Minimizing Errors, Maximizing Incentives: Optimal Court Decisions and the Quality of Evidence*

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Abstract

We examine the influence of the quality of evidence about underlying behavior in setting optimal evidentiary standards by the Law, and on the substantive behavior by individuals and firms. We show how differences in the informativeness of available technologies for care determine that technologies with higher levels of noise about actual behavior should be subject to harsher legal standards. This result is obtained by reformulating the incentive problem between a Court and Injurer in terms of Type I and Type II errors. Finally, we discuss how this methodology can be applied to other incentives problems in other economic settings.

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1 Introduction

Legal systems attempt to influence behavior by individuals and organizations, so that they adopt desirable courses of action, and avoid undesirable or illegal conduct. This function is commonly carried out and enforced through the use of a wide array of "sticks", that is, sanctions and penalties understood in a broad sense, imposed upon deviant behaviors. Less often, it is achieved through "carrots", that is, through positive incentives or rewards for compliant behavior. One of the major obstacles for the adequate functioning of these schemes, is that those in charge of applying the legal consequences to the agents (Courts, juries, agencies) can seldom directly observe and evaluate the underlying behavior that takes place in reality, but are only able to observe the trace or evidence left behind by the actual conduct of the agent. The signals of behavior that can reach the legal enforcer are imperfect, sometimes very imperfect.

To be more specific, let us think of risky activities that can produce negative effects to third parties, such as pollution to the environment, bodily harm to individuals, or financial harm to other firms. The Law tries to induce those engaging in these activities to exert some degree of care, of precautionary behavior, that will reduce the likelihood of causing harm to others, or the magnitude of such harm. The most widely used tool to induce those precautionary measures is the threat of legal liability for the damages caused. When determining liability, however, Courts or other adjudicators do not have direct observation of the level of care that the potentially liable party actually took, but have to rely on inferences from the evidence (witnesses, reports, physical traces of behavior, expert evaluation about the course of events, and so on) that is available. The agent, who is undertaking the activity will know that he is expected to meet liabilities depending upon the amount and reliability of evidence about actual care which he will be able to present to the legal adjudicator. This introduces a crucial element of uncertainty not only in legal decision-making itself, but also in the decision about underlying behavior.

In this setting, we characterize the Court's optimal decision rule, which is akin to the negligence rule with appropriate due care and evidentiary standards. We study this problem in a general principal-agent framework, where the Court acts as principal to the injurer-agent, and decides the liability of the injurer based on imperfect information on the injurer's care level. We find that the optimal harshness of legal standards depends on the informativeness of care technologies, so that more informative technologies should optimally be subject to more lenient evidentiary standards about non-compliant behavior. When agents are able to shift to care technologies with less noise about actual behavior, the Law, by moving to less harsher standards decreases Type I error–convicting defendants who took the desired actions–and increases the incentives for care.

Our general framework allows us to analyze how evidentiary standards influence the choice of action by agents. We also analyze the choice of technology and its effect on legal decision-makers and how they set about establishing evidence standards. Although for concreteness we will use the scenario of liability for accidents, the analysis would extend to other similar settings.

Obviously, the relationship between substantive legal standards of behavior and evidentiary issues when courts have to decide under uncertainty has been addressed by the literature. But most contributions focus on optimal decisions at the trial phase.[1] In the context of Criminal Law and its enforcement, imperfect observation by courts and the possibility of legal error has also been extensively analyzed.[2] The papers in the literature that are most closely related to our analysis are those that frame the underlying behavioral incentives as a result of the evidentiary standards of proof in assessing posterior probabilities of taking care that courts establish: Johnston (1987), and Demougin and Fluet (2006). More recently, Fluet (2010), in a set-up of noisy observation of care, analyzes the efficiency properties of one-sided (such as simple negligence) and two-sided (such as contributory or comparative negligence) liability rules, and the conditions for efficient results, as well as the issue of uniform vs. case specific standards of proof.

[1] Sobel (1985) looks at the choice of information to be disclosed, and which party should do it, in terms of limiting the negative effects of mistakes in applying legal rules. Sanchirico (1997), and Demougin and Fluet (2006) analyze the optimal determination of evidentiary standards. Hay and Spier (1997), and Gomez (2002) look at the rules that allocate the burden of presenting evidence to one or the other party in a legal dispute.

[2] Png (1986), Miceli (1991), Lando (2000), Rizzolli and Saraceno (2010), and Polinsky and Shavell (2008) for a survey.

Our paper is different from these existing contributions in our description of the Court's problem, where we focus on the costs of punishing the innocent in the Court's effort to agents to adopt desirable courses of action. We also extend the literature with new results on the Court's behavior allowing for very general Court preferences over effort and Court error, and in a context where there are different technologies for behavior with varying degrees of informativeness. In such settings we characterize the optimal standard set by the Law. We consider the problem both in a setting with perfect information on the agent's cost of care, as well as when there is asymmetric information on those costs. This allows us to provide explanations for some observed patterns in the evolution of accident Law, such as the choice between durable and non-durable precaution technologies, as well as between organizational and individual care measures, an issue that has for a long time been discussed in the legal and the Law and Economics literature.

Starting with the early contributions by Grady (1988, 1994) the theory of Tort Law has emphasized the importance of the dichotomy between durable and non-durable precautions in the functioning of legal liability. Some types of precautionary measures extend their risk-reducing effects in a permanent way, or at least they reduce the risk of accident for a relatively extended period of time and for a reasonably high number of opportunities for the materialization of the risk. When an emission producing firms installs a pollutant arrester device, the precautionary measure reduces the likelihood and/or the amount of dangerous pollutants released for the number of years of the working life of the applied technology. Other precautions, however, have only short-lived risk reducing effects, sometimes a very short-lived impact indeed. When an employee of the emitting firm checks the functioning of the pollutant arrester, it only controls performance and reduces the risk of external pollution for the shorter period before the next required check-up arrives. Sometimes these check-up intervals are extremely short, as when a driver looks at the rear mirror before changing lanes in the highway, a precaution that produces effect only for a single occasion of accident, and not for the later instances of changing lanes.

A related but not entirely identical dichotomy in care technologies refers to the level of adoption of care measures, opposing the organizational level with the individual level. It is almost a banal observation among commentators of accident Law, that legal liability is increasingly placed not upon individual agents, but upon organizations inside which the individual agents operate. For instance, vicarious and enterprise liability make the firms inside which the individuals whose behavior has caused the accident, the first and preferred liable parties. The same may be said of governmental liability. Moreover, legal systems increasingly bring to the forefront of the decision to impose liability, or to exempt from liability, the policies designed and implemented, and the general measures adopted, not at the individual level, but at the organizational level. The focus of the liability issue gradually shifts from individual behavior towards organizational action and choices with respect to certain risks of harm. This is clearly the case in the field of industrial accidents, but also in others, such as environmental liability or liability for sexual harassment.

In the paper we explicitly model the choice of technologies possessing different levels of informativeness about the underlying action. We characterize in such a setting of differentiated informativeness generated by precautionary technology choices, the optimal incentives for behavior using the standards set by courts. Of course, court's rulings on liability will be based not upon a direct observation of the compliance by the injurer with the desired behavior, but on the amount of evidence of the level of care actually adopted by the injurer. In our setting, injurers not only decide upon the level of behavior, they also have to make choices regarding precautionary technologies to be adopted. With the term precautionary technology we do not intend to simply capture the option between a manpowered and a machine-powered risk reducing methodology, but generally the choice of procedure to deal with the risk of accident (level of decision-making, formality of procedure, use of physical or human capital, and so forth).

It is clear that not all precautionary technologies, in this broad sense, are equally informative to the court in terms of the evidence of care actually observed by the injurer. Some technologies will be able to provide more reliable evidence in court that a higher level of care has been actually implemented by the injurer. For instance, if the risk reduction methodology is embodied in a physical device whose level of quality and performance can be easily subject to objective estimates and evaluations, and thus, can be more easily verified, the court will be more likely to believe that the level of care taken was higher than when there is no physical device to be analyzed by experts, but one has to rely on witnesses of the conduct of different individuals who had to take the steps to reduce risk. The same would happen if the technology involves formalized general procedures and protocols whose overall effectiveness can be more easily assessed than individual non-formalized actions to reduce risk. The evidence assembled on the "quality" of the organizational processes and protocols, and on the compliance with their requirements, will be more informative about having reached a relatively high degree of risk-reducing care, than the scattered evidence that may be assembled concerning the less-organized individual separate actions to achieve the same purpose. Accordingly, when courts have observed certain evidence linked to a formalized organizational precautionary technology –be it physically embodied in a device or not–what they will infer about the satisfaction of the legal standard of care probably will not dramatically differ from the actual behavior. On the other side, when the evidence refers to individual actions, the lower degree of informativeness and reliability of that evidence will determine that the inferences to be made by the court on the basis of such evidence reflect relatively poorly the actual level of care chosen by the injurer.

