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Insolvency and Biased Standards - The Case for Proportional Liability

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Insolvency and Biased Standards - The Case for Proportional Liability*

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Abstract

We analyze liability rules in a setting where injurers are potentially insolvent and where negligence standards may deviate from the socially optimal level. We show that proportional liability, which sets the measure of damages equal to the harm multiplied by the probability that it was caused by an injurer's negligence, is preferable to other existing negligence-based rules. Moreover, proportional liability outperforms strict liability if the standard of due care is not set too low. Our analysis also suggests that courts should rely on statistical evidence and bar individualized causal claims that link the harm suffered by a plaintiff to the actions of the defendant. Finally, we provide a result which might be useful to regulators when calculating minimum capital requirements or minimum mandatory insurance for different industries.

Keywords: judgment proof problem, uncertain causation, court error and misperception, proportional liability, disgorgement.

JEL-Classification: K13.

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1 Introduction

We analyze how different liability rules perform in the presence of two sources of inefficiency. First, some injurers may be insolvent due to limited liability or because their assets are insufficient to satisfy a judgment against them (the "judgment proof problem"). Second, courts may err in determining whether an injurer acted negligently, for example, because of hindsight bias. Although access to expert witnesses may reduce the occurrence of court errors and certain legal strategies (such as mandatory insurance, minimum capital requirements, and veil piercing) can mitigate the judgment proof problem, both problems continue to pervade areas such as environmental torts and medical malpractice.[1] In light of these issues, it is important to evaluate whether certain liability rules are better suited than others to induce socially efficient behavior.

It has been frequently argued in the literature that negligence is more robust against the judgment proof problem than is strict liability (Shavell, 1986; Craswell and Calfee, 1987, Landes and Posner, 1987) but also more vulnerable to court errors in determining the standard of due care (Shavell, 1987, p. 79ff; Cooter, 1991). However, as Grady (1983) and Kahan (1989) point out, these results hinge on the notion that the scope of liability under the negligence rule is unrestricted; that is, a negligent injurer is liable for all harm done, including the harm that would have occurred even if the injurer had taken due care. They argue that this regime, known as *full liability*, does not correspond to actual law since the scope of liability is legally restricted by the requirement that harm was actually *caused* by the injurer's negligence. Therefore, an injurer is not liable for harm that would still have occurred even if the injurer had taken due care. Grady (1983) and Kahan (1989) showed that a negligence rule with a restricted scope of liability, referred to as *threshold liability*, is neither robust against the judgment proof problem nor vulnerable to setting the due care standard above the socially optimal care level.

[1] Kornhauser and Levesz (1990) point to the problem that the strict liability rule under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is likely to drive some injurers into bankruptcy.

While, as a matter of legal doctrine, the causation requirement should be taken into account, courts often do not apply it in situations of uncertain causation (see, e.g., Shavell, 2004, p. 253, n. 36). Instead, if harm materializes and the injurer is negligent, courts will often award full damages if they cannot *rule out* that the harm was caused by the injurer's negligence. For example, if negligence increases the probability of harm from 20% to 50%, the probability that the harm was caused by the negligence is 60% ((50%-20%)/50%). Then, given a preponderance of the evidence standard, the court can decide that it is more likely than not that the harm was caused by the negligence. It can consequently hold the injurer fully liable. A more controversial example is the case where the probability of an accident increases from 40% to 50%. Here, the ex-post probability of causation would be 20% (50%-40%)/50%), i.e., it is more likely than not that the harm was *not* caused by the injurer. Hence, under a preponderance of the evidence rule, the injurer would not be liable and there would not be any incentives for the injurer to take care. However, it is not clear that courts actually make decisions in this way. There is evidence that courts only require proof up to a given evidence standard that the injurer's negligence caused the *probability* of harm to increase.[2] If this can be established - normally a straightforward task - all damages are granted (full liability). To the same effect, the German Federal Court (BGH) shifts the burden of proof to the injurer, if it can be established that he acted with gross negligence. He then has to prove *beyond a reasonable doubt* that his negligence did not cause the harm.[3]

Moreover, threshold liability, as formalized by Kahan (1989), implicitly assumes that, ex

[2]In *Evers v. Dollinger, 95 N.J. 399 (1984)*, the Supreme Court held that, in the context of a claim of medical malpractice, when there is evidence that the defendant's negligence increased the risk of harm to the plaintiff and that the harm was in fact sustained, it becomes a jury question whether or not the *increased risk* constituted a *substantial factor* in producing the injury. The Court determined that a less onerous burden of establishing causation should be applied. See also *Hake v. Manchester Tp., 98 N.J. 302 (1985)*; *Scafidi v. Seiler, 225 N.J. Super. 576 (App.Div.1988)*; *Battista v. Olson, 213 N.J. Super. 137 (App.Div.1986)*; *Gaido v. Weiser, 227 N.J. Super. 175 (App.Div.1988)*. Both *Dubak v. Burdette Tomlin Memorial Hosp., 233 N.J. Super. 441, 450-452 (App.Div.1989)* and *Zuchowicz v. United States, 140 F.3d 381 (U.S. Court of Appeals for the Second Circuit, 1998)* contain very insightful discussions of increased risk/substantial factor theory. In *King v. Burlington Northern Santa Fe Ry. Co. 277 Neb. 203, 762 N.W.2d 24 Neb.,2009* the Court, suggests that any positive association that could reasonably support a causal inference could be sufficient to send a case to a jury. See also Grechenig and Stremitzer (2009) for a survey of court practice across jurisdictions.

[3]See Stoll, 1976, pp. 145, 155ff and Wagner (2004).

post, courts can verify with certainty whether or not the harm was caused by the negligence of the injurer. Therefore threshold liability cannot be applied to situations of uncertain causation.[4] However, it is possible to account for the causation requirement in a *probabilistic* way. Many scholars have proposed a negligence rule under which the negligent injurer would be liable whenever an accident occurs but the liability would be proportional to the probability of causation.[5] This has become known in the literature as *proportional liability* and has been applied by courts in particular in cases of "market share liability"[6] and in cases in which plaintiffs are "indeterminate".[7] Indeed, as Schweizer (2009) shows, proportional liability follows from applying the causation requirement analyzed by Kahan (1989) to situations of uncertainty about causation.[8]

The main result of our paper is that proportional liability outperforms other existing negligence-based rules in a setting where injurers are potentially judgment proof and courts make errors in determining the standard of due care. Moreover, we demonstrate that proportional liability is preferable to strict liability if the standard of due care is set equal to or above the socially optimal level (which is the case than concerns most commentators). When the due care standard is set below the socially optimal level, the relative performance of the two rules is ambiguous. Yet, proportional liability is still likely to outperform strict liability if the deviation from the socially optimal care level is not too big.[9] The intuition for these results is that proportional liability combines the best of two rules: In contrast to threshold liability, proportional liability is as robust against the judgment proof problem as

[4] Kahan (1989) discusses the case of uncertain causation and considers an all-or-nothing rule in combination with a preponderance of the evidence standard of proof. We will not analyze such a rule since it does not achieve socially efficient behavior even if the standard of due care is set at the socially optimal care and injurers are solvent (see Kahan, 1989, pp. 440-41; Shavell, 1987, Proposition 1, pp. 592-593).

[5] See e.g. Landes and Posner (1983), Rosenberg (1984), and Shavell (1985).

[6] See e.g. *Sindell v. Abbott Laboratories, 26 Cal.3d 588, 607 P.2d 924, 163 Cal.Rptr. 132 (1980).*

[7] This is the case where the harm – for example cancer – can be "caused" by a particular substance, but where it is impossible to pinpoint which particular person's cancer would have occurred naturally and which would not have occurred but for exposure to the substance (see the famous case In Re *"Agent Orange" Product Liability Litigation, 597 F. Supp. 740 (E.D.N.Y. 1984).*)

[8] This is true if we rule out that harm can be prevented precisely because the injurer was negligent.

[9] That is, ruling out extreme assumptions about the precaution technology and the distribution of wealth across potential injurers.

full liability if the due care standard is set at or below the socially optimal level of care.[10] At the same time, in contrast to full liability, proportional liability preserves the robustness of threshold liability to setting the due care standard above socially optimal care. Not only does proportional liability prevent overinvestment in care, but it also generates less underinvestment in care at low levels of wealth constraints than under full liability. Therefore, a regime which imposes *less* liability on injurers actually *reduces* the underinvestment in care if courts set the standard of due care higher than the socially optimal level.[11] Yet, even under proportional liability, an overly high standard of care remains costly (albeit less costly than under full liability). So, courts should still worry about hindsight bias.

