_1)\, dx_1 + v\delta^*. \end{aligned} \tag{26}$$

where δ^* is the level of deterrence that would be achieved if society directly observed the whole potential evidence, as in section 4. Since the integral is non negative, $\delta = \delta^*$ if the victim is perfectly informed. When the burden is on the injurer, $\theta(x_1) \equiv 1$. Substituting for $\eta(x_1)$ from (24), it can be checked that

$$\delta = (1-u)(p_l - p_h) + u\delta^*. \tag{27}$$

If the injurer is perfectly informed, this also implies the same level of deterrence as under direct observation of the complete evidence.

When neither party is perfectly informed, the assignment of the burden of proof depends on the information content of X_1 by itself, on the extent of the parties' access to all the potential evidence, as well as on the difference between the informational content of X_1 and X. One particularly simple case is when both parties are equally well informed on average. From (24), with $u = v < 1$ the likelihood difference reduces to

$$\eta(x_1) = (1-u)\left[p_l g_l(x_1) - p_h g_h(x_1)\right].$$

In this case, strategic incentives to conceal evidence cancel out and the princi-

pal may take submissions at their face value.[21] The burden is then necessarily on the victim when X_1 is informative and must be on the injurer when X_1 is strictly uninformative.

7 Rule-based implementation

To complete the analysis, we reexamine the issue of implementation when decisions are delegated to courts under the preponderance of evidence standard. One difference between more-likely-than-not in a mechanism design framework and the preponderance of evidence rule is that the latter requires a prior assignment of the "burden of persuasion". The burden of persuasion is on the victim if the court must be convinced that negligence is strictly more likely than diligence. It is on the injurer if he must persuade the court that diligence is strictly more likely. A second difference is that preponderance of evidence will be applied on the basis of the equilibrium probabilities of disclosure, with the court as a player in the game.

In practice, the burden of persuasion is usually assigned to the party bearing the "burden of production" on the main contested issue. From the foregoing section we know that in some situations the burden of production must rest on a specific party, while in others the assignment is arbitrary. Let $b(s)$ for $s \in S$ denote the burden assignment for all schemes satisfying proposition 3, with $b(s) = 1$ when the assignment is unambiguously on the injurer and $b(s) = 0$ when it is unambiguously on the victim or indifferent. Among all possible schemes, let us select the scheme $\theta(z, s)$ as follows. When $b(s) = 1$, and noting that this corresponds to situations where $\eta(x_1, s) > 0$ for all x_1, $\theta(x_1, s) = 1$ for all x_1 and $\theta(x, s) = 1$ unless $p_l(s)f_l(x, s) < p_h(s)f_h(x, s)$. When $b(s) = 0$, $\theta(x_1, s) = 0$ unless $\eta(x_1, s) > 0$ and $\theta(x, s) = 0$ unless $p_l(s)f_l(x, s) > p_h(s)f_h(x, s)$. Under the scheme $\theta(z, s)$, which obviously satisfies proposition 3, both the burden of production and the burden of persuasion are on the same party. Moreover, the victim is assigned the burden of production in all situations where $b(s) = 0$. It is easily checked that the chosen scheme minimizes the frequency of suits.[22]

[21] This extends to imperfectly informed parties the idea that competition between parties allows the principal to be "naive", as in Milgrom and Roberts (1986) or Froeb and Kobayashi (1996).

[22] An alternative burden assignment partition is $b'(s) = 1$ if the burden of production is unambiguously on the injurer or indifferent and $b'(s) = 0$ otherwise. Under the scheme

With ε-disclosure costs, $\theta(z,s)$ implies a unique equilibrium in the disclosure subgame as described in section 5. We now modify this subgame by appending a terminal stage where a court determines liability on the basis of the submitted evidence. This stage substitutes for the mechanism $\theta(z,s)$ imposed by the principal. Specifically, we assume as before that a victim filing suit necessarily submits the realization of X_1. In addition to communicating X_1 as such, filing suit shows the occurrence of harm and the causal relation to the injurer. It also communicates some of the characteristics of the situation s, including $p_h f_h$, $p_l f_l$, u, v and the burden of proof assignment $b(s)$. Once a suit is filed, both parties decide simultaneously whether to submit X_2. At the "close of the evidence", the court decides whether the injurer is to be held liable.

Proposition 4 *An optimal scheme can be implemented as a sequential equilibrium with courts applying preponderance of the evidence, given the burden of proof assignment.*

Let $d(z,s) \in \{0,1\}$ be the court's strategy, where $d=1$ denotes the decision to hold the injurer liable. Clearly, the scheme $\theta(z,s)$ is implemented if $d(z,s) = \theta(z,s)$ is an equilibrium strategy under the preponderance standard, given the burden of proof assignment $b(s)$. It is straightforward to show that this strategy can indeed be part of an equilibrium and we only give the outline of the argument for situations where the burden of proof is on the victim.