Legal standards have a differential impact on both kinds of precautionary technologies. Given that non-formalized technologies are less informative of actual levels of care taken, it is comparatively harder using that technology to produce for the court an inference that the desired behavior has taken place. For the same standard applied to the two sets of precautionary technologies, life is more difficult for those using the non-formalized and less informative one, and courts, albeit formally requiring the same standard in both, are in fact harsher on the latter, because the evidence of having satisfied the standard will be harder to provide, thus requiring higher levels of care.

In the paper we show that the harshness in the evidentiary requirements of observing the desired levels of care decreases with the informativeness of the evidence generated by the precautionary technology, and this implies harsher results for injurers employing less informative technologies.

We also extend these main results in several directions that have been left unexplored by the literature. First, we consider the choice of optimal evidentiary standards for populations of heterogeneous agents. Second, we provide a theory of the changes in the informativeness of care technologies and the harshness of legal evidentiary standards, which may illuminate trends in accident Law, such as the overall expansion in litigiousness about external harms, and the increase in the findings of liability by courts.

2 The Model

2.1 Accident Setting

An agent, the injurer, is engaged in a risky activity that can produce accidents. The agent has access to a precaution technology, δ, and can use this technology with varying degrees of care, $e \in \{e_L, e_H\}$. The cost of each care level is given by $c(e)$ where $c_\delta(e_H) > c_\delta(e_L)$. Accidents occur with probability $p_\delta(e)$ with $p_\delta(e_L) > p_\delta(e_H)$. The magnitude of the loss is constant and denoted by $D > 0$. For the first part of our analysis the precaution technology is fixed so that it will be convenient to drop the δ subscripts to reduce notational clutter. Finally, to simplify the presentation and without loss of generality we let $c(e_H) = c$, $c(e_L) = 0$, $p(e_H) = p \in [0, 1]$ and $p(e_L) = 1$.

2.2 Evidence of care

In the case of accident, the principal, the Court, decides whether or not the injurer is liable and hence has to compensate the victim for the loss from the accident. The Court has no direct observation of the injurer's care and its decision is based on the evidence brought before it in the form of interviews, reports, documents, etc. This evidence is represented by a signal $\pi \in [0,1]$, an index of the amount of evidence indicating that the agent has taken high care. Formally, π, is a realization of a random variable Π with distribution function $f(\pi|e_j)$. This distribution depends on the level of care taken by the agent, $e_j = e_H$ or e_L. For convenience we assume that f is differentiable and non-zero on $[0,1]$. Let $F(\pi|e_j)$ denote the corresponding cumulative distribution function.

A higher π represents greater evidence that the agent took high care. To ensure that taking high care translates into more evidence that the agent took high care, we assume that the signal is monotone, that is, $f(\pi|e)$ satisfies the Monotone Likelihood Ratio Property (MLRP):

$$\frac{f(\pi|e_H)}{f(\pi|e_L)} \text{ is increasing in } \pi.$$

This condition ensures that more evidence is "good news" about care (Milgrom (1981)), that is, $\Pr(e_H|\pi)$ is increasing in π.

2.3 The Court's decision problem

The Court wants to provide incentives to exert high care (otherwise the problem is trivial). We also assume that the Court is concerned with penalizing the innocent. In this first version of the model, it is a natural assumption since convicting an innocent (Type I error) is the only error that can arise in equilibrium. Later on, however, we will generalize our setup and type II error (acquitting the guilty) will also arise in equilibrium. Then, we will assume that the social costs of convicting the innocent exceed the benefits of convicting one more guilty individual, or in other words, that Type I errors are more serious than Type II errors–a criterion shared by most legal scholars, see for example Posner (1999), Miceli, (1991) and Lando (2009).

The Court can commit to a decision rule based on the evidence present. The Court decision rule is represented by the function $\tau(\pi)$: the probability that the Court will rule that the injurer is guilty, and hence has to pay damages equal to D, when faced with evidence π.[3] For any Court decision rule, $\tau(\pi)$, the injurer will chose high effort if the cost of high effort plus the corresponding expected liability costs are lower than the expected liability cost of low effort, that is if

$$p\int_{\pi}\tau(\pi)\,D\ F_{\delta}(d\pi|e_H)+c\leq\int_{\pi}\tau(\pi)\,D\ F_{\delta}(d\pi|e_L)\,. \tag{IC}$$

From all the rules that satisfy (IC), the Court will choose the one that minimizes Type I error, which is equivalent to minimizing the expected liability cost of agents taking high effort (the innocent). Therefore the Court's problem will be:

$$\min_{\tau(\pi)} p\int_{\pi}\tau(\pi)\,D\ F_{\delta}(d\pi|e_H)\quad\text{subject to (IC).}$$

2.4 Timing

The timing of the model is described as follows: 1) The Court sets a decision rule, $\tau(\pi)$. 2) The agent chooses his level of care. 3) Nature determines whether an accident happens or not and, the level of evidence π, according to the probabilities and information structures described above. 4) Finally, in case of accident, the agent is forced to compensate the victim according to the realized evidence and the Court's decision rule. In the next section, we analyze the Court's optimal decision rule.

3 The Court's optimal decision rule

3.1 Evidentiary Standards

Given that we are analyzing a monotone informational setting, it is natural to consider decision rules that are characterized by an evidentiary standard, $\bar{\pi}$, such that if $\pi\leq\bar{\pi}$ the Court finds

[3] A Court could implement a more general decision rule by, conditional on the amount of evidence π, choosing the compensation the injurer has to pay (as a fraction of the maximum liability, that is, full damages) ηD, $\eta\in[0,1]$, as well as the probability that compensation is imposed, $\gamma\in[0,1]$. Then, $\tau(\pi)D=\eta(\pi)\gamma(\pi)D$ represents the expected compensation to be paid and all results continue to hold.

the injurer guilty and makes him pay full damages, while if $\pi \geq \bar{\pi}$ the Court finds the injurer not guilty and the injurer does not have to pay anything. We refer to these as threshold based rules. Such rules can be implemented by Courts as negligence rules with appropriate due care and evidentiary standards.[4] The next proposition shows that such decision rules are optimal.

Proposition 1 *For any decision rule $\tau(\pi)$ that satisfies (IC), there exists a threshold based rule with an evidentiary standard, $\bar{\pi}_\tau$, such that (IC) is satisfied and generates less Type I error:*

$$p \int_\pi \tau(\pi) \; F_\delta (d\pi | e_H) \geq pF(\bar{\pi}_\tau | e_H).$$

That is, for any decision rule that induces high effort there is a threshold rule with a corresponding evidentiary standard that induces high effort and lowers the expected liability cost of agents taking high effort. The sketch of the proof is as follos: start with a rule $\tau(\pi)$ that satisfies (IC). Then, look for the evidentiary standard that generates the same expected cost for those exerting low effort than under $\tau(\pi)$:

$$\int_\pi \tau(\pi) \, D \; F_\delta (d\pi | e_L) = F(\bar{\pi}_\tau | e_L) \, D \; .$$

Then show that a threshold rule based on a standard $\bar{\pi}_\tau$ generates lower expected liability costs for those exerting high effort than under $\tau(\pi)$. This is true because with monotone signals (MLRP), low signals are always more likely to come from low effort, and a threshold rule that concentrates punishment on low signal realizations, is less likely to be punishing those taking high effort. As those exerting low effort are indifferent between the two rules, and those exerting high effort prefer $\bar{\pi}_\tau$, then the threshold rule necessarily satisfies (IC).

Proposition 1 implies that we can concentrate on threshold based rules without loss of generality.[5] This greatly simplifies our analysis, since our mechanism design problem reduces to characterizing the Court's optimal evidentiary standard, $\bar{\pi}$. The Court's problem now becomes

$$\begin{array}{rl} & \min_{\bar{\pi}} pF(\bar{\pi} | e_H) \, D \\ \text{s.t.} & pF((\bar{\pi}) | e_H) D + c \leq F((\bar{\pi}) | e_L) \, D \qquad \text{(IC)} \end{array} \tag{1}$$

[4]Demougin and Fluet (2008) provide a discussion of how such rules could be delegated to a court.

[5]The use of threshold rules is the standard approach followed by the law and economics literature for the analysis of negligency under evidentiary uncertainty, see Johnston (1987), Lando (2002), Demougin and Fluet (2008).