We also present an interesting policy implication about the value of accuracy in adjudication (see Kaplow, 1994). Rose-Ackerman (1990) has previously argued that courts should rely on statistical evidence and forbid individualized causal claims in market-share liability cases because such information does not improve welfare. Therefore, efforts to link the harm suffered by a plaintiff to the actions of a particular defendant only wastes resources. Our analysis suggests that such evidence should be barred even if information on causation is available *without cost*. Finally, we show that the minimum wealth level for which first-best care levels can be induced has an intuitive meaning and can be calculated easily. This finding could be useful to inform legislators who wish to set minimum capital requirements or mandatory insurance provisions for different industries.

To the best of our knowledge, our paper is the first to analyze the effects of wealth constraints on the performance of proportional liability (and disgorgement liability) and to focus explicitly on the interaction of the judgment proof problem with the possibility of court error. However, the paper is related to a larger literature analyzing the effect of the judgment proof problem on the incentives created under different liability rules. Shavell (1986) analyzes

[10]This might be surprising, as one would expect that proportional liability performs better than full liability as the wealth constraint binds more often under full liability than under proportional liability. The reason this is not the case is that both rules cause injurers to pay more than is necessary to induce the efficient care level. As long as the wealth constraint just eats away the slack for deterrence purposes it does not matter. As soon as it starts to matter, it does so for both rules alike.

[11]This is in the same vein as Ganuza and Gomez (2008) but otherwise a different story.

the effects of the judgment proof problem with respect to full and strict liability. Kahan (1989) explores how wealth constraints affect threshold liability. Closest to our analysis are Kornhauser and Levesz (1990) and Landes (1990) who analyze how the relative efficiency of rules for imposing liability and apportioning damages among joint tortfeasors is affected by the potential insolvency of some of the actors. Yet, the driving force in their models is the effect of different rules on the strategic interaction among joint tortfeasors, which is absent from our paper as we are only concerned with a single injurer. Moreover, those papers assume that the standard of due care is set at the socially efficient level, while the present paper also considers the consequences of the judgment proof problem if the standard of due care is set at socially inefficient levels.[12]

Our paper is organized as follows: Section 2 sets up the model and derives a few useful benchmarks. Section 3 describes the different negligence-based liability rules and derives results about their relative performance in the presence of wealth constraints when the due care standard is set equal to the socially optimal level of care. Sections 4 and 5 analyze the cases where the standard of due care is set higher or lower than the socially optimal level of care. Section 6 concludes.

2 Model

We consider a unilateral accident model with two risk-neutral parties: an injurer and a victim. The injurer undertakes a dangerous activity and chooses a level of care $x \in R_0^+$. Subsequently, with a probability of $p(x) \in [0,1]$, the victim suffers harm $h \in R^+$, where $p(\cdot)$ is a decreasing and twice differentiable convex function in x. To guarantee an interior solution to the social welfare problem, assume that $p'(0) = -\infty$ and $p'(\infty) = 0$. We assume

[12] In a recent paper, Leshem and Miller (2009) compare full liability and proportional liability in a model of costly litigation. They recommend full liability on the ground that it leads to higher rates of compliance (conceding that it will also lead to higher rates of litigation and therefore to higher litigation cost). Yet, compliance is only unambiguously welfare increasing if it is assumed that courts set the standard of due care at the socially optimal level. Hence, they implicitly rule out the possibility of systematic court error. As they also assume solvent injurers, the two main ingredients of our model, court error and the judgment proof problem, are absent from their analysis.

care to be non-monetary in nature but to have an opportunity cost of x.[13] The injurer's wealth is $w \in R_0^+$. In the remainder of this section, we derive a few useful benchmarks:

Social optimum. The social cost of engaging in the activity can be written as the sum of the cost of care and the expected harm, $x + p(x)h$. The care level, x^*, which minimizes social cost is therefore implicitly given by the following first order condition:

$$1 + p'(x^*)\, h = 0. \tag{1}$$

Throughout the care level satisfying (1) will be referred to as the socially optimal level of care.

No liability. Absent institutional arrangements, the injurer incurs the entire cost of care but bears neither harm nor liability. He will therefore exercise no care at all, regardless of his level of wealth. This is clearly inefficient.

Strict liability. Alternatively, if the injurer is strictly liable in the case of an accident, he will have to pay for all harm, unless he is judgment proof and therefore pays only his wealth, w. Hence, he will minimize his expected costs, $x+p(x)\min[h,w]$, by choosing socially optimal care x^* if $w \geq h$. However, if the wealth constraint binds, $w < h$, he will choose $\tilde{x}(w)$, which satisfies the following first-order-condition:

$$1 + p'(\tilde{x}(w))\, w = 0. \tag{2}$$

It follows from the convexity of $p(x)$ that $\tilde{x}(w) < x^*$, i.e., strict liability induces wealth-constrained injurers to exercise positive yet inefficiently low care (see Shavell, 1986).

Moreover, the lesser the wealth, the lower the level of care and the expected costs of the

[13] One could interpret x as the cost of effort that can be evaluated in monetary terms but does not reduce the wealth constraint. Alternatively, one could think of x as an investment that is made in an asset which is subsequently transferred to a limited liability company. The value of the asset would then determine the wealth constraint. The assumption is the same as in Shavell (1986).

injurer; that is:[14]

$$\frac{d\tilde{x}(w)}{dw} = -\frac{p'(\tilde{x}(w))}{p''(\tilde{x}(w))} > 0, \text{ and } \frac{d[\tilde{x}(w) + p(\tilde{x}(w))w]}{dw} = p(\tilde{x}(w)) > 0. \tag{3}$$

3 Negligence and causation

3.1 Full-liability

As a matter of legal doctrine, injurers under a negligence rule are liable for damages if two conditions are met. First, the injurer must have acted negligently, i.e., exercised less than due care, $\bar{x}$. Second, the injurer's negligence must have *caused* the accident, i.e., without his negligence, the accident would not have occurred.[15] However, standard accident models have usually disregarded the causation requirement and implicitly assumed that the injurer, if found negligent, must compensate the victim for all the harm done whenever an accident occurs. This has become known as the "full liability" regime. Some scholars (e.g., Shavell, 2004, p. 253, n. 36) argue that courts often do not apply the causation requirement in situations where the cause of the accident is not known with certainty ex-post. Instead, courts will often award full liability if they cannot *rule out* that the harm (or accident) was caused by negligence. Given that uncertain causation is the rule rather than the exception, "full liability" seems to fit real world behavior of courts in a very relevant class of cases. Under full liability, negligent injurers are liable to compensate the victim for h. However, if the wealth constraint binds, $w < h$, the injurer is judgment proof and accordingly only pays w. Therefore, the injurer's liability is equal to $D = \min[h, w]$, and his expected cost can be written as:

$$J_F(x) = \begin{cases} x & x \geq \bar{x} \\ x + p(x)h & x < \bar{x} \wedge w \geq h \\ x + p(x)\,w & x < \bar{x} \wedge w < h. \end{cases} \tag{4}$$

The following lemma restates Shavell's result (Proposition 1 of Shavell, 1986).

[14] In the following we will sometimes write $\tilde{x}$ for $\tilde{x}(w)$.

[15] In this paper, acting negligently means exercising less than "due care" as determined by whoever sets the standard, regardless of whether it is determined efficiently.

Lemma 1 *Full liability: If due care is set at the socially optimal level of care,* $\bar{x} = x^*$*, full liability induces the injurer to exercise socially optimal care* x^**if his wealth is greater than or equal to a cut-off value* $\bar{w} < h$*. Otherwise, the injurer behaves as if he is strictly liable and exercises too little care* $\tilde{x}(w) < x^*$*. The cut-off value* $\bar{w}$ *is implicitly defined by* $x^* = \tilde{x}(\bar{w}) + p(\tilde{x}(\bar{w}))\bar{w}$*.*

Proof. See Shavell (1986) or, for convenience, Appendix A. ■

The explanation of Lemma 1 hinges on the discontinuity of the injurer's cost function at due care equal to socially optimal care. This discontinuity follows because the injurer does not incur any liability if he exercises due care but is liable for the entire harm (including the harm which would have occurred if he had exercised due care) if found negligent. Liability is therefore higher than is necessary for inducing socially optimal care, which makes full liability, to a certain extent, robust towards judgment proofness and other possible imperfections. While Lemma 1 defines the cut-off value $\overline{w}$ only implicitly, we will show in section 3.5 that it has an intuitive meaning and can be easily calculated.