Suppose the proposition is true. Parties then expect the court to play $d(z) = \theta(z)$, where reference to s is omitted for simplicity. In equilibrium, $z = x_1$ occurs only when $\eta(x_1) > 0$ and when the injurer is either uninformed or is informed but $p_l f_l(x) > p_h f_h(x)$. The equilibrium conditional probability of "x_1 and not X_2" is therefore

$$\begin{aligned} \widehat{P}_j(x_1) &= 1 - u + u \int \theta(x_1,x_2) f_j(x_2 \,|\, x_1)\, dx_2 \\ &= 1 - u \int \left[1 - \theta(x_1,x_2)\right] f_j(x_2 \,|\, x_1)\, dx_2 \\ &= P_j(x_1) + v \int \theta(x_1,x_2) f_j(x_2 \,|\, x_1)\, dx_2 \,, \end{aligned} \tag{28}$$

$\theta'(z,s)$ defined as above, but now with respect to $b'(s)$, the victim files suit when he has evidence that negligence is at least as likely as diligence, rather than strictly more likely as under $\theta(z,s)$.

where $P_j(x_1)$ is the same as in proposition 3. The resulting equilibrium likelihood difference is

$$\begin{aligned}\widehat{\eta}(x_1) &= p_l g_l(x_1)\widehat{P}_l(x_1) - p_h g_h(x_1)\widehat{P}_h(x_1) \\ &= \eta(x_1) + v\int \theta(x_1,x_2)\left[p_l f_l(x_1,x_2) - p_h f_h(x_1,x_2)\right] dx_2. \quad (29)\end{aligned}$$

The integral is nonnegative by definition of $\theta(x)$. Hence $\eta(x_1) > 0$ implies $\widehat{\eta}(x_1) > 0$, which means that the court would want to hold the injurer liable under the preponderance standard.

Suppose now that a suit is filed, but that at the close of the evidence $z = x_1$ where $\eta(x_1) \leq 0$. This can only occur at an information set off the equilibrium path. The court's beliefs at this information set can be rationalized by considering that victims sometimes mistakenly file suit. Once a suit is filed, they nevertheless behave rationally with respect to disclosing X_2, given the court's strategy $d(x) = \theta(x)$. Since the injurer's equilibrium strategy is not to disclose X_2 when the victim sues with $\eta(x_1) \leq 0$, the conditional probability of "x_1 and not X_2" is now believed to be

$$\begin{aligned}\widehat{P}_j(x_1) &= 1 - v + v\int \left[1 - \theta(x_1,x_2)\right] f_j(x_2\,|\,x_1)\, dx_2 \\ &= 1 - v\int \theta(x_1,x_2) f_j(x_2\,|\,x_1)\, dx_2 \\ &= P_j(x_1) + u\int \left[1 - \theta(x_1,x_2)\right] f_j(x_2\,|\,x_1)\, dx_2\,. \quad (30)\end{aligned}$$

The likelihood difference is

$$\begin{aligned}\widehat{\eta}(x_1) &= p_l g_l(x_1)\widehat{P}_l(x_1) - p_h g_h(x_1)\widehat{P}_h(x_1) \\ &= \eta(x_1) + u\int \left[1 - \theta(x_1,x_2)\right]\left[p_l f_l(x_1,x_2) - p_h f_h(x_1,x_2)\right] dx_2. \quad (31)\end{aligned}$$

The integral is now non positive by definition of $\theta(x)$, so that $\eta(x_1) \leq 0$ implies $\widehat{\eta}(x_1) \leq 0$. The burden of persuasion being on the victim, preponderance of the evidence means that the injurer should not be held liable.

Note that the court's decision regarding the defendant's liability may be interpreted as relying only on legally admissible evidence. An outside observer seeking the truth on this matter would for instance want to know c_h, c_l, w and L so as to infer the injurer's behavior from the incentives he

faced. By contrast, the court deals with a contest between two parties, one of whom has the burden of proof with respect to the claim of negligence (or diligence). To reach its decision the court considers only a restricted set of evidence. Moreover, the only strategic considerations taken into account are those pertaining to the disclosure of evidence and the interpretation of the submitted evidence, given the incentives faced by the litigants.

