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Document Version

Accepted author manuscript

Published in:

The Journal of Legal Studies (Chicago)

DOI:

[10.1086/685498](https://doi.org/10.1086/685498)

Publication date:

2016

License

Unspecified

Citation for published version (APA):

Carbonara, E., Guerra, A., & Parisi, F. (2016). Sharing Residual Liability: The Cheapest Cost Avoider Revisited. *The Journal of Legal Studies (Chicago)*, 45(1), 173-201. <https://doi.org/10.1086/685498>

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Journal article (Post print version)

Cite: Sharing Residual Liability : The Cheapest Cost Avoider Revisited. / Carbonara, Emanuela; Guerra, Alice; Parisi, Francesco. In: *The Journal of Legal Studies (Chicago)*, Vol. 45, No. 1, 2016, p. 173-201.

DOI: [10.1086/685498](https://doi.org/10.1086/685498)

Uploaded to [Research@CBS](#): September 2016

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ABSTRACT

Economic models of tort law evaluate the efficiency of liability rules in terms of care and activity levels. A liability regime is optimal when it creates incentives to maximize the value of risky activities net of accident and precaution costs. The allocation of primary and residual liability allows policy makers to induce parties to undertake socially desirable care and activity levels. Traditionally, tort law systems have assigned residual liability either entirely on the tortfeasor or entirely on the victim. In this paper, we unpack the cheapest-cost-avoider principle to consider the virtues and limits of loss-sharing rules in generating optimal (second-best) incentives and allocations of risk. We find that loss sharing may be optimal in the presence of countervailing policy objectives, homogeneous risk avoiders, and subadditive risk, which potentially offers a valuable tool for policy makers and courts in awarding damages in a large number of real-world accident cases.

1. INTRODUCTION

“To err is human,” the great poet famously wrote (Pope 1711, l. 325). No doubt the tort lawyer would happily agree. It seems indeed an inescapable characteristic of human activity that accidents arise from time to time. Yet, while accidents may be an inevitable part of life, we can nev-

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[*Journal of Legal Studies*, vol. 45 (January 2016)]

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ertheless take steps to ensure that they are a somewhat less frequent part of it. For although accidents may not be entirely eliminable, exercising sensible precautions may at least reduce their likelihood.

The most obvious function of tort law then is to incentivize prospective injurers and potential victims to exercise optimal precautionary care when undertaking risky activities, balancing the cost of precautions against the expected cost of accidents.¹ By assigning liability to negligent parties, the law of negligence incentivizes potential injurers to exercise optimal care under threat of liability. Recognizing that potential injurers tend to behave nonnegligently, potential victims are likewise incentivized to exercise optimal care under threat of uncompensated injury.

Yet precautionary care is not the only relevant factor in minimizing the expected cost of accidents. Reducing the magnitude or frequency of the risky activity also decreases the probability of accidents. For example, an individual may lower the probability of a potential car accident by taking care (for example, driving slower and driving sober) but also by simply driving less often.² Similarly, the likelihood that a pedestrian will be hit by a car is affected not just by drivers' and pedestrians' precautions but also by the number of miles driven and the number of road crossings during a day. Law and economics scholars call this factor activity level, distinguishing it from ordinary care precautions for several reasons.³ First, parties' care levels are generally verifiable by courts, whereas their activity levels are often more difficult to determine. Second, even when activity levels can be ascertained by courts, determining their optimality may be very difficult, inasmuch as the value of the parties' activities is

1. We do not mean to imply that this function was consciously recognized at the inception of tort law (see Parisi [2001] for a historical perspective on the development of tort law). Nor do we mean to suggest that the economic interpretation of tort law is the only one, although it has undoubtedly become the dominant perspective (see Coleman [1982, 1991] for alternative moral theories on tort law).

2. The statistics tell us that the more miles you drive, the higher the chance that you will be involved in an accident (see, among others, National Highway Traffic Safety Administration. Fatality Analysis Reporting System [<http://www.nhtsa.gov/FARS>]): by driving 10,000 miles per year, the probability of being involved in an accident is approximately 10 times higher than it would be if driving only 1,000 miles per year.

3. The distinction between care and activity level was originally articulated by Shavell (1980) and Polinsky (1980). Their insights have resulted in follow-up work (Landes and Posner 1987; Shavell 1987, 2004; Hylton 1991; Miceli 1997; Cooter and Ulen 2007), criticism (Diamond 1974; Latin 1986; Grady 1988; Gilles 1992), and empirical research (Edlin and Karaca-Mandic 2006).

difficult to measure by a third-party decision maker.⁴ For these reasons, courts directly control parties' incentives to take precautions (namely, by setting the standard of due care) but exert some influence on activity levels only indirectly. The allocation of residual liability is the court's lever for influencing activity-level incentives, forcing the residual bearer to internalize the full expected cost of potential accidents.⁵

Until recently, tort scholars have been primarily concerned with incentives to take care, investigating the scope and magnitude of liability when one or more of the parties behaves negligently. However, in equilibrium, prospective injurers and potential victims will both behave non-negligently, and therefore a large number of the accidents that occur in reality will arise despite the due diligence of the individuals involved.⁶ Thus, assuming that a tort regime is efficient with respect to precautionary care, we have the question of how society deals with such nonnegligent accidents takes on acute significance, and unsurprisingly a growing body of research is directed toward this topic (Calabresi 1996; Calabresi and Cooper 1996; Gilles 1992; Parisi and Fon 2004; Dari-Mattiacci and De Geest 2005; Parisi and Singh 2010; Garoupa and Ulen 2013; Dari-Mattiacci, Lovat, and Parisi 2014).

In dealing with nonnegligent accidents, tort regimes have traditionally adopted all-or-nothing approaches, whereby losses from accidents are assigned either entirely to the tortfeasor or entirely to the victim, with no possibility of division.⁷ In this paper, we analyze the conditions under

4. "Activity level" has also been used as a catchall term for any precaution that a court will not consider when evaluating negligence. In one sense, therefore, activity levels are by definition those evidentiary factors that are inaccessible or are otherwise ignored by courts.

5. Although optimal precautionary investments reduce the probability of an accident, risk is rarely eliminated entirely. Accidents may still arise, and their cost must be borne by someone. We refer to liability for accidents arising when both injurer and victim acted nonnegligently interchangeably as residual liability or residual loss. The allocation of residual liability plays a determinant role in maximizing the value of risky activities. See, among others, Cooter and Ulen (2007, p. 348) and Dari-Mattiacci, Lovat, and Parisi (2014).

6. We use the terms "diligent" and "nonnegligent" interchangeably.

7. Under negligence-based rules—simple negligence, contributory negligence, and comparative negligence—the victim must absorb the residual loss (namely, the loss that occurs when both parties are nonnegligent), while under strict-liability-based rules—strict liability and strict liability with a defense of dual contributory negligence, contributory negligence, or comparative negligence—the injurer bears the residual loss. In brief, negligence-based rules burden the victim, while strict-liability-based rules burden the injurer with the cost of faultless accidents. See Cooter and Ulen (2007) and Dari-Mattiacci and Parisi (2015) for a comprehensive taxonomy of liability rules.

which loss sharing proves to be more effective than conventional all-or-nothing liability regimes in minimizing losses from accidents. We proceed by relaxing the standard assumptions used in earlier tort models. Our critical analytical move is to unbundle Calabresi's (1970) cheapest-cost-avoider principle to distinguish situations in which sharing the loss generates superior activity-level incentives. We show that the allocation of residual loss has nontrivial consequences on a number of additional variables. This suggests that, even in a world in which all relevant actors are risk neutral, the optimal allocation of residual liability should play an important role in the normative choice of tort liability.