3.2 Certain causation - threshold liability

While full liability practically ignores the legal requirement of causation, threshold liability, as first discussed by Grady (1983) and elaborated and formalized by Kahan (1989), incorporates the legal doctrine of causation in situations of *certain* causation. Under threshold liability, the injurer is liable for damages if he acted negligently *and* if his negligence caused the accident. The legal doctrine of causation excludes from the scope of liability accidents that would have occurred even if the injurer had not been negligent. To illustrate this regime take the example by Kahan (1989) of the owner of a cricket ground who is legally required to have a fence 10 ft tall but only builds a fence 9 ft tall. Kahan argues the cricket ground owner is liable if a ball crosses the fence between 9 and 10 ft high and causes harm but not if the ball crosses the fence above 10 ft. This is because, in the latter case, harm is not *caused* by the owner's deviation from due care. More generally, under threshold liability, if an accident has occurred and the injurer exercised less than due care, he will only be liable with probability

$$\pi(x) \equiv \frac{p(x) - p(\bar{x})}{p(x)}, \tag{5}$$

which reflects the probability of causation (see, e.g., Ben-Shahar, 1999, p.651; Tabbach, 2008). The amount of damages under threshold liability, however, is the same as the amount of damages under full or strict liability. This means that the injurer pays h unless he is judgment proof and then only pays w. His expected cost function can be written as:

$$J_T(x) = \begin{cases} x & \text{if } x \geq \bar{x} \\ x + p(x)\pi(x)h & \text{if } x < \bar{x} \wedge w \geq h \\ x + p(x)\pi(x)w & \text{if } x < \bar{x} \wedge w < h. \end{cases} \tag{6}$$

3.3 Uncertain causation - proportional liability

Following Kahan (1989), we have so far implicitly assumed that the court can verify with certainty at which height the cricket ball which caused harm crossed the fence. Most of the time, however, the court would only observe that a cricket ball crossed the fence and know from experience that this happens less often if the fence is higher. If the data is really good the court would know at which probability the balls cross the fence depending on its height. Yet, in these cases, it is no longer possible to say with certainty what would have happened if the injurer had exercised due care. In these cases, threshold liability can no longer be applied.[16]

As argued above, in situations of uncertain causation courts often award full damages putting the burden of the uncertainty on the negligent injurer. Alternatively, courts may find the injurer liable if it is more likely than not that his negligence caused the harm.[17] Yet, there is a third alternative, commonly referred to as "proportional liability", which is occasionally applied by courts in situations of uncertain causation.

[16] Threshold liability as formulated in this paper can be applied to situations of uncertain causation in the following way. Suppose that in the face of uncertainty over causation the courts or juries would toss an appropriate coin reflecting the probability of causation $\pi(x) \equiv \frac{p(x)-p(\bar{x})}{p(x)}$ and the probability of non-causation $1 - \pi(x)$ and would find the injurer liable in the relevant case. We would like to thank Jacob Nussim for offering us this interpretation of threshold liability.

[17] Rules in which the probability threshold required to impose liability is $x \in [0, 1]$ were analyzed, for example, by Shavell (1985) and shown to induce socially non-optimal care even in the absence of wealth constraints. We therefore do not analyze these rules in the present paper.

Under proportional liability, a negligent injurer is always liable if an accident occurs, but he is only liable for damages that equal the harm discounted by the probability

$$\pi(x) \equiv \frac{p(x) - p(\bar{x})}{p(x)} \tag{7}$$

that the harm was caused by his negligence.[18] A negligent injurer will therefore be liable for damages of $\pi(x)\,h$ which are less than harm. Since damages will be paid in full only if the injurer has sufficient wealth, $w \geq \pi(x)\,h$, his expected cost function is:

$$J_P(x) = \begin{cases} x & \text{if } x \geq \bar{x} \\ x + p(x)\pi(x)h & \text{if } x < \bar{x} \wedge w \geq \pi(x)\,h \\ x + p(x)\,w & \text{if } x < \bar{x} \wedge w < \pi(x)\,h. \end{cases} \tag{8}$$

Note that if the injurer's wealth is greater than harm, $w \geq h$, it follows from expressions (6) and (8) that the injurer's *expected liability* is the same under both threshold and proportional liability. However, if the injurer's wealth is in the interval $w \in (\pi(x)\,h,\ h)$, the wealth constraint binds under threshold liability but not under proportional liability. Hence, the injurer's expected payoffs under threshold and proportional liability coincide in the absence of wealth constraints but are otherwise different. This difference stems from the assumption that, under threshold liability, the level of damages is a *binary* variable equal either to h or 0, depending on whether the accident was caused by negligence or not. In contrast, under proportional liability, the injurer is always liable for damages, but damages are given by a continuous variable equal to $\pi(x)h \in (0, h)$.

3.4 Robustness towards judgment proofness

The difference between threshold and proportional liability that we have just identified plays an important role in the relative performance of these two liability rules in the presence of wealth constraints. In addition, these two liability rules have close connections to strict and full liability as stated in the following proposition.

[18] The probability of causation can be calculated as in (7) if we rule out the possibility that harm is prevented *because* the injurer fell short of exercising due care. (See Schweizer (2009) for a rigorous treatment of the application of the causation requirement under uncertainty.) Given this assumption, the causation requirement is equivalent to the rule of proportional liability as proposed by Shavell (1985) and others. This rule exactly internalizes the consequences of deviating from the due care standard.

Proposition 1 *If due care is set at socially optimal care, then for all wealth levels (1) threshold liability induces the same care as strict liability and (2) proportional liability induces the same care as full liability. This implies that proportional liability dominates threshold liability.*

Proof. Part (1): If the injurer abides by due care, he clearly chooses x^*. Since $x + p(x)\pi(x)h = x + [p(x) - p(x^*)]h$ only differs from $x + p(x)h$ by a constant, $-p(x^*)h$, it follows that x^* which minimizes the latter also minimizes the former expression. Hence, for all $x \neq x^*$, it holds that:

$$x^* = x^* + [p(x^*) - p(x^*)]h < x + [p(x) - p(x^*)]h. \tag{9}$$

Therefore, the injurer will never deviate from x^* if his wealth constraint does not bind. However, if $w < h$, the injurer will deviate from x^* and choose $\tilde{x}(w)$. This follows since, by the definition of $\tilde{x}(w)$ (see expression 2), it holds that:[19] $x^* = x^* + [p(x^*) - p(x^*)]w > \tilde{x} + [p(\tilde{x}) - p(x^*)]w = \tilde{x} + p(\tilde{x})\pi(\tilde{x})w$.

Part (2): If the injurer abides by due care, he will choose x^*. If his wealth constraint does not bind, $w \geq \pi(x)h$, he will never exercise less than due care, as it follows from expression (9) that this cannot be optimal. Hence, the judgment proofness of the injurer, $w < \pi(x)h$, is a necessary condition for acting negligently. Yet, in addition, it must hold that acting negligently is worthwhile for the injurer:

$$\tilde{x} + p(\tilde{x})w < x^* \iff w < \frac{x^* - \tilde{x}}{p(\tilde{x})} \equiv \bar{w}. \tag{10}$$

The value of w implicitly defined by this condition (with equality) is the cut-off value $\bar{w}$ derived in Lemma 1. Condition (10) is also sufficient for the injurer to exercise less than socially optimal care, as $\tilde{x} + p(\tilde{x})w < x^*$ implies that $w < \pi(\tilde{x})h$. To see this, note that it holds that: $\pi(\tilde{x})h - \overline{w} = \pi(\tilde{x})h - \frac{x^* - \tilde{x}}{p(\tilde{x})} = \frac{\tilde{x} + p(\tilde{x})h - [x^* + p(x^*)h]}{p(\tilde{x})} > 0$ by the definition of x^*. ■

The fact that threshold liability is less robust to wealth constraints than full liability has already been hinted at by Kahan (1989, Proposition 4 in the Appendix). Proposition 1 shows

[19] Note that $x + [p(x) - p(x^*)]w$ and $x + p(x)w$ only differ by a constant.