3.2 Minimizing Errors, Maximizing Incentives

A Court that imperfectly observes the injurer's actions and uses an evidentiary standard $\bar{\pi}$ makes Type I errors, which occur with probability $\mathbb{T}_I(\bar{\pi}) = F(\bar{\pi}|e_H)$; and Type II error, which occur with probability $\mathbb{T}_{II}(\bar{\pi}) = 1 - F(\bar{\pi}|e_L)$. This illustrated in the next Figure

[Figure 1 around here]

This (and subsequent) figure represent signals with the following linear information structure which satisfies MLRP:

$$\begin{aligned} f_\delta(\pi|e_H) &= 1 - \frac{\delta}{2} + \delta\pi, \quad F_\delta(\pi|e_H) = \pi - \frac{1}{2}\delta\pi(1-\pi), \\ f_\delta(\pi|e_L) &= 1 + \frac{\delta}{2} - \delta\pi, \quad F_\delta(\pi|e_L) = \pi + \frac{1}{2}\delta\pi(1-\pi), \end{aligned}$$

where the parameter $\delta \in [0, 2]$ indexes the precaution technology (in Figure 1, $\delta = 1.75$ and $p = 0.75$). In Section 4 we analyze changes in δ, which, as we will see, represents changes in the quality of the evidence (a higher δ implies more informative evidence, that is, a closer relationship between care and observed evidence).

We can conveniently rewrite the Court's problem in terms of Type I and II errors. The rewriting of the objective function is immediate, while for the incentive compatibility constraint:

$$\begin{aligned} pF((\bar{\pi})|e_H)D + c &\leq F((\bar{\pi})|e_L)D \\ pF((\bar{\pi})|e_H)D - F((\bar{\pi})|e_L)D &\leq -c \\ pF((\bar{\pi})|e_H) + 1 - F((\bar{\pi})|e_L) &\leq 1 - \frac{c}{D} \\ p\mathbb{T}_I(\bar{\pi}) + \mathbb{T}_{II}(\bar{\pi}) &\leq 1 - \frac{c}{D}. \end{aligned}$$

Then, the Court's problem is equivalent to the following error minimization problem:

$$\begin{array}{rl} & \min_{\bar{\pi}} \mathbb{T}_I(\bar{\pi}) \\ \text{s.t.} & p\mathbb{T}_I(\bar{\pi}) + \mathbb{T}_{II}(\bar{\pi}) \leq 1 - \frac{c}{D} \qquad \text{(IC)} \end{array} \tag{2}$$

3.3 The weighted error function.

The relationship between the Court's evidentiary standard and the agent's incentive to exert high effort crucially depends on the properties of the weighted error function:[6]

$$\Phi(\pi) = \mathbb{T}_{II} + p\mathbb{T}_I = 1 - F\left((\bar{\pi})\,|e_L\right) + pF((\bar{\pi})\,|e_H).$$

Lemma 1 *The weighted error function has a unique minimum on the interval* $[0,1]$ *at* $\pi_{\min}$*. The function takes values* $\Phi(0) = 1$ *and* $\Phi(1) = p$*.*

The parameter p determines the amount of error when one applies the strictest standard ($\bar{\pi} = 1$). We also refer to this standard as the strict liability regime, as it imposes the full cost of the accident on the injurer whenever there is an accident. The parameter p captures the difference in the probability of accident occurrence between the high and low care levels, and hence it may be interpreted as the informativeness of the accident on the level of care. The standard that minimizes the error function, $\pi_{\min}$, depends on p. Let $p_{\min} = \frac{f(1|e_L)}{f(1|e_H)}$.

Corollary 1 *The standard that minimizes* Φ*,* $\pi_{\min}$*, is decreasing with* p*. For* $p \leq p_{\min}$*,* $\pi_{\min} = 1$*.*

For settings where $p \leq p_{\min}$ the sole occurrence of the accident is highly informative about the level of care (*res ipsa loquitur*) and increasing the standard leads to greater incentives for high care. On the contrary, if $p > p_{\min}$ the effect of increasing the standard on effort is not so straightforward. Given a high standard of evidence ($\pi \geq \pi_{\min}$) increasing the standard implies an increase in the total amount of error which reduces the incentives for effort.

As we will see below, we will be mainly interested in the set of standards below $\pi_{\min}$. Let $\Phi_{\mathbb{D}}$ be the error function defined on this set, $\mathbb{D} = [0, \pi_{\min}]$, so that $\Phi_{\mathbb{D}}$ is a decreasing function (and a higher standard increases the incentives to take care).

Figure 2 illustrates the shape of the Φ function for $\delta = 1.75$ (and $p = 0.75$) as well as $\pi_{\min}$, the interval $\mathbb{D}$, and the function $\Phi_{\mathbb{D}}$.

[6] The weighted error function corresponds to the deterrence curve in Demougin and Fluet (2005).

[Figure 2 about here]

3.4 The optimal evidentiary standard

Having analyzed the weighted error function, we can now solve the Court's problem and characterize the corresponding optimal standard:

$$\begin{array}{c} \min_{\bar{\pi}} p\mathbb{T}_I \\ \text{s.t.} \quad \Phi(\pi) \leq 1 - \frac{c}{D} \qquad \text{(IC)} \end{array} \tag{3}$$

Proposition 2 *There exists a cost level, $c_{\max} = (1 - \Phi(\pi_{\min}))D$, such that if $c \leq c_{\max}$ then the optimal standard is $\bar{\pi}^*(c) = \Phi_{\mathbb{D}}^{-1}\left(1 - \frac{c}{D}\right)$ which is increasing in c. If $c > c_{\max}$ high care cannot be induced.*

The intuition of this proposition is as follows: For a given cost, there is a set of standards that generates enough incentives to induce high care. As Type I error is monotonically increasing in the evidentiary standard, the Court chooses the minimum of these. If the cost of exerting care increases, it becomes more difficult to induce high care, and the Court has to increase the optimal standard.

Figure 3 illustrates Proposition 2 by characterizing the optimal evidentiary standard when $\delta = 1.75$, $p = 0,75$, and $\frac{c}{D} = 0.4$. In Figure 3 we can observe the set of standards that induce high care, $\mathbb{H}(c)$, and the optimal standard, $\pi^*(c)$–the lowest in this set. A higher c (corresponding to the lower green horizontal line at $\frac{c}{D} = 0.42$) implies a higher optimal evidentiary standard, π^*.

[Figure 3 around here]

In the previous proposition, we showed that there is a maximum cost, $c_{\max}$, that determines when it is possible to induce high care. It is interesting to consider whether or not the Court can induce high care when the costs of exerting care are lower or equal than the expected benefits from reducing the probability of accident. Let c_{eH} be the maximum cost for which it is efficient to induce high care, that is $c_{eH} = (1 - p)D$.

Lemma 2 *If it is efficient to exert high care* ($c \leq c_{eH}$)*, then it is possible to induce high care* ($c \leq c_{\max}$)*, that is* $c_{eH} \leq c_{\max}$.

This lemma is proven by evaluating the incentives to take care with the strictest standard, $\bar{\pi} = 1$. This standard implies $\Phi(1) = p$. Replacing $\Phi(1) = p$ in the incentive compatibility constraint we obtain $p \leq 1 - \frac{c}{D}$, which is precisely the condition for the cost of high care to be socially optimal. As the strictest standard corresponds to strict liability, we obtain a known result in the literature of Law and Economics: strict liability (the injurer is always liable in case of accident) induces the efficient amount of care since the injurer internalizes all the costs. In other words, as it is always possible to use strict liability, the Court is sure to be able to induce a high level of care when it is efficient to do so.

However, the highest evidentiary standard $\bar{\pi} = 1$ (strict liability) is in general not optimal.

Corollary 2 *The highest evidentiary standard* $\bar{\pi} = 1$ *is optimal if and only if*

- $c = c_{eH}$*, that is* c *is equal to the maximum cost for which it is efficient to induce high effort; and*
- $p \leq p_{\min}$*, the accident is very informative about the level of care.*

In the previous discussion, we saw that for $c > c_{eH}$ strict liability does not provide incentives for high care. If $c \leq c_{eH}$, the optimal standard is increasing in the cost of high care (by Proposition 2). Thus, the highest standard may only be optimal for the highest cost of care in the set, that is when $c = c_{eH}$. Furthermore, from our discussion in the previous section, the monotonicity of incentives for care depends on the value of p. For strict liability to be optimal, incentives for care must be at their maximum at $\bar{\pi} = 1$, and this can only occur if Φ is monotone, that is if $p \leq p_{\min}$. The economic intuition behind this is that strict liability generates too much Type I error so that it will be optimal only if p is low enough, that is when high care reduces the probability of an accident so much that there is very little Type I error.[7]

[7] The ideat that the presence of the accident is strong evidence of low care is related to the legal notion of res ipsa loquitur.