The paper is structured as follows. In Section 2, we provide a review of the existing literature on loss sharing between nonnegligent parties. In Section 3, we set up a simple tort model to compare loss sharing and all-or-nothing liability as alternative second-best solutions in allocating a loss from an accident between a nonnegligent tortfeasor and his nonnegligent victim. In Section 4, we discuss the conditions under which loss sharing in equilibrium may prove to be superior to conventional liability rules in affecting second-best activity levels. We proceed analytically by unpacking the cheapest-cost-avoider principle into a number of factors, namely, the least risk producer, the cheapest activity avoider, the cheapest risk avoider, the best mix of activities, the best scale of activities, and the best risk bearer.⁸ We find that the choice between liability rules depends on the interaction of these factors and that loss-sharing rules become more appealing in the presence of countervailing policy objectives and homogeneous conditions of risk. In particular, we show that loss sharing is desirable not only when parties are risk averse but also when they are risk neutral. In case of risk-averse parties, loss sharing plays a mutual insurance role, placing a greater portion of the risk on the best risk bearer. Interestingly, as pointed out in more recent law and economics literature, sharing nonnegligent losses provides a form of risk spreading that avoids the dilution of incentives and the moral hazard problems caused by standard liability insurance (Parisi and Fon 2004; Parisi and Singh 2010; Dari-Mattiacci, Lovat, and Parisi 2014). Loss sharing can also yield second-best activity-level incentives when parties are risk neutral, as it encourages higher activity levels by more productive and less

8. The current literature refers to several factors encompassed in the cheapest-cost-avoider principle, including cheapest risk avoider, cheapest precaution taker, best risk bearer, and most effective precaution taker. For a complete list of these factors with brief analytical definitions, see Parisi (2013).

risky parties, which enhances social welfare. In this paper we bring to light several important policy considerations in assigning the optimal allocation of residual risk. In Section 5, we conclude by offering a condensed summary of our results and a brief discussion of their significance.

2. RESIDUAL LOSS SHARING IN LEGAL AND ECONOMIC THEORY

The adoption of optimal precautions is not a panacea against accidents. When both parties undertake due care, an accident may nevertheless occur, and someone ultimately needs to bear the loss. Since Shavell (1980), scholars generally refer to such faultless loss from accidents as residual loss or residual liability. Traditionally, legal rules assign the entire residual loss either to the victim (negligence rules) or to the tortfeasor (strict-liability rules).⁹ Residual-loss-sharing rules would instead allow the residual loss to be shared when neither party is at fault. Figure 1 illustrates the allocation of the loss from accidents under residual loss sharing and compares it with a traditional rule of comparative negligence. In a comparative-negligence regime, losses from accidents are shared when both parties are negligent. In a comparative-nonnegligence regime, they are instead shared when neither party is negligent. Hereinafter, we refer to this latter form of loss sharing as residual loss sharing.

In legal theory, 14th-century commentators and 15th-century legal humanists considered explicitly the problem of apportioning losses among faultless parties. Seventeenth-century natural law scholars such as Hugo Grotius (1583–1645) and Samuel Pufendorf (1632–94) took a clear position in favor of residual loss sharing, criticizing the so-called fault principle and formulating an alternative paradigm of liability, which they called the principle of compensation. Grotius ([1625] 1925) proposed moving away from the fault principle, suggesting that, absent fault, there was no reason to let losses fall on the innocent victims, just as there was no obvious reason to shift the entire loss from accidents on the tortfeasor. The essence of their arguments was that when neither party is negligent or when negligence cannot be assessed, equitable principles may warrant sharing the residual loss between the parties. American tort scholars have expressed support for the idea of residual loss sharing, ar-

9. The allocation of nonnegligent losses (residual liability) affects the activity-level choices of the parties. These activity-level effects were first articulated by Shavell (1980). See also Polinsky (1980), Shavell (1987), and Singh (2006, remark 4).

Loss Sharing between Negligent Parties				Residual Loss Sharing between Nonnegligent Parties			
		Injurer				Injurer	
		<i>Negligent</i>	Share	<i>Negligent</i>	Injurer	<i>Diligent</i>	Victim
Victim	<i>Diligent</i>						
		<i>Diligent</i>	Injurer	<i>Diligent</i>	Injurer	<i>Diligent</i>	Share

Figure 1. Comparison of loss sharing and residual loss sharing

guing that the possibility that strict liability is a sliding scale and not an exact point of reference must be recognized (Palmer 1988, p. 1306). Loss sharing is therefore often regarded as a logical alternative to the seemingly unfair all-or-nothing allocations of liability for faultless accidents (Gershonowitz 1986, p. 485; see also Grimley 2000, p. 534; Strassfeld 1992, p. 949).

Yet, notwithstanding these historical antecedents, only a handful of law and economics scholars have given attention to the possibility of residual loss sharing. Calabresi was the first to consider the value of deterring accidents between faultless parties. Calabresi (1965) observes that systems that apportion liability on the basis of fault deter only those accidents that are caused through fault and ignore the value of deterring accidents that are faultless. Calabresi (1970) later returned to this issue, assessing the merits of loss sharing between faultless parties. Calabresi (1970, p. 39) states that “the justification found most often among legal writers today for allocation of accident losses on a nonfault basis, is that accident losses will be least burdensome if they are spread broadly among people and over time.”

Unquestionably, the implementation of the nonnegligent allocations of liability proposed by Calabresi poses dogmatic difficulties in legal theory. In a negligence regime, injurers can be readily identified as those individuals whose greater care could have prevented the accident; in a nonnegligence regime, when multiple parties are involved, identification of the injurer may be more problematic. Although proximate causation could be used in nonnegligence regimes to solve the scope of the liability conundrum, the theoretical difficulties in defining the scope of nonnegligent liability may have curtailed the success of Calabresi’s (1965, 1970) original proposal (see Parisi and Fon 2005). A quarter-century later, Calabresi (1996) and Calabresi and Cooper (1996) returned to the idea of distributing the loss between nonnegligent parties. Calabresi and Cooper (1996) stress the desirability of dividing losses between faultless parties

instead of having a legal rule that puts the entire burden on either the plaintiff or the defendant. At that time, however, Calabresi's arguments in favor of residual loss sharing ran against what had become the conventional wisdom in the law and economics literature, according to which any form of loss sharing would be undesirable because it would dilute care-level incentives (Brown 1973).