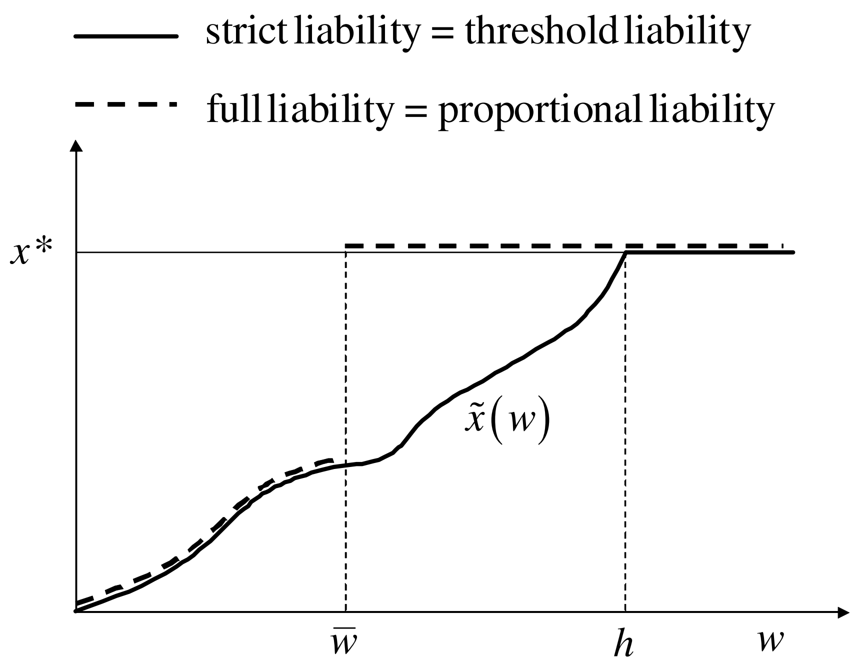

Figure 1: Liability rules if due care is set at the socially optimal care level.

that threshold liability actually performs as poorly as strict liability. Proportional liability, however, which coincides with threshold liability in the absence of wealth constraints, is more robust to the judgment proof problem and actually performs as well as full liability. Figure 1 summarizes these results by depicting the level of care taken by injurers as a function of their wealth under the different liability rules.

3.5 Calculating the cut-off value: disgorgement liability

Proposition 1 states that proportional liability performs the same as full liability over the entire range of wealth constraints. This is puzzling as one might expect proportional liability to outperform full liability since the wealth constraint binds more often under the latter than under the former. The reason why this intuition is wrong is that damages under full and proportional liability are higher than necessary to induce socially optimal care. Therefore, even though judgment proofness lowers the effective level of damages under both rules, it does not impair the performance of these rules as long as it just eats away the portion of damages not needed for deterrence purposes. Judgment proofness starts to matter when it reaches the lower bound of what is necessary to induce socially optimal behavior. But then it matters for both rules alike.

This explanation suggests a method to calculate the cut-off value $\bar{w}$ which is implicitly defined by $\tilde{x}(w) + p(\tilde{x})w = x^*$. As it turns out, this method is closely connected to another liability rule. Consider a negligence-based liability rule which is designed to stipulate damages that are just high enough to make the injurer abide by socially optimal care (or more generally due care). In other words, consider a rule under which, whenever the injurer is judgment proof, he will act negligently. Under such a rule, damages $D(x)$ should for all $x < x^*$ satisfy the condition $x + p(x)D(x) = x^*$, or equivalently:[20]

$$D(x) = \frac{x^* - x}{p(x)}. \tag{11}$$

This rule is referred to as "disgorgement liability" (see, e.g., Polinsky and Shavell, 1992; Arlen, 1992, p. 419). Under disgorgement liability, a negligent injurer is liable if an accident occurs, but the damages he has to pay are equal to the gains he obtains from deviating from the due care standard, $x^* - x$, multiplied by the inverse of the probability of an accident, $p(x)$. Hence, if an accident occurs, a negligent injurer will have to pay $D(x)$ unless his wealth constraint binds, $w < D(x)$, in which case he pays w. His expected payoff can be therefore written as:

$$J_D(x) = \begin{cases} x & \text{if } x \geq x^* \\ x^* & \text{if } x < x^* \wedge w \geq D(x) \\ x + p(x)\,w & \text{if } x < x^* \wedge w < D(x). \end{cases} \tag{12}$$

We can derive the following proposition:

Proposition 2 *Disgorgement liability: If due care is set at socially optimal care, then: (1) for all wealth levels disgorgement liability induces the same care as full and proportional liability; that is, injurers will exercise x^* if $w \geq \bar{w}$, and otherwise they will exercise $\tilde{x}(w) < x^*$. (2) The cut-off value $\bar{w}$ is equal to the highest possible damage payment under disgorgement liability; that is, $\bar{w} = \max_x \frac{x^* - x}{p(x)}$.*

[20] Strictly speaking, to induce the socially optimal care, damages should be a little bit higher than $\frac{x^* - x}{p(x)}$, since otherwise the injurer is indifferent among all $x \in [0, x^*]$. We shall assume that damages are set in order to induce injurers to take due care.

Proof. See Appendix B. ■

Part (1) is straightforward. The explanation of part (2) hinges on the fact that damages under disgorgement liability are designed to make sure that the injurer abides by due care. Therefore, if there existed a care level $\hat{x} < x^*$ which would result in a damage payment that the injurer could not pay in full due to the judgment proof problem, i.e., $D(\hat{x}) > w$, then the injurer could choose $\hat{x}$ and reduce his expected costs compared to x^*, since $\hat{x} + p(\hat{x})w < \hat{x} + p(\hat{x})D(\hat{x}) = x^*$. Therefore, to induce x^* it is necessary that the wealth constraint will not bind for any $x < x^*$. This, in turn, implies that wealth must be at least as high as the highest possible damages payment under disgorgement liability. Proposition 2 provides an intuitive and easy way to calculate the level of wealth for which injurers under full and proportional liability no longer abide by the socially optimal level of care. This could be useful conceptual framework to inform legislators about how to calculate minimum capital requirements or minimum mandatory insurance provisions for different industries.

4 Due care above socially optimal care

So far we have analyzed the effects of wealth constraints under different negligence-based liability rules assuming that due care is set at the socially optimal care. In this part we will analyze the effects of wealth constraints under these negligence liability rules assuming that due care is set above socially optimal care. We will demonstrate that proportional liability outperforms *all* other negligent-based liability rules.

The assumption that due care is set above socially optimal care is realistic. Determining socially optimal care requires a tremendous amount of information. Courts can easily make conceptual mistakes in assessing the costs of precautions, the effectiveness of such precautions in reducing harm, or the amount of harm resulting from accidents. Generally speaking, mistakes need not be biased. However, if courts follow the notion of "better safe than sorry," they will systematically err in setting due care above socially optimal care. Similarly, information costs force courts to set an average, reasonable person standard of care, rather than an individualized standard, tailored to each and every injurer. Thus, due care is set too low for some injurers and too high for others.[21] Finally, a well documented cognitive bias suggests that, with the benefit of hindsight, courts are more likely to consider behavior which caused harm to be negligent (hindsight bias, see, e.g., Camerer et al., 1989).

4.1 Threshold liability

We begin by demonstrating that setting due care above the socially optimal level of care does not alter incentives under threshold liability.

Lemma 2 *Threshold liability: If due care is set above socially optimal care, then injurers behave as if they were strictly liable for all wealth levels.*

Proof. The injurer never exercises more care than $\bar{x}$. If the wealth constraint does not bind $w \geq h$, and the injurer exercises less than $\bar{x}$, the injurer will choose x^*because x^* clearly minimizes $x + [p(x) - p(\bar{x})]\, h$ and, by definition of x^*, $x^* + p(x^*)h < \bar{x} + p(\bar{x})h$ for all $\bar{x} \neq x^*$, so that $x^* + [p(x^*) - p(\bar{x})]\, h < \bar{x}$. If, however, $w < h$, the injurer will choose $\tilde{x}(w)$ since $\tilde{x}(w)$, by definition, minimizes $x + p(x)w$, and hence $\tilde{x} + [p(\tilde{x}) - p(\bar{x})]w < x^* + [p(x^*) - p(\bar{x})]w$. ■

The explanation of Lemma 2 is simple. Threshold liability performs the same as strict liability if due care is set at the socially optimal level of care (see part (1) of Proposition 1). In addition, Kahan (1989) has demonstrated that, without wealth constraints, threshold liability does not distort injurers' incentives even if due care is set above socially optimal care. Since setting the standard of due care above optimal care does not affect the level of wealth for which injurers become insolvent, it follows that injurers will behave as if they were strictly liable.

4.2 Proportional liability

In contrast to threshold liability, the robustness of proportional liability is negatively affected if due care is set above socially optimal care. Nevertheless, proportional liability remains

[21] In the next section we will examine the consequences of setting due care below optimal care under different negligence-based liability rules.

superior to threshold liability.

Lemma 3 *Proportional liability: If due care is set above socially optimal care, then the injurer will exercise* x^* *if his wealth is above or equal to a cut-off value* $\bar{w}_P$. *Otherwise, he will exercise* $\tilde{x}(w) < x^*$. *The cut-off value* $\bar{w}_P$ *is implicitly defined by* $\tilde{x}(\bar{w}_P) + p(\tilde{x}(\bar{w}_P))\bar{w}_P = x^* + [p(x^*) - p(\bar{x})]h$ *and it holds that* $\bar{w} < \bar{w}_P < h$.