4 Informativeness and the standard of negligence

We now turn to what constitutes the central analysis of the paper, namely the link between informativeness of care technologies and the harshness of standards. So far we have assumed the existence of a single precaution technology. Now, we consider that the agent may exert care using different technologies that generate different types of evidence. In particular, we start by assuming that there are two alternative technologies δ and δ', that both technologies are equally efficient in terms of care (cost and probability of accident are the same, $c_\delta = c_{\delta'} = c$, and $p_\delta = p_{\delta'} = p$) and they only differ in terms of evidence provision (i.e. informativeness of the signal, Π).

In general, the evidence produced by two different technologies can differ both in its nature as well as in its informativeness about the care of the agent. The nature of the evidence can be different as, for example, one technology may require evidence in the form of witness reports, while the other may require evidence in the form of scientific studies. In order to compare evidence standards from different technologies we will use the notion of harshness defined as follows:

Definition 1 *An evidentiary standard $\bar{\pi}_\delta$ is harsher than another $\bar{\pi}_{\delta'}$ if $\bar{\pi}_\delta$ generates more Type I error than $\bar{\pi}_{\delta'}$, that is $\mathbb{T}_I(\bar{\pi}_\delta) \geq \mathbb{T}_I(\bar{\pi}_{\delta'})$.*

Notice that when comparing standards when using the same technology, a harsher standard is one that requires more evidence of care. To clarify the different roles of the technology and the standard in determining errors we will use the more explicit notation $\mathbb{T}_I(\bar{\pi};\delta)$ as needed.

Care technologies may also differ in terms of the informativeness of the evidence they generate. We have assumed that there is a link between evidence and exerted care (MLRP). This link can be stronger (more informative evidence) for some technologies than for others. For the rest of the paper, we will assume that the parameter δ ranks technologies according to their informativeness.

There are several informativeness orders. We use the notion defined in Lehmann (1988):

Definition 2 *Technology δ is more (Lehmann) informative than technology δ' if*

$$\forall \pi, \quad F_{\delta}^{-1}(F_{\delta'}(\pi|e_H)|e_H) \geq F_{\delta}^{-1}(F_{\delta'}(\pi|e_L)|e_L).$$

This condition is used to define informativeness of signals in many economic problems as it defines informativeness in terms of the value of information in decision making problems: a signal X is more informative than another Y if every decision-maker with preferences in a particular class (single-crossing preferences) prefers X to Y (Lehmann 1988, Persico 2000, Jewitt 2007). Thus, a signal is more informative if it allows decision-makers to make better decisions (that is to get more value out of their decisions). It is shown by Jewitt (2009) that Lehmann's notion of informativeness is equivalent to Blackwell sufficiency in a dichotomous setting which is the one used in this analysis. Ganuza and Penalva (2010) provides alternative criteria of informativeness based on the dispersion of posterior conditional expectations. The weakest of these criteria, integral precision (based on convex order) is implied by all previously mentioned informativeness criteria. Ganuza and Penalva (2010) show that integral precision is equivalent to Lehmann in dichotomous setting. Then, as dispersion of conditional expectations is easily verified, we use integral precision to prove that the signals in our parametric example are Lehmann ordered (see Appendix).

Lehmann's notion of informativeness is particularly appropriate in our analysis as it implies that with more informative signals it is possible to construct more powerful hypothesis tests. Next lemma adapts this result to our framework:

Lemma 3 *Let $\bar{\pi}_{\delta}^{\alpha}$ and $\bar{\pi}_{\delta'}^{\alpha}$ be defined by $\mathbb{T}_I(\bar{\pi}_{\delta}^{\alpha};\delta) = \mathbb{T}_I(\bar{\pi}_{\delta'}^{\alpha};\delta') = \alpha$. If technology δ is more informative than technology δ', then for all $\alpha \in [0,1]$, $\Phi_{\delta}(\bar{\pi}_{\delta}^{\alpha}) \leq \Phi_{\delta'}(\bar{\pi}_{\delta'}^{\alpha})$.*

4.1 Optimal standards with a single agent type

Lemma 3 allows us to analyze how a change in the informativeness of the technology affects social welfare and the Court's choice of the optimal standard that we characterized in the previous section. The next Proposition compares the solutions of the Court's problem (Equation (3)) for two alternative technologies ranked in terms of their informativeness.

Proposition 3 *Let $\bar{\pi}^*_\delta$ and $\bar{\pi}^*_{\delta'}$ be the optimal standards for technologies δ and δ'. If technology δ is more informative than δ', then $\bar{\pi}^*_\delta$ is less harsh than $\bar{\pi}^*_{\delta'}$.*

This Proposition implies that the optimal harshness of legal standards depends on the informativeness of the care technologies, so that more informative technologies allow for more lenient legal standards.[8]

Furthermore, the Court's objective and the injurer's incentives are aligned:

Corollary 3 *If the Court sets the optimal standard for each technology, the more informative one will minimize the costs of the injurer and maximize social welfare.*

As the Court is inducing high care, the welfare of both the Court and the injurer is decreasing in Type I error, which is minimized by the more informative technology (Proposition 3).[9]

Corollary 4 *A more informative technology increases the range of costs for which the Court can induce high care: $c_{\max}$ is increasing in δ.*

With a given technology, the highest cost level for which the Court can induce care is $c_{\max}$ which solves $\Phi(\pi_{\min}) = 1 - \frac{c}{D}$. As the informativeness of the technology increases, by Proposition 3, the Type II errors induced by the standard $\pi_{\min}$ can be lowered while keeping the same harshness, thereby making high care incentive compatible for cost levels that are slightly higher than $c_{\max}$.

[8] [[Grady]]This result can be applied to existing discussions on differences in harshness applied to injurers using different precaution technologies. For example, a low δ can be associated with non-formalized precaution technologies, such as an informal system of prevention of sexual harassment in the workplace. Correspondingly, a high δ can be associated with organizational precaution technologies, such as centrally managed and coordinated policies for managing the environment in the workplace. Then, a direct implication of Proposition 3 is that it is optimal for Courts to be harsher with injurers using non-formalized precautions than on those using technologies of an organizational nature.

[9] This result helps understand the increased introduction of organizational precaution technologies in firms, hospitals, etc., even if they are not more effective in reducing risks.

5 Optimal standards with a heterogenous population

We now proceed to characterize the optimal standard for a population of heterogenous agents, or equivalently, for a situation in which the Court is uncertain about the injurer's cost of care. The main difficulty of this generalization is that Type II errors will arise in equilibrium.

We start with a single care technology δ and assume the cost of care c_i belongs to $[0, D]$. Costs of care are distributed according to $G(c)$ with pdf $g(c)$ and support $[0, D]$. Then, generally, for any standard set by the Court there will be some agents who will take high care and others who will take low care.

The choice of care in the population is characterized as follows:

Lemma 4 *Given a standard, $\bar{\pi}$, there is a type of agent with cost of care $\bar{c}$, characterized by $\Phi(\bar{\pi}) = 1 - \frac{\bar{c}}{D}$, such that agents with cost $c_i \geq \bar{c}$ prefer to use low care while those with costs $c_i \leq \bar{c}$ prefer to use high care.*

This result is illustrated in Figure 4

[Figure 4 around here]

The standard chosen by the Court in Figure 4, $\mathbb{T}_I(\bar{\pi}) = 0.4$, cuts the weighted error curve $\Phi(\pi)$ at $1 - \frac{c}{D} = 0.5325$ and thereby identifies the agent type who is indifferent between the two levels of care, $\bar{c}$. The distribution of cost types, $g(c)$, is displayed on the LHS of the Figure, by the y-axis. Agents with $c \geq \bar{c}$ are represented by the red-shaded area under the pdf, while those with $c \leq \bar{c}$ are represented by the green shaded area under the pdf.

Lemma 4 implies that when setting the evidentiary standard the Court has to take into account three factors: (i) the amount of care in the population, which is captured by the level of care of the agent that is indifferent between high and low care, $\bar{c}(\bar{\pi})$, (ii) the amount of Type I error, $\mathbb{T}_I(\bar{\pi})$, and (iii) the amount of Type II error, $\mathbb{T}_{II}(\bar{\pi})$. We can then describe the preferences of the Court using a social welfare function $W(\bar{c}, \mathbb{T}_I, \mathbb{T}_{II})$ that depends on these three variables.