Recent contributions to this literature reveal the limits of the conventional wisdom, thus opening new horizons and opportunities in this field of research. The concern that loss sharing may dilute incentives is correct as a general matter but is not applicable when loss sharing is carried out only with respect to nonnegligent parties (that is, residual loss sharing). In particular, recent research in the law and economics literature shows that a spreading of the residual loss in equilibrium can be accomplished while preserving efficient incentives to take care. The first contribution to study the incentive effect of residual loss sharing is Parisi and Fon (2004). The authors show that residual loss sharing does not necessarily undermine care-level incentives while studying the effects of a rule of comparative causation (a species of residual loss sharing in which liability is divided between faultless parties on the basis of their causal contribution to an accident).¹⁰ Parisi and Fon (2004) do not derive a general proof, and their model shows that loss sharing in the form of comparative causation under negligence is in most cases compatible with full incentives for optimal care. Parisi and Singh (2010) provide a more general proof of the compatibility of residual loss sharing under comparative causation with incentives to take optimal care.¹¹ In the latest contribution to the topic, Dari-Mattiacci, Lovat, and Parisi (2014) show that, under some sufficient

10. Loss sharing in tort law has been advocated in other formulations, for example through comparative negligence in the presence of negligent parties (see Bar-Gill and Ben-Shahar [2003] for a critical review of related literature), several potential tortfeasors (Landes and Posner 1980; Kornhauser and Revesz 1989, 1990, 1994), or asymmetric costs of precautions (Rubinfeld 1987) or under conditions of evidentiary uncertainty (Dari-Mattiacci and De Geest 2005). Although starting from different assumptions and purposes, the results of Dari-Mattiacci and De Geest (2005) are complementary to ours: they argue that if the costs of precautions are larger than the value of the harm, there exists some sharing of the loss that yields a lower level of social loss than all-or-nothing rules (see the discussion on the riskiness of activities in Section 4.1). Luppi, Parisi, and Pi (2016) formulate the traditional tort model in terms of expected loss sharing—instead of actual loss sharing as in our formulation—to account for individual role uncertainty. They argue that, under conditions of uncertainty, activity-level incentives are insensitive to changes in liability regime.

11. For an analysis of the effects of liability rules on parties' incentives to take care, see also Landes and Posner (1983), Haddock and Curran (1985), and Singh (2006).

conditions,¹² parties' compliance with the standard of due care can be achieved in equilibrium not only for any residual-loss-sharing rule implemented among negligent parties (Landes and Posner's [1980] result) but also for any loss-sharing rule implemented among nonnegligent parties. Dari-Mattiacci, Lovat, and Parisi (2014, sec. 3) analyze the optimal setting of residual loss sharing in a specification of their initial general model, in which parties' activity levels are independent of each other in the production of the expected loss from an accident. They further restrict the analysis by using two functional forms of the loss function: a linear and a quadratic loss function. Our paper generalizes and extends Dari-Mattiacci, Lovat, and Parisi's (2014, sec. 3) analysis in considering a more general model without employing specific functional forms to investigate different interrelations of parties' activities in the production of the expected accident loss (see Section 4).

Building on a generalization of these results, our paper tackles two novel interrelated questions. While Parisi and Fon (2004), Parisi and Singh (2010), and Dari-Mattiacci, Lovat, and Parisi (2014) establish the independence of the problem of residual liability, they do not investigate when and how loss-sharing rules ought to be employed. In this paper, we investigate which factors should guide the optimal allocation of residual liability and under which conditions residual loss sharing among faultless parties may be preferable to conventional all-or-nothing rules. We identify several characteristics of parties' activities and accident functions that should optimally guide the apportionment of the residual loss. We relate these characteristics to Calabresi's (1970) cheapest-cost-avoider principle and identify six factors that are embedded in it. We offer a more generalized accident model to consider all possible relationships between the riskiness and the value of activities, the interaction of the parties' activities in the production of risk, returns to scale from the activities, and parties' relative risk preferences.¹³ The analysis of these factors, consid-

12. In Dari-Mattiacci, Lovat, and Parisi (2014), the plausible conditions under which compliance with the standard of due care is a Nash equilibrium are the following: the standards of due care and the loss-sharing rule are set at the (second-best) socially optimal levels, or a party's (optimally chosen) activity level decreases in its due level of care (that is, an increase in a party's due-care level reduces its chosen level of activity).

13. Other authors analyze the heterogeneities among parties and their activities in independent yet related studies. Emons (1990) and Emons and Sobel (1991) analyze liability rules when risk-neutral parties have different marginal utilities from their actions. They argue that liability-sharing rules implement a superior allocation of activity levels compared with negligence rules. Garoupa and Ulen (2013) question one implicit assumption regarding the activity-level effect, namely, the positive monotonic relationship be-

ered in isolation and collectively, allows us to understand under which conditions loss-sharing rules are preferable to conventional all-or-nothing rules.

3. SETTING THE STAGE: LOSS SHARING AMONG NONNEGLIGENT PARTIES

We begin by defining terms and articulating our assumptions. We consider a bilateral nondurable care model in which two parties—the potential tortfeasor (T) and the potential victim (V)—influence the unilateral risk of an accident (where only the victim suffers the loss if an accident occurs) by engaging in two different types of precautionary measures: care level and activity level.

Following the conventional notation, x and y denote the tortfeasor's and victim's care levels, respectively, and z and u denote the tortfeasor's and victim's respective activity levels. Let $w = w(z, x)$ be the injurer's level of wealth, and let $b = b(u, y)$ be the victim's level of wealth. We begin adopting the standard assumptions of tort models (Landes and Posner 1987; Shavell 1987; Miceli 1997; Dari-Mattiacci, Lovat, and Parisi 2014): both parties' utilities decrease in care level at a constant or increasing rate and increase in activity level at a decreasing rate; that is, $w_x < 0$, $w_{xx} < 0$, $w_z > 0$, and $w_{zz} < 0$ for the tortfeasor and $b_y < 0$, $b_{yy} < 0$, $b_u > 0$, and $b_{uu} < 0$ for the victim. We relax some of these assumptions in Section 4.5 to consider the effect of increasing returns, namely, $w_{zz} > 0$, $b_{uu} > 0$, on the optimal allocation of residual liability. We plausibly assume that an increase in a party's due-care level reduces its optimally chosen level of activity.¹⁴

We now turn to the cost of accidents. Following the conventional setup (Shavell 1980, 1987), we assume that the probability of an accident $q(z, u)$ increases at a constant or increasing rate as parties increase their activity levels, that is, $q_z, q_u > 0$, $q_{zz}, q_{uu} \geq 0$. We also assume that

tween the probability of accident and the risky activity. They point out definitional issues for activity levels and discuss the complementary role of liability and regulation in incentivizing socially optimal precautions. These contributions can find a formal extension and a deeper analysis of other sources of heterogeneity among tortious activities in our research.

14. The definition of due-care standards influences parties' activity choices and might change depending on the interrelation between care and activity levels. The standard accident model assumes the cost of care to be proportional to activity level (Shavell 1987, 2004). Nussim and Tabbach (2009) relax this assumption in a unilateral accident model and analyze the effect of different interactions between the injurer's care and activity levels on the definition of due-care standards.

the expected loss suffered by the victim in the event of an accident $L(x, y)$ decreases in care levels at a decreasing rate, that is, $L_x, L_y < 0$, $L_{xx}, L_{yy} > 0$.¹⁵ Following Dari-Mattiacci, Lovat, and Parisi (2014), we consider parties' activities as independent in the production of the loss from an accident; that is, $q_{zu} = 0$. We relax this assumption in Section 4.4 to consider cases in which parties' activities are substitutes, $q_{zu} < 0$, or complements, $q_{zu} > 0$.¹⁶

The share of the residual loss borne by the injurer is denoted σ , such that $0 \leq \sigma \leq 1$. In other words, σ represents the allocation rule for losses from accidents in the absence of fault.¹⁷

The optimization problem is formulated as a two-stage problem in which the choice of activity levels in the second stage is affected by the first-stage definition of the liability rule σ by the social planner. The model is thus solved by backward induction. We consider the case of risk-neutral agents. (We discuss some special insights related to the case of risk-averse agents in Section 4.6.) Along with the existing literature, in Appendix B we show that both parties have incentives to comply with the second-best due-care standards, x^{d^*} and y^{d^*} .¹⁸ We refer to this result as loss-sharing neutrality. The tortfeasor and the victim therefore choose the activity levels that maximize their utility functions, which are, respectively,

$$U_T = w(z, x^{d^*}) - \sigma q(z, u)L(x^{d^*}, y^{d^*}) \quad (1)$$

and

$$U_V = b(u, y^{d^*}) - (1 - \sigma)q(z, u)L(x^{d^*}, y^{d^*}). \quad (2)$$

15. Strictly speaking, we make the assumption that q_{zz} and q_{uu} are greater than 0 only in the range of an optimum since q is bounded above by 1.