8 Concluding comments

This paper has analyzed the efficiency properties of the "standard of proof" in common law for a finding of negligence and of "burden of proof" assignments when evidence is imperfect and rests with the parties. Our results can be extended or qualified in numerous ways. First, our analysis has dealt only with the so-called unilateral care problem where the probability of harm does not depend on the actions of potential victims. Consideration of a negligence rule is then motivated by the fact that potential tort-feasors may be wealth-constrained. We have also assumed that litigation costs were negligible, which justified minimizing aggregate "primary costs" defined as the sum of care costs and expected harm. That assumption has allowed us to abstract from out of court settlements, since these provide no bargaining surplus in such a context. We have also taken for granted that at the start of procedures parties knew exactly what evidence they would be able to present in court. This again may be justified by the assumption of negligible litigation costs, in the sense that we could disregard the parties' decision problem as to whether they should invest in uncovering evidence. We briefly discuss the implications or issues raised when some of these assumptions are relaxed.

In our framework, the purpose of a burden of proof assignment is to induce parties to disclose evidence, given that the extent of the evidence available to the parties is unknown and that parties may be asymmetrically informed. By contrast, Hay and Spier (1997) analyze burden of proof rules for the case where both parties are known to be perfectly informed, but where there are non negligible costs of submitting evidence. Assuming such costs are not large enough to prevent disclosure altogether, they show that burden of proof assignments can be used to economize on the costs of transmitting information to courts. The appropriate allocation of the burden then depends on society's priors about whether the evidence is likely to favor the plaintiff or the defendant and on the parties's costs of producing evidence. Similar

results can also be derived in our framework.

To give a simple example, consider a subset of situations differing only by the injurers' wealth. Suppose that filing suit reveals only the occurrence of harm and the causal relation to the injurer, while the complete evidence X is informative as defined in the previous sections. Suppose also that both parties are approximately equally informed on average, with probabilities $u \simeq v$ only slightly smaller than unity. From the point of view of inducing disclosure and of the realized level of deterrence, it does not matter in such a case which party bears the burden of proof. Finally, suppose that filing suit involves negligible costs, while submitting the complete evidence has costs C_P for the plaintiff and C_D for the defendant. If the plaintiff has the burden of proof, he files suit only when he can submit the complete evidence and when $p_l f_l(x) > p_h f_h(x)$. If β is the proportion of careless injurers (this is endogenous as it depends on the level of deterrence), assigning the burden of proof to the victim leads to average litigation costs

$$v\left[(1-\beta)p_h\alpha_h^* + \beta p_l \alpha_l^*\right] C_P,$$

where α_j^* is the probability that an injurer with care level j will be found liable under the preponderance standard.

On the other hand, if the burden is on the injurer, the plaintiff always files suits because this involves negligible costs and he may expect to win with some probability (the defendant is not always able to produce counter-evidence). When informed, the defendant produces the complete evidence provided $p_l f_l(x) < p_h f_h(x)$. Average litigation costs are then

$$u\left[(1-\beta)p_h(1-\alpha_h^*) + \beta p_l(1-\alpha_l^*)\right] C_D.$$

Under the above assumptions, the burden assignment minimizing litigation costs depends on the proportion of careless injurers and on the parties's costs of presenting evidence.[23] However, when parties are unequally informed or when u and v differ significantly from unity, a burden assignment also affects deterrence. A complete analysis then requires trading-off "primary costs" and litigation costs. Furthermore, with non negligible litigation costs, the possibility of out of court settlements should also be taken into account.

[23] For instance, unless he faces much greater costs of submitting evidence, the victim should bear the burden if β is small and the evidence has strong information content (i.e. if α_h^* is small).

Do litigation costs affect the optimal standard of proof? Suppose in the foregoing example that such costs justify assigning the burden of proof to the victim. With preponderance of evidence as the standard of proof, the realized level of deterrence is $\delta = v\delta^*$, where $\delta^* = p_l\alpha_l^* - p_h\alpha_h^*$ is the deterrence that would be obtained if the complete evidence were directly observable. A standard of proof stronger than preponderance would require the plaintiff to show that negligence is more likely than diligence by some margin. That is, the victim wins the suit only if the evidence submitted satisfies $p_l f_l(x) > k p_h f_h(x)$, for some $k > 1$. Such a standard leads to less deterrence, but it also reduces the number of suits and the resulting litigation costs. This follows from the fact that $k > 1$ implies smaller values for both α_h and α_l. However, abstracting from jumps in the likelihood ratio, it can be shown that k slightly larger than unity involves only a second-order effect on deterrence, even though it has first order effects on α_h and α_l. Hence, using a stronger standard than preponderance would seem to be warranted. Despite this observation, it could nevertheless be reasonable for society to require courts to use the preponderance standard (unless the optimal k is very different from unity). The reason is simply that the meaning of preponderance is easily communicated, whereas optimal deviations from this standard would be highly situation specific and therefore difficult to include in a set of instructions to a court or jury.[24]