Proof. See Appendix C. ■

The formal proof of the lemma is somewhat tedious and therefore relegated to the appendix. Under proportional liability, the injurer can, to a certain extent, *choose* whether he wants to become judgment proof (this happens for $w \in [\pi(x^*)h,\ \pi(\tilde{x})h))$. This is because, by decreasing the level of care, he can increase liability if an accident occurs. It is straightforward to show that the injurer always prefers choosing socially optimal care, x^*, over due care, $\bar{x}$. If wealth is below a cut-off value $\bar{w}_P$, the injurer prefers choosing less than socially optimal care, $\tilde{x}(w)$, and becomes judgment proof instead of choosing x^*. The main challenge is to prove that it cannot be the case that $\bar{w}_P < \pi(x^*)h$. If this were possible, x^* would not be available because of the wealth constraint and it would be impossible to generally derive a preference ordering between $\tilde{x}(w)$ and $\bar{x}$.

The intuition behind Lemma 3 is the following. Setting the standard of due care above the socially optimal care level does not distort the incentives of relatively high wealth injurers because the expected cost function under proportional liability is the same as under threshold liability if the wealth constraint does not bind (i.e., the relevant portion of the injurer's expected cost function has the same shape as under strict liability). On the other hand, setting the standard of due care above the socially optimal level, $\bar{x} > x^*$, increases the expected cost of injurers who take optimal care from $x^*$to $x^* + [p(x^*) - p(\bar{x})]h$ as they are now legally considered to be negligent. This makes it more attractive for some marginal injurers to become judgment proof by choosing the lower care level $\tilde{x}$ rather than the socially optimal care x^*. In other words, the minimum wealth level necessary to implement optimal care increases.

It follows that proportional liability outperforms the threshold rule. Under both rules the induced care level is never distorted upwards (i.e., the injurer always prefer to exercise socially optimal care over due care), but the range of wealth constraints for which the first-best can be induced is larger under proportional liability than threshold liability. However, even under proportional liability the range shrinks as the standard of due care is set above the socially optimal level.

4.3 Full liability

If due care is set above socially optimal care, proportional liability is negatively affected, i.e., the level of wealth required to induce socially optimal care increases. As we will demonstrate now, setting due care above socially optimal care has more damaging consequences for full liability.

Lemma 4 *Full liability: If due care is set above socially optimal care then: (1) If $\bar{x} > x^* + p(x^*)h$, the injurer will behave as if he were strictly liable. (2) If $\bar{x} \in (x^*, x^* + p(x^*)\, h)$, the injurer will take too much care, $\bar{x} > x^*$, if his wealth is above or equal to a cut-off value $\bar{w}_F$. Otherwise, the injurer will take too little care, $\tilde{x}(w)\,(< x^*)$. (3) The cut-off value $\bar{w}_F$ is defined implicitly by $\bar{x} = \tilde{x}(\bar{w}_F) + p(\tilde{x}(\bar{w}_F))\bar{w}_F$, and it holds that $\bar{w}_P < \bar{w}_F < h$.*

Proof. Appendix D. ■

The explanation for the first part of Proposition 4 is straightforward. If the standard of due care is set excessively high, injurers will ignore the standard and therefore will be liable for any harm. Consequently they face the same incentives as under strict liability. The second result is also very intuitive. If the standard of due care is set above socially optimal care (but not too high), relatively wealthy injurers will prefer to abide by the higher standard because they become fully liable for any harm even if they only slightly deviate from the due care standard. This causes their expected cost function to jump down at the level of due care (both part 1 and part 2 of the Proposition restate well well-known results). The intuition for the third result is very similar to the explanation for the last part of Lemma 3.

Increasing the standard of due care makes it more expensive for potential injurers to abide by the due care standard. This makes it more attractive for some marginal injurers to become judgment proof by choosing the lower care level $\tilde{x}$ rather than due care $\bar{x}$. In other words, the minimum wealth level necessary to implement optimal care increases. Moreover, this minimal wealth level increases at a faster rate for full liability than for proportional liability as $1 > p(\bar{x})\, h$ for all $\bar{x} > x^*$.

Therefore, not only does the range of wealth constraints for which the injurer takes too little care increase more than it increases under proportional liability, but incentives are distorted even if the wealth constraint does not bind. Therefore, if due care is set above socially optimal care, proportional liability outperforms full liability.

4.4 Disgorgement liability

Proportional liability also outperforms disgorgement liability as implied in the following lemma:

Lemma 5 *Disgorgement liability: If due care is set above socially optimal care, then the injurer will take too much care, $\bar{x}$ $(> x^*)$ if his wealth is above or equal to a cut-off value $\bar{w}_D (= \bar{w}_F)$. Otherwise the injurer will take too little care, $\tilde{x}(w)$ $(< x^*)$.*

Proof. See Appendix E. ■

The explanation of Lemma 5 is straightforward. If the injurer is not wealth-constrained, $w > \max D(x)$, he will choose to abide by due care, $\bar{x}$, since the expected costs from deviating from due care is equal to $\bar{x}$.[22] The injurer will always decide to deviate from due care and choose $\tilde{x}(w) < \bar{x}$ whenever he is wealth-constrained, i.e., whenever w is less than $\max D(x) = \max \frac{\bar{x}-x}{p(x)}$.

Thus, proportional liability is superior to disgorgement liability on two accounts: first, proportional liability induces the socially optimal care level while disgorgement liability

[22] Lemma 5 holds strictly by assuming that in the case of indifference the injurer chooses to abide by due care. In addition, note that the cut-off value, $\bar{w}_D (= \bar{w}_F)$, is equal to the maximum damages payment under disgorgement liability.

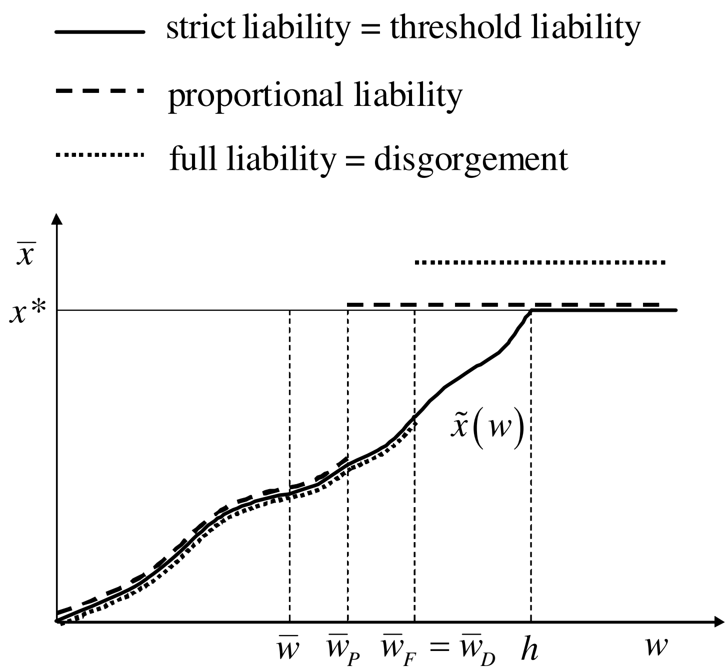

Figure 2: Liability rules under wealth constraints if due care is set above the socially optimal care level, $\bar{x} \in (x^*, x^* + p(x^*)h)$.

induces excessive care; second, the injurer will underinvest in care for a larger range of wealth constraints under disgorgement than under proportional liability as $\bar{w}_D = \bar{w}_F > \bar{w}_P$.

We summarize Lemmas 3 - 5 in the following proposition (see also Figure 2):

Proposition 3 *If due care is set above socially optimal care, then proportional liability dominates strict liability and all other negligence-based liability rules (threshold liability, full liability and disgorgement liability).*

Kahan (1989) has shown that threshold liability has a desirable property compared to full liability as it increases the robustness to setting due care above the socially optimal care level. Proportional liability preserves this desirable property. Absent wealth constraints this is a trivial point, contained in Proposition 2 of Kahan (1989), since, as we have already demonstrated, proportional liability and threshold liability coincide when wealth constraints are absent. In the presence of wealth constraints, however, proportional liability combines the best of two worlds: It is relatively robust towards the judgment proof problem and even outperforms full liability on this account. Moreover, proportional liability preserves the property to be more robust to court error in setting due care at high levels. However, it is not completely robust because the range of wealth constraints for which the socially optimal care level can be induced shrinks. In any case, in this setting, proportional liability still outperforms all the other negligent-based liability rules.