16. Dari-Mattiacci, Lovat, and Parisi (2014, sec. 3) assume the loss function to have an additive form; that is, the parties' activity levels are independent of each other in the production of the expected loss from an accident. Our general formulation allows us to extend the framework in Dari-Mattiacci, Lovat, and Parisi (2014, sec. 3) to consider different interactions of parties' activity choices in the production of the expected loss from an accident (see Section 4.4). See also Dharmapala and Hoffmann (2005) and Singh (2006).

17. In the limiting cases, $\sigma = 0$ is the allocation produced by a negligence rule, $\sigma = 1$ is the allocation produced by a strict-liability rule, and $0 < \sigma < 1$ is the allocation produced by a residual-loss-sharing rule.

18. It has been established in the literature that under any fault-based liability rule, if due-care standards and the loss-sharing rule among nonnegligent parties are set at the (second-best) socially optimal level, parties have optimal incentives to comply with the due-care standards regardless of the loss-sharing rule implemented among negligent parties (Singh 2006; Dari-Mattiacci, Lovat, and Parisi 2014).

Suppressing arguments inside the functions, we define the privately optimal activity levels z^* and u^* by the following first-order conditions:

$$z^*: w_z - \sigma q_z L = 0 \quad (3)$$

and

$$u^*: b_u - (1 - \sigma)q_u L = 0. \quad (4)$$

The social planner's task is to maximize the total surplus of the parties (expressed by the sum of parties' utilities in equations [1] and [2]) with respect to the liability share σ , given the privately optimal activity levels. The socially optimal σ is thus implicitly expressed by the following first-order condition:

$$\sigma^{**}: \frac{dz^*}{d\sigma}(w_z - q_z L) + \frac{du^*}{d\sigma}(b_u - q_u L) = 0. \quad (5)$$

The social planner designs the optimal liability scheme anticipating the parties' reactions to marginal changes in their respective shares of liability.

4. OPTIMAL LOSS SHARING: UNBUNDLING THE CHEAPEST-COST-AVOIDER PRINCIPLE

We now analyze the optimal value of σ , as given by equation (5), to understand the conditions under which loss sharing could be desirable and more efficient than conventional all-or-nothing liability rules. We consider several factors in isolation, exploring the optimal assignment of residual liability when a particular factor is determinative. We discuss the interaction of factors and their significance in Section 5.

4.1. Riskiness of the Activity: The Least Risk Producer

The first building block in our analysis highlights the riskiness of the activity, defined as the marginal increase in the probability of an accident when either the injurer or the victim increases its activity level (that is, q_i , $i = z, u$).

Setting aside other factors, we find that the relative riskiness of the activity may also determine the optimal allocation of the residual loss, as identified in proposition 1. (All proofs are in Appendix A.)

Proposition 1: Least Risk Producer. *Ceteris paribus*, when the injurer's activity is substantially riskier than the victim's, strict-liability rules are preferable. When the victim's activity is substantially riskier than

the injurer's, negligence rules are preferable. When the parties' activities present similar levels of riskiness, loss-sharing rules are socially desirable. In particular, when activities are equally risky, it is optimal that parties share the loss in equal measure.

Intuitively, all things being equal, if the injurer's activity is more likely to increase the probability of an accident with respect to the victim's activity, it is preferable to shift a larger portion of the residual loss to the tortfeasor. When the injurer's activity is substantially riskier, the adoption of a strict-liability rule may be warranted. Clearly, for activities of comparable value, the net value of a tortfeasor's dangerous activity is smaller because it creates a greater expected loss due to accidents. Consequently, from a social welfare point of view, reductions in such dangerous activities will be less costly than reductions in less harmful activities. The converse holds true when the victim's activity poses the greater risk. In both cases, all-or-nothing liability systems are preferable to a loss-sharing rule. This may explain the adoption of strict liability in cases involving abnormally dangerous (or ultrahazardous) activities (for example, transportation of dynamite or other explosives) and the use of no-liability regimes to mitigate victims' extraordinary exposures to risk (for example, low-skilled skiers choosing the most difficult slopes or cyclists riding on high-speed roads).¹⁹ Concerns of practical implementability may arise with respect to the application of this proposition, although courts and juries can, in most cases, discern the relative difference in the riskiness of parties' activities.

4.2. Value of the Activity: The Cheapest Activity Avoider

The next building block for understanding the optimal allocation of residual liability involves the value of the parties' activities. Accidents are often the unavoidable by-product of otherwise desirable human activities. However, not all activities are equally desirable. The optimal liability rule, *ceteris paribus*, should make the party who can reduce its activity

19. These findings are consistent with Cooter and Ulen (2007, p. 349): "Usually one party's activity level affects accidents more than the other party's activity level. Efficiency requires choosing a liability rule so that the party whose activity level most affects accidents bears the residual costs of accidental harm." We extend the intuition of Cooter and Ulen (2007) by showing that sharing rules might be the preferred option when one party's activity is riskier but relative riskiness is not substantially different. In other words, all-or-nothing rules are optimal when one party's activity is far riskier than the other party's activity.

level at the lowest cost (cheapest activity avoider) the residual bearer of the loss from an accident. Identifying the cheapest activity avoider entails consideration of the relative value of the parties' activities.

Clearly, the reduction of a more valuable activity will reduce social welfare more than the reduction of a less valuable activity. Thus, all things being equal, residual liability should fall on the party that can reduce its activity level at a lower social cost.

Proposition 2: Cheapest Activity Avoider. Residual liability should be borne by the party who can more cheaply reduce his activity level. *Ceteris paribus*, when the injurer's activity is substantially more valuable than the victim's, negligence rules are desirable. When the victim's activity is substantially more valuable than the injurer's, strict-liability rules are desirable. When the parties' activities have comparable values, loss-sharing rules are preferable to all-or-nothing allocations. In particular, when activities are equally valuable, it is optimal for parties to share the loss in equal measure.

A reduction in the level of activity results in a reduction in the probability of an accident but also a decrease in the total value of the activity. All things being equal, the cost of nonnegligent accidents should be borne by the individual who undertakes the less valuable activity, because a reduction in activity level will be less costly from a social welfarepoint of view.²⁰ For example, efficiency should favor the activity of a doctor who needs to drive to visit his patients over somebody who uses his car to distribute marketing ads. If liability rules could be linked to some observable characteristic such as profession (or other proxy for the value of the activity), then it might be possible to efficiently allocate the residual loss on the basis of the relative values of the parties' activities. This result may also provide a positive explanation for the heightened standard of liability (that is, gross negligence or intent is required for liability) when socially valuable activities such as ambulance driving or firefighting are involved.

20. A variant of the idea that residual liability should be borne by the party who can more cheaply reduce its activity level can be found in Cooter and Ulen (2007). As already mentioned, the idea that losses can be shared expands the domain of possibilities compared with the conventional all-or-nothing approach.