Additional strategic considerations must be taken into account when litigation costs also include the cost of uncovering evidence. If the plaintiff has the burden of proof, he must assess the probability of acquiring favorable evidence before filing suit. The return on this investment depends on the probability that the defendant has been careless, on the information value of potential evidence and on the standard of proof.[25] Depending on whether he has been negligent or diligent, the injurer will also face different incentives to invest in the production of evidence. How these decisions affect the optimal standard of proof and burden of proof assignment is unclear.

Another extension would be to examine bilateral care problems, where

[24] If a finding of negligence imposed real social costs (stigma, etc.), as opposed to being a pure transfer from injurer to victim, a more demanding standard of proof would also be warranted. In the limit, if such costs are very large, one could obtain the reasonable doubt standard as in criminal proceedings.

[25] For instance, it is not worthwhile filing suit if the evidence is likely to be perfectly informative, but there is little chance that the injurer has actually been negligent (e.g. Hylton, 1990).

the probability of harm depends on the behavior of both parties. In such a context, it is well known that the negligence rule is useful even when agents are never judgment proof. Under the pure negligence rule the injurer is held liable if he has been found negligent. Under the traditional rule of negligence with contributory negligence, the injurer is held liable if found negligent and if the victim is not found negligent. Both rules are known to be equivalent when the evidence provides perfect information about care. Does the equivalence still hold when the evidence is imperfect? In particular, should the same standard of proof be applied to assess the plaintiff's and the defendant's negligence? And how should the burdens of proof be assigned with respect to these issues? We leave these questions for further research.

A Appendix

Proof of proposition 3: For any scheme $t_1(x)$ and $t_2(x)$, define

$$t_2^v(x) = \begin{cases} t_2(x) & \text{if } t_2(x) > t_1(x) \\ t_1(x) & \text{otherwise} \end{cases} \tag{32}$$

and

$$t_2^u(x) = \begin{cases} t_2(x) & \text{if } t_2(x) < t_1(x) \\ t_1(x) & \text{otherwise} \end{cases} \tag{33}$$

Equation (20) can then be rewritten as

$$\begin{aligned} \Delta &= v \int \left(t_2^v(x) - t_1(x)\right) \left(p_l f_l(x) - p_h f_h(x)\right) dx \\ &\quad + u \int \left(t_2^u(x) - t_1(x)\right) \left(p_l f_l(x) - p_h f_h(x)\right) dx \\ &\quad + \int t_1(x) \left(p_l f_l(x) - p_h f_h(x)\right) dx \end{aligned} \tag{34}$$

In the optimal scheme, $t_1(x)$, $t_2^v(x)$ and $t_2^u(x)$ must be such as to maximize Δ subject to $t_2^v(x) \geq t_1(x)$, $t_2^u(x) \leq t_1(x)$, the lower and upper bounds on transfers and to $t_1(x)$ being constant in x_2.

Taking $t_1(x)$ as given, the first integral is clearly maximized by

$$t_2^v(x) = \begin{cases} \min[w, L] & \text{if } p_l f_l(x) > p_h f_h(x) \\ t_1(x) & \text{if } p_l f_l(x) < p_h f_h(x) \end{cases} \tag{35}$$

The second integral by

$$t_2^u(x) = \begin{cases} t_1(x) & \text{if } p_l f_l(x) > p_h f_h(x) \\ 0 & \text{if } p_l f_l(x) < p_h f_h(x) \end{cases} \tag{36}$$

Conditions (35) and (36) are satisfied if $t_2(x) = \psi^*(x)\min[w, L]$, where $\psi^*(x)$ is as defined in proposition 1. To see this, suppose $p_l f_l(x) > p_h f_h(x)$ so that $t_2(x) = \min[w, L]$. When $t_2(x) > t_1(x)$, (32) implies

$$t_2^v(x) = t_2(x) = \min[w, L]$$

and (33) implies $t_2^u(x) = t_1(x)$, as required. The case where $t_2(x) \leq t_1(x)$ is only possible if

$$t_1(x) = t_2(x) = \min[w, L]$$

But then (32) implies $t_2^v(x) = t_1(x)$, while (33) implies $t_2^u(x) = t_1(x)$, again satisfying (35) and (36). A similar argument shows that this choice of $t_2(x)$ leads to the appropriate $t_2^v(x)$ and $t_2^u(x)$ when $p_l f_l(x) < p_h f_h(x)$.