Instead of assuming a particular parameterization of this welfare function, we will consider a general class of welfare functions. These functions, which we refer to as regular welfare functions, are defined as follows:

DEFINITION 3 *A Social Welfare Function* $W(\bar{c}, \mathbb{T}_I, \mathbb{T}_{II})$ *is regular if: i)* $W(\bar{c}, \mathbb{T}_I, \mathbb{T}_{II})$ *is differentiable and increasing in* $\bar{c}$ *and decreasing in* $\mathbb{T}_I$ *and* $\mathbb{T}_{II}$*; and, ii) For any* $\bar{c}$*,*

$$\left|\frac{\partial W}{\partial \mathbb{T}_I}\right| \geq \left|\frac{\partial W}{\partial \mathbb{T}_{II}}\right|.$$

The first property establishes that a regular social welfare function values high care and low Type I and Type II errors (differentiability is assumed for convenience but is not necessary for the analysis).[10]

The second property establishes that the relative social importance from a change in $\mathbb{T}_I$ is everywhere greater than from a change in $\mathbb{T}_{II}$. As we discussed above, this assumption reflects the general fairness concern with the problem of convicting the innocent in legal discourse and practice ("it is better to let the crime of a guilty person go unpunished than to condemn the innocent").[11]

As we have changed the Court's objective function, we have to reconsider the optimality of threshold based rules. Fortunately, we can establish a result similar to Proposition 1.

PROPOSITION 4 *Given a regular social welfare function* $W(\bar{c}, \mathbb{T}_I, \mathbb{T}_{II})$*, and a decision rule* $\tau(\pi)$*, there is a threshold based rule with an evidentiary standard,* $\bar{\pi}_\tau$*, that generates the same or greater social welfare according to* $W(\bar{c}, \mathbb{T}_I, \mathbb{T}_{II})$*.*

[10] We do not explicitly introduce the cost of effort since this would complicate the analysis unnecesarily. First, all our results hold is we constrain the Court maximization problem to the set of "efficient standards", $\pi \in [0, \pi_{eH}]$ where $\bar{c}(\pi_{eH}) = c_{eH}$. Secondly, if W is decreasing in $\bar{c}$ for $c > c_{eH}$, given that W is decreasing in $\mathbb{T}_I$ and that $\left|\frac{\partial W}{\partial \mathbb{T}_I}\right| \geq \left|\frac{\partial W}{\partial \mathbb{T}_{II}}\right|$ then the optimal standard will lie in the "efficient" interval, $\overline{\pi}^* \in [0, \pi_{eH}]$.

[11] In the economically oriented literature on Law enforcement it is customary [Miceli (1991), Lando (2000)] to give asymmetric weight to Type I and Type II errors, due to fairness concerns in society. Moreover, even without imposing an a priori condition on the social preferences over the ratio of one and the other kind of legal errors, there are several reasons why society will be more concerned about mistaken findings of liability: effects on socially valuable activity levels [Kaplow and Shavell (1994); risk aversion of agents [Rizzolli and Stanca (2009)]; and also intrinsic costs of imposing liability [Rizzolli and Saraceno (2010)], which of course are very substantial in the case of non-monetary sanctions such as imprisonment, but are also relevant in the case of monetary damages and penalties.

The proof follows the same lines as the one for Proposition 1: identify the threshold rule that generates the same $\mathbb{T}_{II}$ and show that it generates lower $\mathbb{T}_I$. To conclude the proof it suffices to show that the same $\mathbb{T}_{II}$ with a lower $\mathbb{T}_I$ implies that the incentives for exercising high effort are greater, and hence $\bar{c}$ is higher.[12]

With a single agent we have seen that greater informativeness leads to greater social welfare with a less harsh standard (Proposition 3). A similar result can also be obtained in the general setting.

PROPOSITION 5 *Consider two technologies δ and δ' such that technology δ' is less informative than δ and its corresponding optimal standard is $\bar{\pi}\prime$. i) With technology δ, a set of standards exists that provide greater welfare for all regular social welfare functions; ii) If the standard $\bar{\pi}$ generates greater welfare for all regular social welfare functions under δ then $\bar{\pi}$ is less harsh than $\bar{\pi}\prime$, that is $\mathbb{T}_I(\bar{\pi};\delta) \leq \mathbb{T}_I(\bar{\pi}\prime;\delta')$.*

Proposition 5 states that when the informativeness of the technology increases, there is a set of standards for which we can guarantee that welfare increases without further assumptions on social welfare. Moreover, the proposition also states that these "better" standards are less harsh (and increase the amount of care in the population).[13] In the proof we characterize the set of "better" standards as an interval, $[\pi_{L\delta}, \pi_{H\delta}]$. Furthermore, the extremes of this interval are $\pi_{L\delta} = \Phi^{-1}_{\mathbb{D},\delta}\left(1 - \frac{c'}{D}\right)$ where $c' = (1 - \Phi_{\delta'}\left(\pi^*_{\delta'}\right))D$, and $\mathbb{T}_I(\pi_{H\delta}) = \mathbb{T}_I\left(\pi^*_{\delta'}\right)$.

In Figure 5 we depict the effect of an increase in the informativeness of the signal (from $\delta' = 1.25$ to $\delta = 1.75$). Note that the x-axis now identifies Type I error (not standards).

[Figure 5 around here]

[12] As can be deduced from the text, the proof uses condition i) but it does not rely on property (ii) of regular preferences, so that the result holds for all "monotone" social welfare functions.

[13] Nevertheless, this does not imply that given or a specific social welfare function the optimal policy will be less harsh. It is possible that for a given social welfare function and informativeness, an increase in informativeness may lead to a harsher optimal standard. This is because the Court may prefer to take advantage of the lower errors from the more informative technology to increase care so much that it may end up increasing the harshness of the standard.

Figure 5 illustrates how greater informativeness leads to less error–Φ_{δ} is below $\Phi_{\delta'}$(Lemma 3). Also, given an arbitrary optimal standard $\bar{\pi}^{*}_{\delta'}$ for technology δ', Figure 5 also identifies the set of standards that with technology δ generate more welfare for all regular social welfare functions–the section of Φ_{δ} between points B and C (Proposition 5).

5.1 Competing Technologies

So far we have considered what happens when substituting one technology for another. We now consider what happens when there are two technologies available at the same time. Agents, when facing a choice between two technologies, δ and δ', will select the one that provides lower expected costs of precaution. Let $\bar{\pi}$ be the standard applied to agents who choose technology δ and $\bar{\pi}'$ to those that use δ'. Then, an agent with cost of care c faces the following incentive compatibility constraint:

$$c + p \min \left\{ F_{\delta} \left(\bar{\pi} | e_H \right), F_{\delta'} \left(\bar{\pi}' | e_H \right) \right\} D \leq \min \left\{ F_{\delta} \left(\bar{\pi} | e_L \right), F_{\delta'} \left(\bar{\pi}' | e_L \right) \right\} D.$$

Rewriting the incentive compatibility constraint in terms of type I and II errors we obtain:

$$\max \left\{ \mathbb{T}_{II} \left(\bar{\pi}; \delta \right), \mathbb{T}_{II} \left(\bar{\pi}'; \delta' \right) \right\} + p \min \left\{ \mathbb{T}_{I} \left(\bar{\pi}; \delta \right), \mathbb{T}_{I} \left(\bar{\pi}'; \delta' \right) \right\} \leq 1 - \frac{c}{D}.$$

Let $\widehat{W}$ denote the social welfare function that depends on the standards $\bar{\pi}'$, and $\bar{\pi}$ applied on agents using technologies δ' and δ respectively. Then,

$$\widehat{W} \left(\bar{\pi}', \bar{\pi} \right) = W \left(\hat{c} \left(\bar{\pi}', \bar{\pi} \right), \max \left\{ \mathbb{T}_{II} \left(\bar{\pi}; \delta \right), \mathbb{T}_{II} \left(\bar{\pi}'; \delta' \right) \right\}, \min \left\{ \mathbb{T}_{I} \left(\bar{\pi}; \delta \right), \mathbb{T}_{I} \left(\bar{\pi}'; \delta' \right) \right\} \right),$$

where $\hat{c} \left(\bar{\pi}', \bar{\pi} \right)$ is the cost of effort for the agent who is indifferent between exerting low or high care, and $\min \left\{ \mathbb{T}_{I} \left(\bar{\pi}; \delta \right), \mathbb{T}_{I} \left(\bar{\pi}'; \delta' \right) \right\}$ and $\max \left\{ \mathbb{T}_{II} \left(\bar{\pi}; \delta \right), \mathbb{T}_{II} \left(\bar{\pi}'; \delta' \right) \right\}$ are the equilibrium Type I and Type II errors given the agent's incentives.