4.3. Trading Off Riskiness and Value of the Activity: The Cheapest Risk Avoider

When applying the cheapest-cost-avoider criterion in the context of Calabresi's (1970) paradigm, it is especially important to consider the interaction between the factors analyzed above. If the injurer's activity is socially more valuable but riskier than the victim's activity, then the opportunity for a trade-off arises: if an all-or-nothing approach is used, one of the parties will undertake a riskier or a less valuable activity with greater-than-optimal intensity. Loss-sharing rules may offer a more desirable alternative in such cases. To illustrate the point, consider a collision (due to bad weather, heavy traffic, congestion, or poor visibility) between a car and a truck. The collision occurs even though both drivers have taken due precaution (for example, observing speed limits and stopping at stop signs), and only the car is damaged. Consider the case in which the truck driver's activity is socially more valuable but creates greater risk than the car driver's. If a negligence rule applies (as efficiency would require when considering the value of the activity), the truck driver will undertake higher activity levels, notwithstanding the fact that driving the truck creates a greater risk.²¹ If instead a strict-liability rule applies (as efficiency would require when considering the riskiness of the activity), then the driver of the car would engage in an excessive activity level, notwithstanding the lower social value of his activity. In this case, a loss-sharing rule can usefully balance the two countervailing efficiency criteria—the least risk producer and the cheapest activity avoider—in line with a more nuanced efficiency criterion. We refer to this combined rationale as the cheapest risk avoider. The major theoretical conclusion that emerges from the trade-off between the riskiness and the value of activities can be summarized in the following proposition:

Proposition 3: Cheapest Risk Avoider. *Ceteris paribus*, when the injurer's activity is substantially less risky and more valuable than the victim's, then negligence rules are preferable. When the victim's activity is substantially less risky and more valuable than the injurer's, then strict-liability rules are preferable. When one party's activity is more valuable but riskier than the others', loss-sharing rules are preferable to both negligence and strict liability.

21. Once liability has been avoided by taking due care, the truck driver can engage in his activity until the private marginal benefit equals the private marginal cost.

4.4. Coordinating Risks: The Best Mix of Activities

One often overlooked function of residual liability is that of promoting coordination among risky activities. The optimal allocation of activity-level incentives hinges on the relationship between the parties' activities in the production of a loss from an accident. Here we distinguish three possible cases: additive, subadditive, and superadditive risks. Parties' activities create an additive risk, $q_{zu} = 0$, when each activity independently affects the probability of an accident, with no additional interactive effect when both parties' activities are carried out. The overall risk of an accident is determined by the sum of the parties' activities, regardless of which party engages in the larger share of the activity. Similar to independent inputs in a production function, activities that create additive risks contribute linearly to the overall risk of an accident. Given that the parties' activities independently affect the probability of an accident, any allocation of the residual loss is compatible with the social optimum. When risks are additive, the choice among negligence, strict liability, and loss-sharing solutions is driven by the other efficiency considerations discussed in Sections 4.1–4.3.

In real-life tort situations, however, risks are rarely independent and linearly additive. The allocation of residual loss acquires acute importance when risks are interdependent, $q_{zu} \neq 0$. In the first case of nonlinearity, parties' activities create a subadditive risk $q_{zu} < 0$: an increase in the level of activity of one party leads to a larger increase in overall risk compared with a balanced increase in activity level for both parties. Mixing different activities results in a lower risk than concentrating only one activity. Consider, for example, the emission of chemicals and noise into the environment. The presence of moderate quantities of the two pollutants may be less harmful than the presence of high levels of only one pollutant. The risk created by additional units of pollutants may have subadditive effects. Legal systems might tackle these situations through regulation (for example, by putting caps on the maximum quantity of each risky input) or through tort law, by spreading activity-level incentives between the parties. In this case, a loss-sharing rule might help reduce the expected costs from accidents by inducing both parties to mitigate their activity levels.

In the second case of nonlinearity, parties' activities create a superadditive risk $q_{zu} > 0$: both activities contribute to causing the accident, and total harm is greater when the parties engage in their activities con-

junctly. Similar to complementary inputs in a production function, activities that create a superadditive risk contribute nonlinearly to the overall risk of an accident. The resulting risk is not determined by the sum but by the relative mix of the parties' activities. Combining different activities creates a greater risk than concentrating on only one activity. Consider, for example, the presence of pedestrians and cyclists on a trail. The frequency of accidents grows larger as the two activities mix: having all pedestrians or having all cyclists is preferable to mixing the two activities. Legal systems might tackle these situations either by separating complementary activities through regulation (for example, planning pedestrian areas, denying access to bicycles and other slow-moving vehicles on highways, or locating industries with smokestacks far from residences) or through tort law by allocating the residual liability entirely to one party. In this case, all-or-nothing rules are preferable to loss-sharing rules since they produce a result that mimics results achieved by regulation, inducing one of the individuals to reduce his or her activity level to a minimum.

Proposition 4: Best Mix of Activities. *Ceteris paribus*, loss-sharing rules are always more efficient when parties' activities create a subadditive risk. All-or-nothing allocations of the residual loss may become preferable with superadditive risks.

Proposition 4 may explain the dominance of all-or-nothing rules in situations characterized by superadditive risk. For example, at a shooting range, no individual should be walking around the target area, and in an urban environment, no one should be shooting at targets in pedestrian areas. In the case of superadditive risk, the optimal equilibrium is characterized by corner solutions: no walking on shooting ranges, no shooting in pedestrian areas. On the contrary, when risks are subadditive, high concentrations of risky activities may be problematic, and the optimal equilibrium is characterized by an interior solution with a balanced mix of activities. In these straightforward cases, regulation of the activities can accomplish a separation or a mix of activities (for example, pedestrian areas or no bicycles on highways). However, in situations that are not amenable to regulation, the tort system can pursue comparable results by allocating the residual loss to one party or sharing the residual loss among the parties.

4.5. Activity Levels and Returns to Scale: The Best Scale of Activities

An additional factor to consider when choosing the optimal allocation of nonnegligent losses from accidents is the marginal value of activities w_{zz} , b_{mm} . By relaxing the assumption introduced in Section 3 of decreasing marginal value of the parties' activities, w_{zz} , $b_{mm} < 0$, we now consider cases characterized by increasing marginal value of the activities. Allocating the residual loss to one party will affect the parties' activity levels and their ability to optimize the scale at which their activity is carried out. All things being equal, it will be optimal to allocate risk and liability to the party that faces decreasing marginal returns from its activity. The activity with diminishing marginal returns can, in fact, be reduced at a lower cost, given that the portion of the activity that is curtailed is characterized by lower returns.

Proposition 5: Best Scale of Activities. *Ceteris paribus*, a loss-sharing rule is desirable in equilibrium when the marginal returns from the parties' activities are decreasing. Conversely, increasing marginal returns from the activities requires an all-or-nothing approach in equilibrium.

Proposition 5 implies that, in the absence of other justifying factors, increasing marginal returns from the activity represent a necessary condition for all-or-nothing rules to be socially optimal. When marginal returns are decreasing, the value function increases with respect to activity levels at a decreasing rate. The greater the activity level, the lower the return from an additional increase in activity level. Benefits accrue at a decreasing rate, while risks of accident grow steadily. In this case, a loss-sharing rule will induce both parties to mitigate their activity levels and forgo the less valuable final quantities of their activities. Conversely, with increasing marginal returns, increases in activity levels lead to increasingly larger gains. Thus, it may be desirable to allow at least one party (the one with the highest marginal increase) to undertake a higher activity level with the adoption of an all-or-nothing liability regime.

