Bilateral Accidents with Intrinsically Interdependent Costs of Precaution
Author(s): Dhammika Dharmapala and Sandra A. Hoffmann
Source: *The Journal of Legal Studies*, Vol. 34, No. 1 (January 2005), pp. 239-272
Published by: The University of Chicago Press for The University of Chicago Law School
Stable URL: http://www.jstor.org/stable/10.1086/425598
Accessed: 26-06-2016 20:49 UTC

Bilateral Accidents with Intrinsically Interdependent Costs of Precaution

Dhammika Dharmapala and Sandra A. Hoffmann

ABSTRACT

The standard economic model of bilateral precaution postulates that the care that is taken by injurers and victims affects only expected accident loss. This paper considers situations in which each party's precaution also directly affects the other party's cost of taking precaution. When this additional externality is introduced into a model of unilateral harm, none of the standard tort liability rule induce socially optimal behavior by both parties. Moreover, under a contributory negligence rule, the only equilibrium is in mixed strategies; this gives rise to the possibility of litigation in equilibrium. "Tortlike" liability rules that can induce socially optimal care by both parties are characterized. The model is then extended to consider the case of bilateral harm, in which all negligence-based tort rules lead to socially optimal care by both parties, as long as each can sue to recover its full accident losses.

1. INTRODUCTION

In the standard bilateral precaution model of torts, each party's cost of care depends directly only on its own level of precaution. The interdependency between the two parties' total accident costs occurs only via

DHAMMIKA DHARMAPALA is Assistant Professor of Economics at the University of Connecticut. SANDRA A. HOFFMANN is a fellow with Resources for the Future in Washington, D.C. We would like to thank the editor (Alan Sykes) and two anonymous referees for valuable suggestions and Peter Berck, Jim Boyd, Dallas Burtraw, Bob Cooter, Carolyn Fischer, Rachael Goodhue, Avery Katz, Jim Sanchirico, Kathy Segerson, Eric Talley, seminar participants at Georgetown University Law Center, Monash University, and Resources for the Future, participants at the 2001 American Law and Economics Association meetings, and especially Warren Schwartz for helpful discussions and comments. An earlier version of this paper was circulated as a Resources for the Future Discussion Paper (no. 01–13). Dharmapala wishes to acknowledge the financial support of the John M. Olin Foundation. All remaining errors are, of course, our own.

[*Journal of Legal Studies*, vol. 34 (January 2005)]
 0047-2530/2005/3401-0008$01.50

the effects of care on the expected loss from the accident (for example, Shavell 1987, pp. 32–46). In this paper, we analyze bilateral accidents in which one party's level of care also directly influences the cost to the other party of supplying any given level of care. As is well known, the standard bilateral precaution model leads to the conclusion that, with legal standards of care set at the socially optimal levels and with no litigation costs, uncertainty, misperception, error, or wealth constraints,[1] all negligence-based liability rules induce socially optimal care by both injurers and victims.[2] Leong (1989) and Arlen (1990a, 1990b, 1992) generalize the standard bilateral precaution model to accommodate bilateral harm (where accident losses are suffered by both parties). As long as each party can recover damages for its accident losses, the basic result is similar to that of the standard unilateral harm model: in the absence of litigation costs, uncertainty, misperception, error, and wealth constraints, all negligence-based tort rules induce optimal behavior by both parties (Arlen 1990b). We show that with an interdependence between parties' costs of precaution, negligence-based rules no longer guarantee optimal care.

The kind of situation described by this model occurs every day. For example, demand for heavy vehicles, such as sport utility vehicles (SUVs), vans, and trucks, has increased dramatically in the United States in recent years (White 2004). Owners of such vehicles frequently claim that their occupants are safer in the event of a crash; on the other hand, occupants of cars and others who may be struck by heavy vehicles are likely to suffer more severe damage.[3] These externalities affect the expected accident loss and so can be readily accommodated within the standard model (at least its bilateral risk variant).[4] However, owners of heavy vehicles often claim that, in addition to reduced damage in the event of a crash, the greater height of such vehicles improves the driver's ability

1. The standard model has its origins in the analysis of Brown (1973). See also for example, Ordover (1978) on litigation costs, Craswell and Calfee (1986) on uncertainty, and Shavell (1986) on wealth constraints.