5 Due care below socially optimal care

To complete the investigation we analyze the consequences of judgment proofness under the different negligence-based liability rules if due care is set below socially optimal care. Since the analysis is similar to the analysis in the previous sections, we will just state the following proposition (see also Figure 3) and leave the proof to Appendix F:

Proposition 4 *If due care is set below socially optimal care, then: (1) Proportional liability, full liability, and disgorgement liability perform the same for all wealth levels. (2) Proportional liability strictly outperforms threshold liability.*

We can see from Figure 3 that the relative performance of proportional liability and strict liability becomes ambiguous when the due care standard is set below the socially optimal level. For injurers with wealth levels between $\bar{w}(\bar{x})$ and $\bar{w}_T$, proportional liability induces better incentives than does strict liability while the opposite holds true between $\bar{w}_T$ and h. Note, however, that the limit of $\bar{w}_T$ as $\bar{x}$ approaches x^* is h while we know from Proposition 1 that $\bar{w}(\bar{x})$ approaches $\bar{w} < h$. Hence, the range from $\bar{w}_T$ to h is small compared to the range from $\bar{w}(\bar{x})$ to $\bar{w}_T$ for relatively modest downward deviations from the standard of due care. Therefore, ruling out extreme assumptions about the precaution technology and the distribution of wealth across potential injurers, proportional liability will still outperform strict liability if the downward deviation from the socially optimal care level is not too big.

Ganuza and Gomez (2008) have argued that, in the presence of wealth constraints, setting due care below socially optimal care is desirable as a second best. This is because, for any injurer who does not abide by due care when it is set at x^*, there exists a more lenient

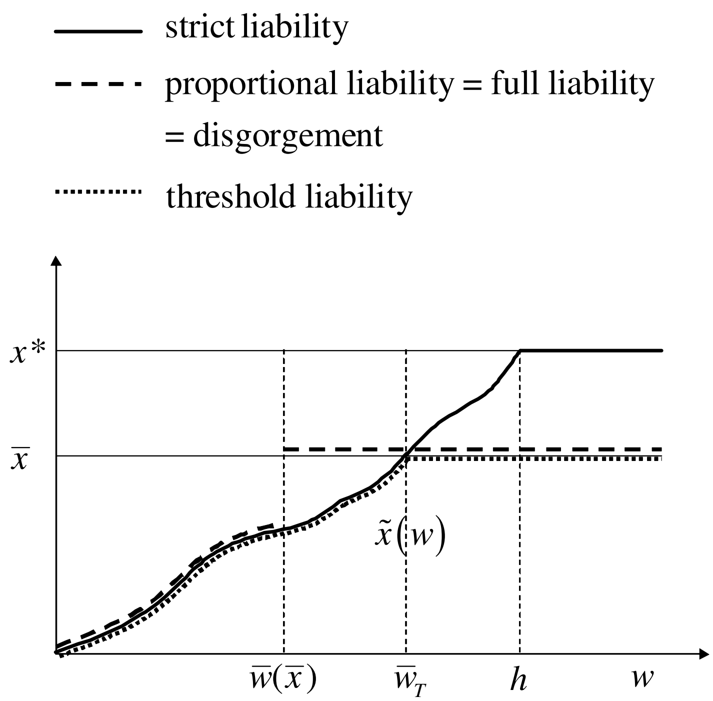

Figure 3: Liability rules under wealth constraints if due care is set below the socially optimal care level.

standard for which the injurer will choose a higher care. Consider an injurer whose wealth satisfies $\tilde{x} + p(\tilde{x})\, w < \bar{x}$. He will not abide by due care and will instead choose $\tilde{x}$. Yet, it is possible to set due care at $\bar{x} \in (\tilde{x},\ \tilde{x} + p(\tilde{x})\, w]$ for which this particular injurer chooses a higher level of care. Hence, there exist distributions of wealth such that a more lenient standard is welfare improving. Dari-Mattiacci (2004), however, argued, that this effect does not occur if the causation requirement is taken into account and the precaution technology is such that only the probability of the harm occurring can be affected. Our analysis suggests that the effect of Ganuza and Gomez (2008) also holds in a setting where care reduces the probability of harm if causation is uncertain and proportional liability is applied. The criticism by Dari-Mattiacci (2004) is only valid under the threshold rule.

6 Concluding remarks

In this paper we analyze how different liability rules perform in the presence of two possible sources of inefficiency: (1) Insolvency and (2) biases in setting the standard of due care. We show that if the due care standard is set at or below the socially optimal care level, proportional liability and full liability perform exactly the same, although under proportional liability the injurer is less likely to be judgment proof. In addition, both rules outperform threshold liability and strict liability. On the other hand, if the standard of due care is set above the socially optimal care level, proportional liability not only outperforms threshold liability, but it also outperforms full liability for two reasons: First, there will not be any distortion for high-wealth injurers under proportional liability. Second, fewer low-wealth injurers will take too little care. Hence, the more injurer-friendly regime induces *less* under-investment in care. We therefore argue that proportional liability is not only a conceptually consistent way of accounting for the causation requirement in situations of uncertain causation, but also an attractive option, relative to other alternatives, from a social welfare perspective.[23] Yet, our analysis demonstrates that even under proportional liability, raising the standard of due care above the socially optimal level is costly. Hence, courts, or whoever sets the standard of due care, should worry about hindsight bias. Although this scenario is of less concern to most commentators, we also show that proportional liability weakly outperforms the other existing negligence rules if the standard of due care is set below the standard of due care. However, the relative performance of proportional liability and strict liability is ambiguous in that case. Still, under plausible assumptions, proportional liability will be preferable to strict liability if the deviation from the socially optimal care level is not too large.

[23] Guido Calabresi and Jeffrey O. Cooper in the their 1995 Monsanto Lecture, published in the Valparaiso University Law Review, Vol. 30. No. 3, decribed the advent of splitting rules, replacing the dominance of all-or-nothing recovery rules, as one of the most important shifts in tort law over the past decades comparable only to the coming of insurance eighty years ago. Calabresi and Cooper deplored that while "splitting rules give us more options, we do not necessarily know whether they create a better package of incentives than existed before" (p. 883). They concluded that a much additional analysis is needed to answer this question. By showing that proportional liability as a prominent example of such a splitting rule has desirable welfare properties, our article contributes to the vast research program outlined in their article.

This paper also provides an intuitive method to calculate the minimum wealth necessary to induce the socially optimal care level. This threshold equals the maximum damage payment under disgorgement liability. The result can inform regulators about how to calculate minimum capital requirements or mandatory insurance provisions in different industries.

Finally, the fact that proportional liability dominates threshold liability presents an interesting policy implication regarding the value of accuracy in adjudication. As explained above, threshold liability and proportional liability account for causation in two different settings. Threshold liability applies to situations of certainty about causation, whereas proportional liability applies to situations of uncertainty about causation. Yet, in many circumstances, the degree of uncertainty may be endogenous as it is possible to invest in more accurate information regarding causation. Indeed, under threshold liability victims (injurers) have incentives to prove (disprove) causation. For example, in Kahan's example of the cricket ground, the owner could install a camera to monitor the fence. Such an investment will increase the number of cases where certainty is indeed achieved. With a camera it would be possible to know at which height the ball crossed the fence (if the crossing took place at a section of the fence within the camera's purview). An interesting question therefore arises about the desirability to spend resources in order to increase the percentage of cases in which causation can be determined with certainty. Our analysis suggests that, in the presence of wealth constraints, it is socially detrimental to invest in proving causation even when that proof is costless because such investment increases the probability that threshold liability will be applied instead of the more efficient proportional liability rule.[24] Hence, it is socially optimal to discourage such investment, for example, by barring the introduction of evidence regarding causation in lawsuits and instead relying on statistical evidence.

We now comment briefly on the simplifying assumptions chosen in this model. First, this paper assumes that injurers as well as victims are risk neutral. This is a common assumption

[24] This differs from the argument by Rose-Ackerman (1990) that individualized causal claims should be discouraged in market-share liability cases because they are worthless and therefore only waste resources. See also Kaplow (1994) for the general argument that the benefits of accuracy be weighed against the cost of achieving it.

in the law and economics literature on torts, which can be justified either if (1) insurance markets are available and the price of insurance is actuarially fair or (2) liability or losses are relatively small when compared to injurers' and victims' assets respectively. However, in certain situations injurers or victims should not be treated as risk neutral but rather as risk averse. Although we do not offer a formal model of this possibility, proportional liability appears to outperform full liability and threshold liability on this account as well. The reason is simple. Compared to all-or-nothing rules (such as full liability and threshold liability), proportional liability has a lower variance of outcomes. Therefore, proportional liability reduces the risk borne by injurers and victims relative to the other negligence regimes.

Second, our model does not account explicitly for administrative costs. The question of which negligence rule is associated with fewer administrative costs is not an easy one however. On the one hand, full liability is simpler to administer than proportional liability because under the latter rule the victim needs to prove causation while under the former he does not. On the other hand, the amount of damages under full liability (and also threshold liability) is larger than under proportional liability, giving injurers and victims greater incentives to spend resources in litigation over the determination of negligence. In any event, proportional liability does not seem to be disadvantaged in comparison to threshold liability. Under both rules the determination of the probability of causation is similar and proportional liability even has the advantage of not requiring causal links to be established on a case by case basis. More importantly, we only propose the application of proportional liability in areas where the necessary data for determining the probability of causation is available. This is the case, for example, in medical malpractice were epidemiological data is often available.[25]

[25] Moreover, encouraging scientific research into the consequences of different modes of action seems to be independently valuable for improving welfare in many other domains in addition to healthcare.