4.6. Loss Sharing versus Insurance: The Best Risk Bearer

With rare exceptions (see Greenwood and Ingene 1978; Shavell 1987; Gollier, Koehl, and Rochet 1997; Nell and Richter 1996, 2003; Privileggi, Marchese, and Cassone 2001),²² the literature on tort law assumes

22. See also Zivin, Just, and Zilberman (2005) for an evaluation of the impact of heterogeneous risk preferences on polluters' liability.

risk neutrality for both parties to isolate the effect of liability on individual incentives.²³ The assumption of risk neutrality in the standard tort model is justified by two compelling arguments in the literature. The first argument is that tort law should be designed to promote efficient incentives, and any attempt to use tort rules to provide an insurance function for the parties would undermine the incentive function of tort liability. The second argument is that parties involved in risky activities generally have access to well-functioning insurance markets, which reduces the need for providing insurance through tort law.

Although useful for the study of incentives to take care, the assumption of risk neutrality obfuscates the analysis of other important policy dimensions that hinge on the optimal allocation of risk. Risk preferences play an important role in individuals' choices of activity levels for risky activities. Policy makers can influence risk-taking behavior by appropriately allocating residual liability. Recent contributions to the tort literature reveal the limits of the conventional approach, showing that under fairly general conditions, loss sharing and other forms of mutual insurance between faultless parties can be implemented without undermining incentives to provide optimal care. Further, not all risks are insurable, and residual loss sharing can provide a form of risk spreading when insurance is not available. Most compellingly, unlike standard insurance, residual loss sharing can spread risk without corroding incentives to take care and creating other moral hazard problems.

As pointed out by Nell and Richter (2003), putting aside other factors, the law should allocate risks and liability to the risk-neutral party or to the party that can more easily hedge against the risk (the best risk bearer). To determine which party is the best risk bearer, the court should ascertain risk preferences and identify which party is in a better position to hedge against the risk. Use of the best-risk-bearer criterion may run into epistemic problems as to the verifiability of risk preferences and concerns about political palatability and tastes for fairness. This may render the best-risk-bearer criterion unlikely to be used as an ad hoc basis of liability. Notwithstanding these limitations, loss sharing could emerge as a desirable legal instrument when parties have similar attitudes toward risk and invest in comparable activities (for example, two average drivers involved in an accident). In this case, loss sharing may provide a form

23. Although risk neutrality may be a reasonable approximation of preferences when corporate actors are involved or when insurance markets are readily available, risk aversion lurks behind all remaining tort situations.

of mutual insurance that operates when a faultless accident occurs: the risk is spread, yet incentives for both parties to take optimal care are preserved. Further, these insights may explain some characteristics of the tort system. For example, the fact that a risk-neutral party should bear residual liability for nonnegligent conduct seems a plausible explanation for the widespread use of strict liability in product liability cases or, more generally, when victims are less likely than their injurers to be able to hedge against the risk of an accident.²⁴

5. ANALYSIS AND CONCLUSIONS

Let us now step back to review the foregoing results from a bird's-eye perspective. We have pulled together several important threads of research from the law and economics literature on torts.

It is a well-established result that activity-level incentives are a function of residual liability. Shavell's (1980) activity-level theorem shows that conventional liability rules based on negligence and strict liability cannot create optimal activity-level incentives for both parties. Negligence and strict-liability regimes apportion residual liability entirely on one party. The effect of this all-or-nothing allocation is that one party (the bearer of residual liability) is fully incentivized to undertake an optimal level of activity, while the other (who does not bear residual liability) has no legal incentive to mitigate his or her activity level.

Decoupling provides a solution by making both parties full bearers of residual liability. Unfortunately, the appeal of decoupling is confined to the realm of economic theory, given its practical untenability in modern tort systems.²⁵

At this juncture, the identification of a second-best apportionment of residual liability becomes critical. In addressing this policy question, our

24. Assuming that victims are more likely than injurers to be risk averse, the adoption of strict-liability rules can be explained, especially in the absence of insurance when defendants are risk neutral or face a diversifiable risk (for example, large producers and corporate entities).

25. The decoupled system requires a faultless victim to remain uncompensated even if the tortfeasor pays for the full amount of the harm (Polinsky and Che 1991): this implies the limited political viability of the decoupling rule on the ground of fairness and is a general offense to the natural sense of justice. In the absence of victims' compensation, it is unclear how disputes would enter the legal system. Without the hope of obtaining compensation for his injuries, a victim has no reason to bring suit against the tortfeasor—thereby bypassing the perfect liability regime entirely.

paper examines loss-sharing rules as an alternative to conventional all-or-nothing rules, identifying the factors that determine who should bear the cost of faultless accidents. We described several factors embedded in Calabresi's (1970) cheapest-cost-avoider principle, all of which bear on the optimal allocation of residual liability.

We summarize the analysis in Table 1. The allocation of residual liability plays a fundamental role in the design of tort liability. The efficiency criteria consider the role of loss sharing for risk-neutral parties. Our analysis shows that when parties are risk neutral, the optimal allocation of residual loss depends on a number of factors, which include the riskiness and the value of their activities, their interaction in the production of risk, and returns to scale from their activities. Our findings explain long-standing principles of the tort system and provide ways of improving them. For example, our results show that the party who carries out the riskier activity should bear the residual liability for nonnegligent conduct. This result can explain the widespread adoption of strict-liability rules in cases of ultrahazardous activities and the use of no liability when the victim came to the nuisance or exposed herself to risk. Similarly, our analysis explains the presence of immunities or heightened standards of liability (gross negligence or intent required for liability) when socially valuable activities are involved. Yet the foregoing analysis begs a follow-up question: how should residual liability be allocated when the factors point in different directions? For example, if the tortfeasor was the least risk producer but the victim was the cheapest activity avoider, who should bear the residual loss? Most real-life situations are characterized by countervailing considerations. In such situations, trade-offs arise, and loss-sharing rules may ultimately emerge as a more desirable alternative to all-or-nothing approaches. Finally, while risk neutrality may be a reasonable approximation of preferences when corporate actors are involved or when insurance markets are readily available, risk preferences remain a relevant factor in the allocation of residual liability. With the aim of exploring a broader range of normative goals, we discussed the possible role of loss sharing in the optimal allocation of risk between risk-averse parties. In interpreting our results, we should keep in mind that residual liability is relevant not only with respect to activity-level incentives but also for investments in unobservable precautions and in the research and adoption of new technologies for precaution (see Dari-Mattiacci and Parisi 2005). Future research could, among other things, consider how different allocations of residual loss among nonnegligent parties might

Table 1. Factors of the Cheapest-Cost-Avoider Principle: Optimal Allocations of Residual Liability

	Strict Liability	Loss Sharing	Negligence
Least risk producer	Injurer's activity is riskier	Parties' activities are equally risky	Victim's activity is riskier
Cheapest activity avoider	Victim's activity is more valuable	Parties' activities are equally valuable	Injurer's activity is more valuable
Cheapest risk avoider ^a	Victim's activity is more valuable and less risky	One party's activity is more valuable but riskier	Injurer's activity is more valuable and less risky
Best mix of activities	Superadditive risk	Subadditive risk	Superadditive risk
Best scale of activities	Victim faces increasing returns	Both face decreasing returns	Injurer faces increasing returns
Best risk bearer	Victim is risk averse	Both parties are risk averse	Injurer is risk averse

^a Combination of the least-risk-producer and cheapest-activity-avoider principles.

promote the adoption of unobservable precautions and foster the development and use of new, safer technologies.