Therefore, the Court's problem becomes:

$$\begin{array}{rl} & \max_{\bar{\pi}', \bar{\pi}} \widehat{W} \left(\bar{\pi}', \bar{\pi} \right) \\ \text{s.t.} & \max \left\{ \mathbb{T}_{II} \left(\bar{\pi}; \delta \right), \mathbb{T}_{II} \left(\bar{\pi}'; \delta' \right) \right\} + p \min \left\{ \mathbb{T}_{I} \left(\bar{\pi}; \delta \right), \mathbb{T}_{I} \left(\bar{\pi}'; \delta' \right) \right\} \leq 1 - \frac{c}{D}. \end{array} \tag{4}$$

The next result illustrates that the presence of competing technologies exacerbates the conflicts of interest between Court and agents and complicates the Court's decision:

LEMMA 5 *If the Court applies an equally harsh standard on both technologies, it is weakly optimal for all agents to use the less informative technology.*

If the Court applies an equally harsh standard on both technologies, agents exerting high effort face the same expected cost of care from using either technology and hence are indifferent between the two. But agents exerting low effort strictly prefer the less informative technology, since this technology generates more type II error.

What we find is that with two competing technologies, social welfare is greater than when only the less informative one is available, but lower than if only the more informative one was available.

LEMMA 6 *Consider two technologies δ' and δ such that technology δ' is less informative than δ, with corresponding optimal standards $\bar{\pi}'$ and $\bar{\pi}$ respectively. Then,*

$$W(\bar{\pi}; \delta) \geq \max_{\bar{\pi}', \bar{\pi}} \widehat{W}\left(\bar{\pi}', \bar{\pi}\right) \geq W\left(\bar{\pi}'; \delta'\right).$$

What we find is that the presence of two coexisting technologies does not eliminate but can reduce the social welfare improvements that we found in Proposition 5.

[Figure 6 around here]

Figure 6 (combined with Figure 5) helps illustrate Lemma 6. In Figure 5 we saw that with a more informative technology, the Court could increase welfare by selecting any standard corresponding to the section of Φ_δ between points C and B. We find the same B and C points on Figure 6, but if δ does not replace δ' and agents can still use δ' and be subject to the standard $\bar{\pi}\prime$ (point A), the Court cannot select all those standards. It will now be able to select standards corresponding to the section of Φ_δ between points C and D only, and not those between D and

B. This is because for points between C and D, both $\mathbb{T}_I$ is lower and $\mathbb{T}_{II}$ is greater than with technolgy δ' (point A) so that all agents prefer the more informative technology (and social welfare is greater than with technolgy δ'). But, for points between D and B, $\mathbb{T}_{II}$ error is lower with technology δ than with δ' and agents with high costs of care prefer to use the less informative care technology (and social welfare is lower than if technology δ' was not available).

Now, consider the Court's problem (in Equation 4) of choosing optimal standards with competing technologies.

LEMMA 7 *In the presence of competing technologies that differ only in terms of their informativeness, an optimal Court policy is to apply the optimal evidentiary standard for those using the more informative technology, and forbid (or impose strict liability on those using) the less informative one.*

We can see this in Figure 6 also. Consider the Court's optimal reaction to the introduction of a more informative technology and let $\bar{\pi}$ be the optimal standard for δ (when technology δ' is not available). By Lemma 6, social welfare is maximized if everyone adopts technology δ with standard $\bar{\pi}$. If $\bar{\pi}$ is a soft standard (a point on Φ_δ to the left of D) then there is no conflicts of interest as Type I error is lower and Type II error higher than at $\bar{\pi}\prime$ (point A). But, if $\bar{\pi}$ is too harsh (a point on Φ_δ to the left of D), then, not all agents will switch to technology δ unless the Court changes the standard for those using δ'. This is because $\bar{\pi}$ generates less Type II error than $\bar{\pi}\prime$ does with the less informative technology. To make the less informative technology less attractive for those exerting low effort, it is optimal to distort the standard, $\bar{\pi}\prime$, making it harsher (and thereby reducing Type II error) until it is below $\mathbb{T}_{II}\left(\bar{\pi};\delta\right)$.

5.2 Differences in efficiency between technologies

So far we have considered technologies that differed solely in terms of their informativeness, though two care technologies are rarely equal in terms of the costs of care, reduction of ensuing harm, or reduction in the probability of accident. We now suppose that technology δ is more informative than δ' but consider the possibility that they also differ in other aspects that affect the efficiency with which they reduce risk.

We have seen that courts have incentives to promote the adoption of the more informative technology. If the more informative is also the more efficient technology then the courts' incentives to promote its adoption and apply harsher standards on the less informative one are even stronger. Similarly, if the less informative technology is sufficiently more efficient, courts can encourage adoption of the more efficient technology by maintaining a common harshness of standards.

An interesting problem arises when differences in efficiency are individual-specific and the Court cannot determine for each agent what is the efficient technology he should be using. To capture this setting we make the following modelling assumption: the probability of accident is the same for all agents ($p_\delta = p_{\delta'} = p$), their cost of effort under both technologies is drawn from the same distribution, $G(c)$, and agents are randomly (and independently) classified into one of the following three groups:

1. Type A [inflexible δ-types]: agents have to assume a (sufficiently high) additional cost for using δ' such that they will not use δ' under any circumstances;

2. Type B [inflexible δ'-types]: agents have to assume a (sufficiently high) additional cost for using δ such that they will not use δ under any circumstances; and

3. Type F [flexible types]: agents who find δ and δ' to be equally efficient.

In this case it may not be socially optimal to ban the use of any one of the two technologies.

Let $\bar{\pi}$ [$\bar{\pi}'$] be the optimal standards for technology δ [δ'] when it is the only technology in the economy. Then, there are circumstances in which courts would not distort these optimal standards.

Lemma 8 *If the optimal standard for δ is more lenient on both the innocent and the guilty,*

$\mathbb{T}_I(\bar{\pi};\delta) \leq \mathbb{T}_I(\bar{\pi}\prime;\delta') $ and $\mathbb{T}_{II}(\bar{\pi};\delta) \geq \mathbb{T}_{II}(\bar{\pi}\prime;\delta')$, then courts optimally apply the standards $\bar{\pi}$ and $\bar{\pi}\prime$, Type F agents choose the more informative technology, and social welfare is maximized.

This is the case where $\bar{\pi}$ corresponds to a point on the section of Φ_δ between points C and D on Figure 6 we discussed above. In this case private and public incentives are aligned as both $\mathbb{T}_I$ is lower and $\mathbb{T}_{II}$ is greater than with technology δ' and all flexible agents prefer the more informative technology.

Nevertheless, there are circumstances when flexible types do not find the more informative sufficiently attractive (from the social welfare perspective). Then, the Court needs to weight the costs and benefits of distorting the optimal standards. By distorting the standards it can improve welfare by making the more informative technology more attractive to the flexible types. But, distorting standards implies reducing welfare for inflexible types. What we find is that:

Proposition 6 *If the Court finds it optimal to distort the optimal standards it will do so by increasing the difference in harshness between the two.*

Thus, if may not be optimal to distort standards if the welfare effects on the inflexible types are too large. But, if it is sufficiently important to have flexible agents adopt the more informative technology, this can be done in two ways: by making the standard on the less informative standard harsher (as was done in the previous section), or by softening the standard on the more informative one. Either way, the difference in harshness of standards increases. This new policy may be optimal if the costs of distorting the standards for the inflexible types using the less informative technology are high relative to the cost of applying too soft standards on agents using the more informative technology. What we rule out is the Court reducing the difference in harshness of standards–imposing equal treatment of technologies is not a good policy.

6 Conclusions

In the paper we present a general framework to understand how the quality of evidence about the underlying behavior that the legal system tries to induce from the agents affects the choice of evidentiary standards by the Law, which in turn will determine the incentives that the agents will face in order to adopt the desired levels of behavior. In this setting we analyze the optimal policies in terms of the harshness of the evidentiary standards, and show how some traditional issues, such as the use of strict liability instead of negligence can be presented under a new light.