7 Appendix

7.1 Due care at socially optimal level

7.1.1 Appendix A: Full liability

Proof. If the injurer abides by the due care standard he will choose care level x^* as raising care above x^* will only increase costs without reducing the expected liability (see expression 4). If the injurer does not abide by the standard, the care level $\tilde{x}$ which minimizes his expected cost is implicitly given by the following first-order condition:

$$1 + p'(\tilde{x}) \min[h,\ w] = 0. \tag{13}$$

For $w \geq h$, $x^* < x^* + p(x^*) h < \tilde{x} + p(\tilde{x}) h$ for all $\tilde{x} \neq x^*$(see expression 1), so the injurer will choose x^* for $w \geq h$. If $w < h$, expression (13) becomes

$$1 + p'(\tilde{x}) w = 0 \tag{14}$$

and it follows from the convexity of $p(\cdot)$ that the injurer chooses $\tilde{x}(w) < x^*$ provided he deviates from the standard. However, the injurer will only deviate from the standard if

$$x^* > \tilde{x} + p(\tilde{x}) w \iff w < \bar{w} \equiv \frac{x^* - \tilde{x}(\bar{w})}{p(\tilde{x}(\bar{w}))}. \tag{15}$$

Expression (15) only implicitly defines the cut-off value. Let us now prove that such a cut-off actually exists and that $\bar{w} < h$. As $\tilde{x}$ is defined to minimize $x + p(x) w$ it is clear that $\tilde{x} = 0$ for $w = 0$. Hence, the potential injurer deviates as $x^* > 0 + p(0) 0 = 0$. Now, suppose that $w = h$. Then, the potential injurer will always abide by the standard of due care as $x^* < x^* + p(x^*) h < \tilde{x} + p(\tilde{x}) h$ for all $\tilde{x} \neq x^*$. As $\tilde{x} + p(\tilde{x}) w$ is continuous for $w \in (0, h)$ and since by the envelope theorem

$$\frac{d}{dw}[\tilde{x} + p(\tilde{x})w] = \frac{\partial}{\partial w}[\tilde{x} + p(\tilde{x}) w] = p(\tilde{x}) > 0 \tag{16}$$

it follows from the intermediate value theorem that there exist a unique cut-off $\bar{w} \in (0, h)$ such that the injurer is indifferent between abiding by the due care standard or not. He will strictly prefer to abide by the standard if $w > \bar{w}$ and to deviate from it and choose $\tilde{x}(w)$ if $w < \bar{w}$. ■

7.1.2 Appendix B: Disgorgement liability

Proof. 1) If the injurer abides by the due care standard, he will choose x^*. Moreover, if the wealth constraint does not bind, the injurer has no incentive to deviate from the due care standard, as his expected costs from deviation is x^* (i.e., he is indifferent between choosing any care level $x < x^*$). However, if the wealth constraint binds, the injurer deviates from the due care standard and chooses $\tilde{x}$ if:

$$\tilde{x} + p(\tilde{x})\, w < x^* \iff w < \frac{x^* - \tilde{x}}{p(\tilde{x})} = \bar{w}. \tag{17}$$

This is also the condition for the injurer to become judgment proof.

2) We shall now prove that the wealth level $\bar{w}$ is equal to the maximum damage payment (over all x) under the disgorgement rule. Note that the cut-off value $\bar{w}$ is implicitly defined by expression (17). By condition (2) it must hold that

$$1 + p'(\tilde{x}(\bar{w}))\bar{w} = 0. \tag{18}$$

Inserting (17) into (18) gives us:

$$1 + p'(\tilde{x}(\bar{w}))\frac{x^* - \tilde{x}(\bar{w})}{p(\tilde{x}(\bar{w}))} = 0 \iff p(\tilde{x}(\bar{w})) + p'(\tilde{x}(\bar{w}))\left[x^* - \tilde{x}(\bar{w})\right] = 0. \tag{19}$$

which is precisely the FOC that must hold for the problem:

$$x^+ \in \arg\max_{x \leq x^*} \frac{x^* - x}{p(x)}. \tag{20}$$

This proves the lemma. ■

7.2 Due care above socially optimal care

7.2.1 Appendix C: Proportional liability.

Proof. We can derive from the potential injurer's expected cost function (8) that, if he decides to abide by due care, he chooses $\bar{x}$. If he decides to deviate from due care, he will choose x^* if the wealth constraint does not bind, and $\tilde{x}(w)$ otherwise (see 2). Note that to a certain extent, the injurer can choose whether to become judgment proof. This is because

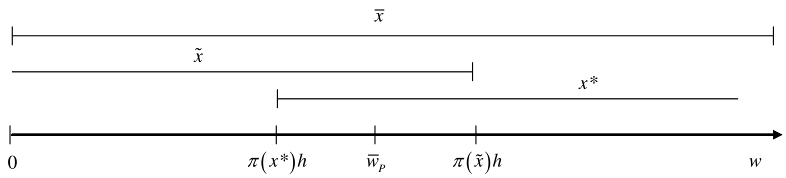

Figure 4: Case distinction.

by decreasing the level of care, he increases liability if harm occurs ($d[\pi(x)h]/dx < 0$). When $w \in [\pi(x^*)h,\ \pi(\tilde{x})h)$, the injurer can choose to become judgment proof by choosing $\tilde{x}$ instead of x^*. Therefore, we can distinguish among three regions. If $w \in [\pi(x^*)h,\ \pi(\tilde{x})h)$, there are three candidates for optimality, $\bar{x}$, x^* and $\tilde{x}(w)$. If $w \geq \pi(\tilde{x})h$, the injurer cannot benefit from judgment proofness, even if he chooses $\tilde{x}$. Hence, there are only two candidates, $\bar{x}$ and x^*. If $w < \pi(x^*)h$, the injurer's wealth constraint binds even if he chooses x^* and there are two candidates, $\tilde{x}$ and $\bar{x}$ (see Figure 4). It follows by the definition of x^* that:

$$x^* + \left[p\left(x^*\right) - p\left(\bar{x}\right)\right] h < \bar{x} + \left[p\left(\bar{x}\right) - p\left(\bar{x}\right)\right] h = \bar{x} \text{ for all } \bar{x} > x^*. \tag{21}$$

Therefore, the injurer never prefers $\bar{x}$ over x^*. It follows that, for $w \geq \pi(\tilde{x})h$, the injurer's optimal choice will be x^*. Moreover, for $w \in [\pi(x^*)h,\ \pi(\tilde{x})h)$, the set of candidates reduces to x^* and $\tilde{x}$. The injurer prefers x^*over $\tilde{x}$ if:

$$\tilde{x} + p\left(\tilde{x}\right) w \geq x^* + \left[p\left(x^*\right) - p\left(\bar{x}\right)\right] h. \tag{22}$$

Note that whenever condition (22) holds, it must also be the case that $w \geq \pi(x^*)h$. To see this, assume the opposite, $w < \pi(x^*)h$. We can then write:

$$\tilde{x} + p\left(\tilde{x}\right) w < x^* + p\left(x^*\right) w \leq x^* + p\left(x^*\right) \pi\left(x^*\right) h = x^* + \left[p\left(x^*\right) - p\left(\bar{x}\right)\right] h, \tag{23}$$

which contradicts condition (22) (the first inequality follows from the definition of $\tilde{x}(w)$). Moreover, whenever condition (22) does *not* hold, it must be the case that $w < \pi(\tilde{x})h$. To see this, note that by the definition of x^* it must hold that:

$$\frac{x^* - \tilde{x} + \left[p\left(x^*\right) - p\left(\bar{x}\right)\right] h}{p\left(\tilde{x}\right)} < \frac{\left[p\left(\tilde{x}\right) - p\left(\bar{x}\right)\right] h}{p\left(\tilde{x}\right)} = \pi(\tilde{x})h. \tag{24}$$

This means that the cut-off value $\bar{w}_P$ is implicitly defined by condition (22) and lies within the interval $[\pi(x^*)h,\ \pi(\tilde{x})h)$. Therefore, the optimal choice will be $x^*$for $w \geq \bar{w}_P$ and $\tilde{x}(w)$ for $w < \bar{w}_P$. It was already shown that $\bar{w}_p < h$.