As a final note, it is worth stressing that the six factors considered in this paper are not alternatives to Calabresi's (1970) cheapest-cost-avoider principle but are components of it. The cheapest-cost-avoider principle stands untouched as the unifying criterion that should guide the optimal allocation of residual loss: the combined effect of the several factors involved will ultimately determine who should be the bearer of residual liability. The existence of countervailing arguments arising from our analysis should not therefore be understood as obscuring Calabresi's (1970) criterion but rather elucidating it. Analyzing the cheapest-cost-avoider principle as factors therefore gives us a framework with which to carry out the analysis, and the aggregate effect of those factors will determine which party is the cheapest cost avoider, if one exists. A healthy dose of skepticism is warranted regarding the ability of policy makers to apply every factor considered here, given the difficulty in measuring some of the factors involved. But these measurement problems are indeed a point of strength of loss-sharing solutions. For practical necessity, when useful information is not known to the judicial system, loss-sharing rules provide a pragmatic and possibly superior alternative to rules in which one party bears the entire cost of accidents. In other words, in cases in which the cheapest-cost-avoider principle fails to uniquely identify one of the parties, loss sharing may emerge as the most desirable and equitable solution. The second-best liability regime, while suboptimal by definition, may be usefully reframed as being the optimal (that is, first-best) distribution of residual liability with the constraint that the total liability assigned cannot be greater than the loss from the accident, as when decoupling. And it is not difficult to see that in many (perhaps most) cases such an optimum will fall somewhere between the limiting cases of negligence and strict-liability regimes, contrary to current adjudicatory practices.

APPENDIX A: PROOFS

Proof of Proposition 1

By considering equations (3) and (4), the second-order effects of marginal changes in σ on the privately optimal activity levels are given by

$$\frac{dz^*}{d\sigma} = \frac{q_z L}{w_{zz} - \sigma q_{zz} L} \quad (\text{A1})$$

and

$$\frac{du^*}{d\sigma} = -\frac{q_u L}{b_{uu} - (1 - \sigma)q_{uu} L}. \quad (\text{A2})$$

By considering equations (3) and (4) and substituting equations (A1) and (A2), equation (5) becomes

$$\frac{(1 - \sigma)q_z^2}{w_{zz} - \sigma q_{zz} L} - \frac{\sigma q_u^2}{b_{uu} - (1 - \sigma)q_{uu} L} = 0. \quad (\text{A3})$$

To isolate the riskiness of activity from the other factors, we consider symmetrical parties except for q_z and q_u . When $q_z = q_u$, equation (A3) is satisfied for $\sigma^{**} = \frac{1}{2}$. By applying the implicit-function theorem, we obtain

$$\frac{\partial \sigma^{**}}{\partial q_z} = -2(1 - \sigma)q_z \left/ \left(w_{zz} - \sigma q_{zz} L \right) \left\{ \frac{q_u^2(-b_{uu} + q_{uu} L)}{[b_{uu} - (1 - \sigma)q_{uu} L]^2} + \frac{q_z^2(-w_{zz} + q_{zz} L)}{(w_{zz} - \sigma q_{zz} L)^2} \right\} \right., \quad (\text{A4})$$

which is positive by construction. Similarly,

$$\frac{\partial \sigma^{**}}{\partial q_u} = 2\sigma q_u \left/ \left(b_{uu} - (1 - \sigma)q_{uu} L \right) \left\{ \frac{q_u^2(-b_{uu} + q_{uu} L)}{[b_{uu} - (1 - \sigma)q_{uu} L]^2} + \frac{q_z^2(-w_{zz} + q_{zz} L)}{(w_{zz} - \sigma q_{zz} L)^2} \right\} \right., \quad (\text{A5})$$

which is negative by construction. Given that $\sigma^{**} = \frac{1}{2}$ when $q_z = q_u$, equations (A4) and (A5) imply that when $q_z > q_u$, $\sigma^{**} > \frac{1}{2}$, whereas when $q_z < q_u$, $\sigma^{**} < \frac{1}{2}$. Q.E.D.

Proof of Proposition 2

To isolate the value of activity from the other factors, we consider symmetrical parties except for w_z and b_u . By considering equations (3) and (4) and substituting equations (A1) and (A2), equation (5) becomes

$$\frac{(1 - \sigma)w_z}{\sigma(w_{zz} - \sigma q_{zz} L)} - \frac{\sigma b_u}{(1 - \sigma)[b_{uu} - (1 - \sigma)q_{uu} L]} = 0. \quad (\text{A6})$$

When $w_z = b_u$, equation (A6) is satisfied for $\sigma^{**} = \frac{1}{2}$. By applying the implicit function theorem, we obtain

$$\begin{aligned} \frac{\partial \sigma^{**}}{\partial w_z} &= 1 - \sigma / \sigma(-w_{zz} + \sigma q_{zz} L) \\ &\times \left\{ \frac{w_z[-w_{zz} + (2 - \sigma)\sigma q_{zz} L]}{\sigma^2(w_{zz} - \sigma q_{zz} L)^2} + \frac{b_u[-b_{uu} + (1 - \sigma^2)q_{uu} L]}{(1 - \sigma)^2[b_{uu} - (1 - \sigma)q_{uu} L]^2} \right\}, \end{aligned} \quad (\text{A7})$$

which is negative by construction. Similarly,

$$\frac{\partial \sigma^{**}}{\partial b_u} = \sigma / (1 - \sigma) [-b_{uu} + (1 - \sigma)q_{uu}L] \times \left\{ \frac{w_z[-w_{zz} + (2 - \sigma)\sigma q_{zz}L]}{\sigma^2(w_{zz} - \sigma q_{zz}L)^2} + \frac{b_u[-b_{uu} + (1 - \sigma^2)q_{uu}L]}{(1 - \sigma)^2[b_{uu} - (1 - \sigma)q_{uu}L]^2} \right\}, \tag{A8}$$

which is positive by construction. Given that $\sigma^{**} = \frac{1}{2}$ when $w_z = b_u$, equations (A7) and (A8) imply that when $w_z > b_u$, $\sigma^{**} < \frac{1}{2}$, whereas when $w_z < b_u$, $\sigma^{**} > \frac{1}{2}$. Q.E.D.

Proof of Proposition 3

This follows straightforwardly from the previous proofs. To isolate the value and the riskiness of activity from the other factors, we consider symmetrical parties except for w_z , b_u , q_z , and q_u . Consider equations (A3) and (A6). Ceteris paribus, when $w_z = b_u$ and $q_z = q_u$, equations (A3) and (A4) are satisfied for $\sigma^{**} = \frac{1}{2}$. From equations (A4), (A5), (A7), and (A8), we obtain that when $q_z < q_u$ and $w_z > b_u$, equations (A3) and (A6) are satisfied for $\sigma^{**} < \frac{1}{2}$, whereas when $q_z > q_u$ and $w_z < b_u$, equations (A3) and (A4) are satisfied for $\sigma^{**} > \frac{1}{2}$. When $q_z < q_u$, equation (A3) is satisfied for $\sigma^{**} > \frac{1}{2}$, and when $w_z < b_u$, equation (A6) is satisfied for $\sigma^{**} < \frac{1}{2}$. When $q_z < q_u$, $w_z < b_u$, and $\partial \sigma^{**} / \partial q_z \sim \partial \sigma^{**} / \partial w_z$, neither of the two effects prevails; thus equation (5) is satisfied for $\sigma^{**} = \frac{1}{2}$. Similarly, when $q_z > q_u$, equation (A3) is satisfied for $\sigma^{**} < \frac{1}{2}$, and when $w_z > b_u$, equation (A6) is satisfied for $\sigma^{**} > \frac{1}{2}$. When $q_z > q_u$, $w_z > b_u$, and $\partial \sigma^{**} / \partial q_z \sim \partial \sigma^{**} / \partial w_z$, neither of the two effects prevails; thus equation (5) is satisfied for $\sigma^{**} = \frac{1}{2}$. Q.E.D.