Given the optimal choice of $t_2(x)$, and noting that how $t_2(x)$ is set does not matter when $p_l f_l(x) - p_h f_h(x) = 0$, the first two integrals in (34) are equal to

$$\begin{aligned} & v \int \psi^*(x) \left(\min[w, L] - t_1(x)\right) \left(p_l f_l(x) - p_h f_h(x)\right) dx \\ & + u \int \left(1 - \psi^*(x)\right) \left(0 - t_1(x)\right) \left(p_l f_l(x) - p_h f_h(x)\right) dx \end{aligned}$$

It follows that

$$\begin{aligned} \Delta &= \min[w, L] \cdot v \int \psi^*(x) \left(p_l f_l(x) - p_h f_h(x)\right) dx \\ &\quad + \int t_1(x) \left[1 - v\psi^*(x) - u\left(1 - \psi^*(x)\right)\right] \left(p_l f_l(x) - p_h f_h(x)\right) dx \end{aligned}$$

Recalling that $t_1(x) = t(x_1)$ and expressing the densities in the second integral as $f_i(x_1, x_2) = g_i(x_1) f_i(x_2 \,|\, x_1)$, this can be rewritten as

$$\begin{aligned} \Delta &= \min[w, L] \cdot v \int \psi^*(x) \left(p_l f_l(x) - p_h f_h(x)\right) dx \\ &\quad + \int t(x_1) \left(p_l g_l(x_1) P_l(x_1) - p_h g_h(x_1) P_h(x_1)\right) dx_1 \end{aligned} \tag{37}$$

where

$$P_j(x_1) = 1 - v \int \psi^*(x_1, x_2) f_j(x_2 \,|\, x_1)\, dx_2 - u \int [1 - \psi^*(x_1, x_2)] f_j(x_2 \,|\, x_1)\, dx_2$$

Considering the $t(x_1)$ which maximizes the second integral in (37), the rest of the proof is then straightforward. ■

Proof of corollary 2: Noting that $g_j(x_1) = \int f_j(x_1, x_2)\, dx_2$, the likelihood difference in (24) can be written as

$$\begin{aligned} \eta(x_1) &= (1 - v) \int \psi^*(x_1, x_2) \left[p_l f_l(x_1, x_2) - p_h f_h(x_1, x_2) \right] dx_2 \\ &\quad - (1 - u) \int [1 - \psi^*(x_1, x_2)] \left[p_h f_h(x_1, x_2) - p_l f_l(x_1, x_2) \right] dx_2 \\ &= (1 - v)\mu^+(x_1) - (1 - u)\mu^-(x_1) \end{aligned} \tag{38}$$

where $\mu^+(x_1)$ and $\mu^-(x_1)$ are short-hand for the first and second integral. The case $u = v = 1$ is obvious, so we assume $u < 1$ or $v < 1$. From the definition of ψ^*, $\mu^+(x_1)$ and $\mu^-(x_1)$ are non negative for all x_1. Moreover, $p_l > p_h$ implies $\mu^+(x_1) > 0$ over a set of positive measure. Since X is assumed informative,

$$\int [1 - \psi^*(x)] \left[p_h f_h(x) - p_l f_l(x) \right] dx = \int \mu^-(x_1)\, dx_1 > 0 \tag{39}$$

which implies $\mu^-(x_1) > 0$ over a set of positive measure.

Consider first the case where X_1 is informative, which means that over a set of positive measure

$$p_l g_l(x_1) - p_h g_h(x_1) = \mu^+(x_1) - \mu^-(x_1) < 0 \tag{40}$$

>From (38), $v \geq u$ then implies $\eta(x_1) < 0$ for some x_1, but $u > v$ with u sufficiently close to unity is sufficient for $\eta(x_1) \geq 0$ for all x_1. This proves part (i). When X_1 is weakly informative $\mu^+(x_1) \geq \mu^-(x_1)$ almost everywhere, but $\mu^+(x_1) = \mu^-(x_1) > 0$ over a set of positive measure. $v > u$ then implies $\eta(x_1) < 0$ over this set, while $\eta(x_1) = 0$ if $v = u$. This proves part (ii). Finally, when X_1 is strictly uninformative, $\mu^+(x_1) > \mu^-(x_1)$ almost everywhere and $u \geq v$ then implies $\eta(x_1) > 0$ for all x_1. However, recalling that $\mu^-(x_1) > 0$ for some x_1, $v > u$ with v sufficiently close to unity is sufficient for $\eta(x_1) < 0$ for some x_1. ■

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