2. The optimality result does not extend, in general, to the choice of activity level. This paper focuses on the choice of levels of care and does not consider the issue of activity levels (but see the discussion in Section 2).

3. White's (2004) empirical analysis uses data on fatal accidents to show that the positive effect for occupants of heavy vehicles is substantially outweighed by the negative effect on other road users.

4. As White (2004) argues, however, the degree to which the new technology is adopted may not be socially optimal, even within the standard framework, if liability rules do not take account of this added externality.

to observe the road and so reduces the effort cost required to take a given level of precaution. For instance, a typical state statute defines the "level of care" to be taken at a stop sign as coming to a complete stop and verifying that the intersection is free of traffic before proceeding (Code of Iowa, chap. 321.322 [2004]). The associated "cost" is the effort or disutility that is involved in taking this level of precaution.[5] By purchasing an SUV, a driver adopts a technology (or method of taking care) that shifts inward her cost of taking precaution (in this case, the cost of checking for traffic). At the same time, the SUV driver potentially shifts out the effort cost to other drivers of taking that same level of precaution. Imagine, for example, a car that is stopped next to an SUV at an intersection. Because of the latter's height, the driver of the car must incur a higher effort cost or disutility to take the given level of precaution (for example, by craning her neck to look around the SUV or by waiting longer until the SUV has cleared the intersection in order to verify that other vehicles are not approaching it). Alternatively, the automobile may be following the SUV. In order to stop in time, the driver may have to slow or allow more following space, or in general pay much closer attention to the SUV's movements than if the vehicle ahead were another automobile that allowed the following car better visibility. In either case, the SUV driver's choice of technology shifts out the car driver's cost of precaution.

This basic problem is not limited to our roadways. Consider a scenario based roughly on the recent oil spill of the *Prestige* off the Spanish and Portuguese coasts.[6] An old, poorly maintained oil tanker is critically damaged in a storm and appears likely to break up. The tanker seeks entry into a nearby port where it might be easier to perform repairs or to transfer the oil to a different vessel. The authorities of the region in which the port is located prohibit entry and send tugs to tow the tanker farther out to sea to prevent spilt oil from reaching fragile coastal areas where it would do the most harm (the region's economy is based heavily on fishing and tourism). Repairs to the tanker are more difficult and costly on the high seas, and the tanker breaks up. Despite the authorities' efforts, the region's coast experiences a major oil spill. Here the victim chooses a method of taking care that increases the injurer's cost of taking

5. This is a somewhat more general notion of "costs" than is sometimes found in the literature (where the focus is on monetary costs, such as foregone earnings due to driving slower—see the discussion of this issue in Section 3.1).

6. See Environmental Literacy Council, *Prestige Oil Spill* (http://www.enviroliteracy.org/subcategory.php/217.html).

precaution. In this case, both parties suffer harm, although it would be a question of fact whether the loss of the oil by the tanker was legally caused by the regional authorities' order.[7] Nevertheless, the victim (the coastal area) has affected not only the expected loss from the accident but also the ease and cost to the injurer (the tanker) of taking care to prevent the loss.

In the standard model, parties interact only by affecting the expected benefit from precaution. In the model presented in this paper, as can be seen from these examples, parties can also interact by directly affecting (shifting) each others' supply of precaution. One might think that this cost-side interdependency would be symmetrical to the interdependency of accident losses in the standard analysis, particularly as the labeling of costs and benefits is somewhat arbitrary. However, we find that this is not the case. When both parties' care affects the others' cost of precaution in an otherwise standard unilateral harm model, none of the standard liability rules can induce optimal care by both injurers and victims.