Proof of Proposition 4

When $q_{zu} \neq 0$, the second-order sufficiency condition for σ^{**} to be an interior second-best solution requires that

$$\left(\frac{\partial u^*}{\partial \sigma} \right)^2 (b_{uu} - q_{uu}L) + \left(\frac{\partial z^*}{\partial \sigma} \right)^2 (w_{zz} - q_{zz}L) - \frac{\partial^2 u^*}{\partial \sigma^2} \sigma q_{uL} - \frac{\partial^2 z^*}{\partial \sigma^2} (1 - \sigma) q_{zL} - 2q_{zu} \frac{\partial u^*}{\partial \sigma} \frac{\partial z^*}{\partial \sigma} < 0. \tag{A9}$$

Condition (A9) is always satisfied when $q_{zu} < 0$. It is more likely to be violated when $q_{zu} > 0$ and is large, which requires by contradiction that $\sigma^{**} \in \{0, 1\}$. With a large q_{zu} , the objective function for the social planner might become convex, which requires no sharing in equilibrium. This is because $q_{zu} > 0$ implies super-additivity. An increase in the activity level of the tortfeasor increases the marginal riskiness of the victim’s activity and vice versa. The social planner thus might want to disincentivate the activity of one of the parties. Q.E.D.

Proof of Proposition 5

The second-order sufficiency condition for σ^{**} to be an interior second-best solution requires that

$$\begin{aligned} & \left(\frac{\partial u^*}{\partial \sigma}\right)^2 (b_{uu} - q_{uu}L) + \left(\frac{\partial z^*}{\partial \sigma}\right)^2 (w_{zz} - q_{zz}L) \\ & - \frac{\partial^2 u^*}{\partial \sigma^2} \sigma q_u L - \frac{\partial^2 z^*}{\partial \sigma^2} (1 - \sigma) q_z L < 0. \end{aligned} \quad (\text{A10})$$

Condition (A9) is always satisfied when $w_{zz}, b_{uu} < 0$. Condition (A10) is more likely to be violated when $w_{zz}, b_{uu} > 0$ and is large, which requires by contradiction that $\sigma^{**} \in \{0, 1\}$. Q.E.D.

APPENDIX B: LOSS-SHARING NEUTRALITY

Loss-sharing neutrality implies that, under any fault-based liability rule, if due-care standards and the loss-sharing rule among nonnegligent parties are set at the (second-best) socially optimal level, parties have optimal incentives to comply with the due-care standards $x^* = x^{d^*}$ and $y^* = y^{d^*}$ regardless of the loss-sharing rule implemented among negligent parties, where the due-care standards x^{d^*} and y^{d^*} maximize the social welfare function. To prove this statement, we consider a general negligence-based liability rule in which σ denotes the sharing rule between nonnegligent parties, θ denotes the sharing rule between negligent parties, and x^{d^*} and y^{d^*} are given standards of care. Under the structural-form model of our analysis, the private maximization problem of the injurer is defined as follows:

$$\max_{x, z} U_T = \begin{cases} w(z, x) - \sigma q(z, u)L(x, y) & \text{if } x \geq x^{d^*} \text{ and } y \geq y^{d^*} \\ w(z, x) - \theta q(z, u)L(x, y) & \text{if } x < x^{d^*} \text{ and } y < y^{d^*} \\ w(z, x) - q(z, u)L(x, y) & \text{if } x < x^{d^*} \text{ and } y \geq y^{d^*} \\ w(z, x) & \text{if } x \geq x^{d^*} \text{ and } y < y^{d^*}. \end{cases} \quad (\text{B1})$$

Similarly, the private maximization problem for the victim is defined as follows:

$$\max_{y, u} U_V = \begin{cases} b(u, y) - (1 - \sigma)q(z, u)L(x, y) & \text{if } x \geq x^{d^*} \text{ and } y \geq y^{d^*} \\ b(u, y) - (1 - \theta)q(z, u)L(x, y) & \text{if } x < x^{d^*} \text{ and } y < y^{d^*} \\ b(u, y) & \text{if } x < x^{d^*} \text{ and } y \geq y^{d^*} \\ b(u, y) - q(z, u)L(x, y) & \text{if } x \geq x^{d^*} \text{ and } y < y^{d^*}. \end{cases} \quad (\text{B2})$$

To prove that parties have incentives to comply with the due-care standard, we need to show that neither party has incentives to deviate from the due-care equilibrium by investing in suboptimal or excessive care. We provide the proof for

the case with suboptimal care. (The proof with excessive care follows similar lines and is available on request from the authors.)

In equilibrium, the injurer is not able to increase his or her payoff by undertaking less than due care ($x < x^{d^*}$) if the following condition holds:

$$w(z^*, x^{d^*}) - \sigma^{**}q(z^*, u^*)L(x^*, y^{d^*}) > w(z, x) - q(z, u^*)L(x, y^{d^*}) \quad (B3)$$

for all $x < x^{d^*}$ and $z = z(x, y^{d^*}, \sigma^{**})$. In fact, given that $x^{d^*}, y^{d^*}, u^* = u(x^{d^*}, y^{d^*}, \sigma^{**})$ and $z^* = z(x^{d^*}, y^{d^*}, \sigma^{**})$ maximize the social welfare function, we must have

$$\begin{aligned} & w(z^*, x^{d^*}) + b(u^*, y^{d^*}) - q(z^*, u^*)L(x^{d^*}, y^{d^*}) \\ = & w[z(x^{d^*}, y^{d^*}, \sigma^{**}), x^{d^*}] + b(u^*, y^{d^*}) - q[z(x^{d^*}, y^{d^*}, \sigma^{**}), u^*]L(x^{d^*}, y^{d^*}) \quad (B4) \\ > & w[z(x, y^{d^*}, \sigma^{**}), x] + b(u^*, y^{d^*}) - q[z(x, y^{d^*}, \sigma^{**}), u^*]L(x, y^{d^*}). \end{aligned}$$

for all $x < x^{d^*}$ and $z = z(x, y^{d^*}, \sigma^{**})$. Since $\sigma^{**} \in [0, 1]$, we have that

$$w(z^*, x^{d^*}) - \sigma^{**}q(z^*, u^*)L(x^{d^*}, y^{d^*}) > w(z^*, x^{d^*}) - q(z^*, u^*)L(x^{d^*}, y^{d^*}). \quad (B5)$$

It follows that

$$w(z^*, x^{d^*}) - \sigma^{**}q(z^*, u^*)L(x^{d^*}, y^{d^*}) > w(z, x) - q(z, u^*)L(x, y^{d^*}) \quad (B6)$$

for all $x < x^{d^*}$ and $z = z(x, y^{d^*}, \sigma^{**})$, which proves that undertaking less than due care is never an equilibrium.

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