Moreover, we also explicitly examine the choice of technology by firms engaged in risky activities, given that not all technologies are equally informative of the true level of care in the evidentiary sense. Some technologies are more informative than others. For instance, when precaution is mainly the outcome of policies and investment decisions carried out at the organizational level, and extending to the farthest corners of the entity that poses the risk of harm, typically the level of informativeness is high. On the other side, when precaution decisions are disorganized, taken at the individual level of all agents who may have some influence on the risk, the evidence concerning these precautions would commonly be weaker. From here, our main theoretical analysis considers the optimal choice of evidentiary standards to induce adequate behavior in the presence of a diversity of precautionary technologies. We find that a higher degree of informativeness by a technology should lead the legal system to impose less harsh evidentiary standards to achieve the same level of underlying behavior. The reverse is the case for technologies that are less informative. Our main results and their extension to heterogeneous populations of agents and competing technologies seems to provide a common explanation to several observed patterns in the evolution of liability for accidents in most developed countries. Our analysis additionally provides a basis for the adjustment of evidentiary standards to actions taken by an injurer after the accident has happened, and more precisely, actions linked to the lawsuit and trial, such as the choice of legal counsel, obstructionist tactics at discovery and other similar types of behavior.

A Appendix

A.1 A Principal-Agent Formulation

Consider a principal who wants to encourage effort from an agent. The agent has a reservation wage equal to U and chooses between two effort levels, $e \in \{e_L, e_H\}$ at a monetary cost of c. The agent's effort affects his productivity, π, where the distribution of π depends on the effort level chosen by the agent, e, and is described by the probability distribution $f(\pi|e)$ and the cumulative distribution function $F(\pi|e_H)$, where $f(\pi|e)$ has the same stochastic structure as described in the text, that is, it has the monotone likelihood ratio property. Suppose the principal wants to encourage effort and can do so by offering the agent an incentive contract of the form: a constant wage W and a bonus B with probability $\gamma(\pi)$ where $\gamma : [0,1] \rightarrow [0,1]$. Only, we assume that the principal does not incur the full cost of the bonus. That is, for the agent the bonus has a higher value than the cost it has for the principal. We can think of this as capturing some additional value that the bonus provides to the agent, which can be pecuniary (for example, the bonus is a signal to the market that increases the agent's human capital), or non-pecuniary (for example, the psychological value of the recognition of one's effort). Thus, we assume that the principal only pays a fraction $\alpha \in [0,1)$ of the bonus the agent receives. Then, the principal's problem is:

$$
\begin{aligned}
&\min_{\gamma(\pi)} W + \int_0^1 \alpha B \gamma(\pi) f(\pi|e_H)\, d\pi \\
&\text{s.t. } W + \int_0^1 B\gamma(\pi) f(\pi|e_H)\, d\pi - c \;\geq\; W + \int_0^1 B\gamma(\pi) f(\pi|e_L)\, d\pi \\
&\text{and } W + \int_0^1 B\gamma(\pi) f(\pi|e_H)\, d\pi - c \;\geq\; U.
\end{aligned}
$$

The monotonicity of the signal implies that the distribution of γ is degenerate, that is there exists $\bar{\pi}$ and p such that

$$
\gamma(\pi) = \begin{cases} 0 \text{ if } \pi < \bar{\pi} \\ p \text{ if } \pi = \bar{\pi} \\ 1 \text{ if } \pi > \bar{\pi} \end{cases},
$$

where $p \in [0,1]$ and will either 0 or 1 up to a small perturbation of the parameters.

The principal, by minimizing the wage schedule will reduce it so as to make the agent indifferent between high effort and the outside option, W, so that the participation constraint will be binding, that is

$$
\begin{aligned}
W + \int_0^1 B\gamma(\pi) f(\pi|e_H)\, d\pi - c \quad &= \quad W + (1 - F(\bar{\pi}|e_H))\, B - c = U \\
&\iff \quad W = U + c - (1 - F(\bar{\pi}|e_H))\, B.
\end{aligned}
$$

We can now rewrite the principal's objective function as

$$\begin{aligned} U+c-(1-\alpha)(1-F(\bar{\pi}|e_H))B &= U+c-(1-\alpha)B+(1-\alpha)F(\bar{\pi}|e_H)B \\ &= U+c-(1-\alpha)B+(1-\alpha)B\mathbb{T}_I. \end{aligned}$$

Also, the incentive compatibility constraint is expressed as

$$\begin{aligned} (1-F(\bar{\pi}|e_H))B+c &\geq (1-F(\bar{\pi}|e_L))B \\ \Longleftrightarrow 1+\frac{c}{B} &\geq \mathbb{T}_I+\mathbb{T}_{II} \end{aligned}$$

Let $a=U+c-(1-\alpha)B$ and $b=(1-\alpha)B$, and the principal's problem is now

$$\begin{aligned} &\min_{\bar{\pi}} a+b\mathbb{T}_I \\ &\text{s.t. } \mathbb{T}_I+\mathbb{T}_{II} \leq 1+\frac{c}{B}, \end{aligned}$$

which is analogous to the Court's problem, namely

$$\begin{aligned} &\min_{\bar{\pi}} p\mathbb{T}_I \\ &\text{s.t.} \quad \mathbb{T}_{II}+p\mathbb{T}_I \leq 1-\tfrac{c}{D}. \end{aligned}$$

A.2 Proofs

Proof of lemma 1: The values of Φ are obtained by direct evaluation while the existence and uniqueness of the minimum is obtained by looking at the derivative of Φ:

$$\Phi'(\pi)=f(\pi|e_L)[p\frac{f(\pi|e_H)}{f(\pi|e_L)}-1].$$

As the likelihood ratio integrates to one (with respect to $f(\pi|e_L)$) and is monotone, Φ has at most one sign change (from negative to positive). As the likelihood ratio is increasing it starts off negative so that the minimum of Φ is either in the interior of $[0,1]$ or at $\pi=1$. Uniqueness comes from the differentiability of f. ■

Proof of Proposition 2: The level $c_{\max}$ is determined as the solution to $\Phi(\pi_{\min})=1-\frac{c_{\max}}{D}$. For $c>c_{\max}$, for all $\pi\in[0,1]$, $\Phi(\pi)>1-\frac{c}{D}$ so that it is not possible to induce high care. For $c\leq c_{\max}$, let $\mathbb{H}(c)$ be the set of π that satisfy the incentive compatibility contraint for a given c. The set $\mathbb{H}(c)$ is a closed interval such that for all $\pi\in\mathbb{H}(c)$, $\Phi(c)\leq 1-\frac{c}{D}$, and the minimum of $\mathbb{H}(c)=\Phi_{\mathbb{D}}^{-1}\left(1-\frac{c}{D}\right)$. As $\Phi_{\mathbb{D}}$ is decreasing and $1-\frac{c}{D}$ is decreasing in c , $\Phi_{\mathbb{D}}^{-1}$ is increasing in c. Also, as $\Phi'(1)\neq 0$, if $c<c_{\max}$, $H(c)$ is a non-singleton set so that $\min H(c)<1$. ■

Proof of Lemma 3: We include the proof for completeness. Let $F_{\delta'}(\pi'_{\delta'}|e_H) = \alpha = F_\delta(\pi_\delta|e_H)$. By the definition of Lehmann informativeness

$$\begin{aligned} F_\delta^{-1}(F_{\delta'}(q|e_H)|e_H) &\geq F_\delta^{-1}(F_{\delta'}(q|e_L)|e_L) \; \forall q \\ \Rightarrow F_\delta^{-1}(F_{\delta'}(\pi'_{\delta'}|e_H)|e_H) &\geq F_\delta^{-1}(F_{\delta'}(\pi'_{\delta'}|e_L)|e_L). \end{aligned}$$

Using $F_{\delta'}(\pi'_{\delta'}|\bar{e}) = \alpha$, the LHS is equal to

$$F_\delta^{-1}(\alpha|e_H) = \pi_\delta.$$

Applying the mononote transformation $F_\delta(\cdot|e_L)$ on both sides of the inequality, we obtain,

$$F_\delta(\pi_\delta|e_L) \geq F_{\delta'}(\pi'_{\delta'}|e_L)$$

$$1 - F_\delta(\pi_\delta|e_L) \leq 1 - F_{\delta'}(\pi'_{\delta'}|e_L)$$

$$\mathbb{T}_{II}(\pi_\delta) \leq \mathbb{T}_{II}(\pi'_{\delta'}).$$

■

Proof of Proposition 3: Let π_δ be the standard with technology δ that is as harsh as $\bar{\pi}^*_{\delta'}$ with technology δ'. By Lemma (Lehmann) above

$$\Phi_\delta(\pi_\delta) \leq \Phi_{\delta'}(\bar{\pi}^*_{\delta'}).$$

As $1 - \frac{c}{D} = \Phi_\delta(\bar{\pi}^*_\delta) = \Phi_{\delta'}\left(\bar{\pi}^*_{\delta'}\right) \geq \Phi_\delta(\pi_\delta)$ and $\Phi_{\mathbb{D}}$ is decreasing then $\bar{\pi}^*_\delta \leq \pi_\delta$ and $\mathbb{T}_I(\bar{\pi}^*_\delta) \leq \mathbb{T}_I(\pi_\delta) = \mathbb{T}_I\left(\bar{\pi}^*_{\delta'}\right)$. ■