To see that $\bar{w}_p > \bar{w}$, remember from expression (10) that $\bar{w}$ is implicitly defined by $\tilde{x}\left(\bar{w}\right) + p\left(\tilde{x}\left(\bar{w}\right)\right) \equiv x^*$. As $x^* < x^* + [p(x^*) - p(\bar{x})]h$ for all $\bar{x} > x^*$, the claim then follows from $\frac{d[\tilde{x}(w)+p(\tilde{x}(w))w]}{dw} > 0$ (see expression 3). ■

7.2.2 Appendix D: Full liability

Proof. If the injurer decides to abide by due care, he will choose $\bar{x}$. If he decides to deviate from due care and the wealth constraint does not bind, $w \geq h$, he will choose x^*, and if the wealth constraint binds, he will choose $\tilde{x}(w) < x^*$. (1) If the standard is set sufficiently high, that is, $\bar{x} > x^* + p(x^*)h$, the injurer prefers to deviate from due care and behave as if he were strictly liable. Hence, for sufficiently high due care standards, full liability degenerates into strict liability (a well-known result in the literature). (2) If, however, due care is set within the interval $\bar{x} \in (x^*, x^* + p\left(x^*\right)h)$, and the wealth constraint does not bind, the injurer will prefer $\bar{x}$ over x^*, since $\bar{x} < x^* + p\left(x^*\right)h$. If the wealth constraint binds, $w < h$, the injurer still chooses $\bar{x}$ as long as:

$$\tilde{x}(w) + p\left(\tilde{x}(w)\right)w \geq \bar{x}. \tag{25}$$

Otherwise, he chooses $\tilde{x}(w)$. So (25) implicitly defines the cut-off value $\bar{w}_F$. (3) Since $\tilde{x} + p\left(\tilde{x}\right)w$ is increasing in w (see 3) and since, by the definition of x^*, it holds that $\bar{x} > x^* + \left[p\left(x^*\right) - p\left(\bar{x}\right)\right]h$, it follows from expressions (22) and (25) that $\bar{w}_P < \bar{w}_F$ from (3). ■

7.2.3 Appendix E: Disgorgement liability

Proof. If there are wealth constraints, the injurer's expected cost under the disgorgement rule is:

$$J_P\left(x\right) = \begin{cases} x & \text{if } x \geq \bar{x} \\ x + p\left(x\right)\min\left[\frac{\bar{x}-x}{p(x)},\ w\right] & \text{otherwise} \end{cases}. \tag{26}$$

If the injurer abides by the standard he will choose $\bar{x}$. If he chooses not to abide by the standard and the wealth constraint does not bind,

$$w \geq \frac{\bar{x} - x}{p(x)} \iff x + p(x)\, w \geq \bar{x}. \tag{27}$$

his payoff will be $\bar{x}$ for all $x < \bar{x}$. Hence, he is indifferent over choosing any investment level $x \leq \bar{x}$. If the wealth constraint binds, he will choose $\tilde{x}$ whenever

$$\tilde{x} + p(\tilde{x})\, w < \bar{x}. \tag{28}$$

This must hold as otherwise the wealth constraint would not bind. Hence, he will choose $\tilde{x}$ whenever wealth is below the cut-off implicitly defined by condition 28 and is indifferent when choosing any $x < \bar{x}$ otherwise. Note that the cut-off is the same as under full liability (see 25). ■

7.3 Appendix F: Due care below socially optimal care

Lemma 6 *If due care is set below socially optimal care, then (1) proportional liability, full liability, and disgorgement liability perform identically for all wealth levels: Injurers will exercise due care, $\bar{x} < x^*$, if wealth is greater than or equal to a cut-off value $\bar{w}(\bar{x})$. Otherwise, injurers will exercise less than due care, $\tilde{x}(w) < \bar{x}$. (2) The cut-off value $\bar{w}(\bar{x})$ is implicitly defined by $\bar{x} = \tilde{x}(w) + p(\tilde{x}(w))w$ and is equal to the highest possible damages payment under disgorgement liability.*

Proof. (i) Full liability. If the injurer abides by due care he clearly chooses $\bar{x}$. In addition, if $w > h$ the injurer will not choose to deviate from due care since for all x, $\bar{x} < x^* < x^* + p(x^*)h < x + p(x)h$. If $w < h$, the injurer will decide to deviate from due care and choose $\tilde{x}$ if and only if $\tilde{x}(w) + p(\tilde{x}(w))w < \bar{x}$. This condition also defines (with equality) the cut-off value $\bar{w}(\bar{x})$. (ii) Proportional liability. If the injurer abides by due care he clearly chooses $\bar{x}$. In addition, if the wealth constraint does not bind, $w > \frac{p(x) - p(\bar{x})}{p(x)} h$, the injurer will choose to abide by due care since for all $x < \bar{x}$, $\bar{x} < \bar{x} + p(\bar{x})h < x + p(x)h$. The second inequality follows because $x + p(x)h$ decreases in x for all $x < x^*$. If the wealth constraint binds $w < \frac{p(x)-p(\bar{x})}{p(x)}h$, the injurer will choose to deviate from due care and choose $\tilde{x}$ if and only if $\tilde{x}(w) + p(\tilde{x}(w))w < \bar{x}$. To see that $\tilde{x}(w) + p(\tilde{x}(w))w < \bar{x}$ implies $w < \frac{p(\tilde{x})-p(\bar{x})}{p(\tilde{x})}h$, observe that $\tilde{x} + p(\tilde{x})w < \bar{x} = \bar{x} + p(\bar{x})h - p(\bar{x})h < \tilde{x} + p(\tilde{x})h - p(\bar{x})h$. The second inequality follows because for $x + p(x)h$ decreases with x for all $x < x^*$. Therefore,

$$\tilde{x}(w) + p(\tilde{x}(w))w = \bar{x} \tag{29}$$

defines the cut-off value $\bar{w}(\bar{x})$. (iii) Disgorgement liability. If the injurer abides by due care, he will choose $\bar{x}$. Moreover, if the wealth constraint does not bind he has no incentive to deviate. However, as soon as the wealth constraint binds, the injurer will choose $\tilde{x}$ as $w < \frac{\bar{x}-\tilde{x}}{p(\tilde{x})}$ implies $\tilde{x} + p(\tilde{x})w < \bar{x}$. To see that the cut-off value is equal to the highest possible damage payment under disgorgement liability observe that this will be the point where the wealth constraint binds first. ■

Lemma 7 *Threshold liability: If due care is set below socially optimal care, then (1) injurers will exercise due care $\bar{x} < x^*$ if wealth is greater than or equal to a cut-off value, $\bar{w}_T$. Otherwise, injurers will exercise less than due care $\tilde{x}(w) < \bar{x}$. (2) The cut-off value $\bar{w}_T$ is implicitly defined by $\tilde{x}(w) = \bar{x}$ and it holds that $\bar{w}_T > \bar{w}(\bar{x})$.*

Proof. If the injurer abides by due care, he chooses $\bar{x}$. If he decides to deviate from due care, he chooses the care level which minimizes $x + [p(x) - p(\bar{x})] \min[w, h]$. As x^*minimizes $x + [p(x) - p(\bar{x})]h$, it holds for all $x < \bar{x} < x^*$ that $x + [p(x) - p(\bar{x})]h > \bar{x} + [p(\bar{x}) - p(\bar{x})] = \bar{x}$. Hence, the injurer will exercise $\bar{x}$ whenever the wealth constraint does not bind. If $w < h$, however, the injurer will choose $\tilde{x}(w)$ unless $\tilde{x}(w) \geq \bar{x}$, in which case he will choose $\bar{x}$. To see this, note that $\tilde{x}(w)$, by definition, minimizes $x + p(x)w$ or, equivalently, $x + [p(x) - p(\bar{x})]w$. Hence $\tilde{x} + [p(\tilde{x}) - p(\bar{x})]w < \bar{x}$. Now, if $\tilde{x}(w) < \bar{x}$, choosing $\tilde{x}(w)$ is optimal for the injurer. If, however, $\tilde{x}(w) \geq \bar{x}$, it holds for all $x < \bar{x} \leq \tilde{x}(w)$ that $x + [p(x) - p(\bar{x})]w > \bar{x} + [p(\bar{x}) - p(\bar{x})]w = \bar{x}$. So the injurer would choose $x = \bar{x}$ instead of any $x < \bar{x}$. It follows that the cut-off, $\bar{w}_T$, is implicitly defined by $\tilde{x}(w) = \bar{x}$. We know from 29 that the cut-off, $\bar{w}(\bar{x})$, is implicitly defined by $\tilde{x}(w) + p(\tilde{x})w = \bar{x}$. Since $\tilde{x}(w)$ is increasing in w (see 3), it follows that $\bar{w}_T > \bar{w}(\bar{x})$. ■

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