Lemma 9 *For any two standards, π and π', under technologies δ and δ' respectively, such that $\bar{c}(\pi) = \bar{c}(\pi')$ and $\mathbb{T}_I(\pi) < \mathbb{T}_I(\pi')$ then $W(\pi;\delta) \geq W(\pi';\delta')$.*

Proof of Lemma 9: For any two π, π' such that $\bar{c}(\pi) = \bar{c}(\pi')$

$$p\mathbb{T}_I(\pi) + \mathbb{T}_{II}(\pi) = p\mathbb{T}_I\left(\pi'\right) + \mathbb{T}_{II}\left(\pi'\right).$$

Let $f(x) = W\left(c, x, 1 - \frac{c}{D} - px\right)$ so that

$$\begin{aligned} f(\mathbb{T}_I(\pi)) &= W(c, \mathbb{T}_I(\pi), \mathbb{T}_{II}(\pi)) \\ f\left(\mathbb{T}_I\left(\pi'\right)\right) &= W\left(c, \mathbb{T}_I\left(\pi'\right), \mathbb{T}_{II}\left(\pi'\right)\right). \end{aligned}$$

Using

$$f(x) - f\left(x'\right) = \int_{x'}^{x} f'(y)\,dy$$

we can write

$$f\left(\mathbb{T}_I\left(\pi'\right)\right)-f\left(\mathbb{T}_I\left(\pi\right)\right)=\int_{\mathbb{T}_I(\pi)}^{\mathbb{T}_I(\pi')} f'\left(x\right)dx$$

Using

$$f'\left(x\right)=\frac{\partial W}{\partial \mathbb{T}_I}-p\frac{\partial W}{\partial \mathbb{T}_{II}},$$

the regularity condition

$$\left|\frac{\partial W}{\partial \mathbb{T}_I}\right|\geq\left|\frac{\partial W}{\partial \mathbb{T}_{II}}\right|>p\left|\frac{\partial W}{\partial \mathbb{T}_{II}}\right|$$

implies

$$f'\left(x\right)<0$$

and hence

$$\begin{aligned} & f\left(\mathbb{T}_I\left(\pi'\right)\right)-f\left(\mathbb{T}_I\left(\pi\right)\right) && < && 0 \\ \iff & W\left(c,\mathbb{T}_I\left(\pi'\right),\mathbb{T}_{II}\left(\pi'\right)\right) && < && W\left(c,\mathbb{T}_I\left(\pi\right),\mathbb{T}_{II}\left(\pi\right)\right). \end{aligned}$$

■

Proof of Proposition 5: Let π^* be the optimal standard with technology δ' and c^*, $\mathbb{T}_I^*$, and $\mathbb{T}_{II}^*$, the corresponding amount of care, Type I error and Type II error respectively.

We proceed by (i) identifying the standard (π_1) with the same Type I error that generates more welfare and more activity (c_1) , (ii) identify the standard (π_2) that with the same level of activity and less Type I error also provides more welfare, and (iii) show that for all $\pi \in [\pi_2, \pi_1]$ you can get more welfare (with less Type I error and more activity).

(i) An increase in the informativeness of the technology implies that it is possible to set a standard with technology δ $\pi_{1\delta}$ that keeps the same harshness ($\mathbb{T}_I^*$) and lowers the Type II error ($\mathbb{T}_{1II} \leq \mathbb{T}_{II}^*$). Applying the characterization in the statement, and using Lemma 3, this standard generates a lower weighted cost of error. Thus, the corresponding cutoff level of care cost is greater ($c_1 \geq c^*$) and these two effects together lead to an increase in welfare:

$$W\left(\pi_1\right)=W\left(c_1,\mathbb{T}_I^*,\mathbb{T}_{1II}\right)\geq W\left(c^*,\mathbb{T}_I^*,\mathbb{T}_{II}^*\right)=W\left(\pi^*\right).$$

We assume $\pi_1 \in \mathbb{D}$. If not, then the shape of Φ_δ implies there is a $\pi_1' \in \mathbb{D}$ such that $\Phi_\delta\left(\pi_1'\right) = \Phi_\delta\left(\pi_1\right) = 1-\frac{c_1}{D}$. By Lemma 9 $W\left(\pi_1'\right) \geq W\left(\pi_1'\right) \geq W\left(\pi^*\right)$, and we proceed using π_1' instead of π_1.

(ii) Similarly, it is posible to set a standard that maintains the same level of activity, c^*. This activity can be achieved by a standard π_2 that solves $\Phi_{\delta,\mathbb{D}}\left(\pi_2\right) = 1-\frac{c^*}{D}$. The greater informativeness of δ means that π_2 can be found so that it has lower Type I error–and hence Type II error has to be higher ($\mathbb{T}_{2I} \leq \mathbb{T}_I^*, \mathbb{T}_{2II} \geq \mathbb{T}_{II}^*$). Note that this standard π_2 is also less harsh that π_1 and $c_2 \leq c_1$, $\mathbb{T}_{2I} \leq \mathbb{T}_{1I}$, and $\mathbb{T}_{2II} \geq \mathbb{T}_{2II}$. By Lemma 9 welfare has increased $W(\pi_2) \geq W(\pi^*)$.

(iii) Let $\hat{\pi} \in [\pi_2, \pi_1] \subset \mathbb{D}$, and let c be the corresponding care level $1 - \frac{c}{D} = \Phi_\delta(\hat{\pi})$. As $\Phi_{\delta\mathbb{D}}$ is continous and decreasing, $c \in [c^*, c_1]$.

Consider evaluating the welfare function at $\left(c, \mathbb{T}_I^*, 1 - \frac{c}{D} - p\mathbb{T}_I^*\right)$ even though $\mathbb{T}_I^*$ and $\mathbb{T}_{II} = 1 - \frac{c}{D} - p\mathbb{T}_I^*$ are not implied by the standard $\hat{\pi}$. By the monotonicity properties of W

$$W\left(c_1, \mathbb{T}_I^*, 1 - \frac{c_1}{D} - p\mathbb{T}_I^*\right) \geq W\left(c, \mathbb{T}_I^*, 1 - \frac{c}{D} - p\mathbb{T}_I^*\right) \geq W\left(c^*, \mathbb{T}_I^*, 1 - \frac{c^*}{D} - p\mathbb{T}_I^*\right).$$

If we now compare $W\left(c, \mathbb{T}_I^*, 1 - \frac{c}{D} - p\mathbb{T}_I^*\right)$ with the welfare obtained using the errors implied by $\hat{\pi}$, using $\mathbb{T}_I(\hat{\pi}) \leq \mathbb{T}_I(\pi_1)$ and Lemma 9

$$W(c, \mathbb{T}_I(\hat{\pi}), \mathbb{T}_{II}(\hat{\pi})) \geq W\left(c, \mathbb{T}_I^*, 1 - \frac{c}{D} - p\mathbb{T}_I^*\right).$$

■

Proof that signals in parametric example are Lehmann ordered: The characterization in Ganuza and Penalva (2010) we use is that for signals ordered in terms of supermodular precision with equal priors. Given that in the dichotomous setting supermodular precision implies integral precision, which in turn is equivalent to Blackwell sufficiency, which in turn implies Lehmann (see Ganuza and Penalva (2010) for definitions and details), as our example has supermodular ordered signals, they are also Lehmann ordered.

It is straight forward to see that for all δ and with equal priors, the marginal distribution of the signals is uniform:

$$\begin{aligned} p(\pi) &= \frac{1}{2} f(\pi | e_L) + \frac{1}{2} f(\pi | e_H) \\ &= \frac{1}{2}\left(1 + \frac{\delta}{2} - \delta\pi\right) + \frac{1}{2}\left(1 - \frac{\delta}{2} + \delta\pi\right) = 1. \end{aligned}$$

Then, for $\delta > \delta'$ to show that the signals are ordered in terms of supermodular precision it suffices (Penalva and Ganuza 2010, Prop 3.ii) to show $f_\delta(\pi | e_H) - f_{\delta'}(\pi | e_H)$ is nondecreasing in π:

$$\begin{aligned} & 1 - \frac{\delta}{2} + \delta\pi - \left(1 - \frac{\delta'}{2} + \delta'\pi\right) \\ =& \frac{1}{2}\left(\delta - \delta'\right) + \pi\left(\delta - \delta'\right). \end{aligned}$$

■

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