The basic intuition for this result is that these tort rules allow for accident losses to be shifted between the parties but make no such provision for shifting precaution costs. In particular, there is no cause of action for one party to recover its precaution costs, or part thereof, from the other. Thus, for example, under a simple negligence rule, the injurer will comply with the standard of due care. Anticipating this, the victim will choose a level of care to minimize the sum of her accident losses and her costs of precaution but has no incentive to consider the injurer's precaution costs (which, under our assumptions, are affected by the victim's choice of care). It might appear that this inefficiency could be corrected simply by the court adjusting the amount of damages awarded in order to account for the cost interdependency. However, we show below that it is not in fact possible to do so within the limitations of traditional tort rules.[8]

The fundamental problem here is that optimality requires that the

7. In the *Prestige* case, Spain has sued the tanker owners, but it does not appear that the tanker owners have countersued Spain for damages (see https://www.lloydsagency.com/Agency/Salvage.nsf/vwSalvageCases/952F3D178BA3850580256C7E00573320?OpenDocument). Thus, this may be viewed as a unilateral harm case in terms of the procedural posture in which lawsuits are brought ex post (see the discussion of this issue in the text below).

8. In principle, it is possible to modify the damages award in a manner that depends on victim precaution; however, this will impair the incentives for the injurer to take optimal care—see the discussion in Section 3.

victim internalize the externality affecting the injurer's costs. Under traditional tort rules, a victim bears only the cost to herself from choosing a suboptimal level of care; such rules do not include fines for victims who fail to take due care. In order to implement the social optimum, it is necessary to consider a wider class of rules. To illustrate this point, we characterize "tortlike" mechanisms (some of which involve the decoupling of liability) that induce optimal behavior by supplementing the injurer's accident liability with a fine paid by the victim or with a payment by the victim to nonnegligent injurers whenever an accident occurs. While these rules may be tortlike, they are not contemplated by conventional tort law.

A second significant result within this framework is that, under a contributory negligence rule, there is no equilibrium in pure strategies. Rather, the only equilibrium is in mixed strategies, which implies that the parties will choose (with some positive probability) to behave negligently in equilibrium. This gives rise to the possibility of successful litigation in equilibrium. This contrasts with the standard model where parties who face negligence rules always satisfy the standard of care, so that, although there are some accidents, all parties are nonnegligent. Existing answers to the question of why we have extensive, successful, tort litigation have focused on information deficiencies, error, and wealth constraints; our analysis reveals an additional possibility.

We also extend the model to the case of bilateral harm (where both parties may suffer accident losses). In these circumstances, as long as both parties can sue to recover their accident losses, all negligence-based tort rules lead to socially optimal behavior by both parties. This might seem to raise questions about the relevance of our inefficiency results in the unilateral harm case. But there are several reasons to believe that the unilateral case is important to torts. First, it is difficult a priori to distinguish between bilateral and unilateral harm cases because the harm has not been realized. As Arlen (1990b) points out, the only unambiguous distinction that can be made between unilateral and bilateral harm cases is the procedural posture in which the cases are brought ex post. From a court's perspective, a unilateral harm case is one in which one party sues as a plaintiff and the defendant in that action does not countersue for damages also sustained. Many, if not most, tort cases involve unilateral harm in this sense. Second, from the practical ex ante perspective of the party taking care, the usual concern would be about one's own action causing another party harm. The choice of the level of precaution is likely to be taken under the assumption that one is trying to prevent unilateral harm; thus, the unilateral harm case matters from a practical perspective. Finally, even from a theoretical ex ante perspective, Arlen (1990b) argues that one could think loosely of unilateral harm cases as those in which one party is engaged in an activity that is typically passive relative to the other (for example, a pedestrian in relation to a car). Under Arlen's conceptualization, our oil spill example could be characterized as a unilateral harm case. While automobile accidents typically involve bilateral harm, there are circumstances in which one could think of an automobile driver as being passive relative to an SUV driver, so our SUV example may not necessarily be a bilateral harm case (for purposes of exposition, we focus on the SUV example throughout the paper to illustrate both the unilateral and bilateral harm models).

Finally, we consider the implications of these results for the circumstances in which tort law can and cannot induce optimal behavior. We find that the externalities can be internalized through tort liability rules if a legal standard of care and liability for damages are imposed on each party that creates externalities (regardless of how many different externalities the party generates) and courts can take account of all relevant externalities in setting legal standards. It is not necessary for the law to create as many causes of action as there are externalities.

In the next section, we further explain the motivation for this paper. The formal model for the unilateral harm case is presented in Section 3. This is then extended to the case of bilateral harm in Section 4. Section 5 discusses the wider implications of the results, and Section 6 concludes.

2. MOTIVATION

Figures 1 and 2 illustrate the difference between the standard model (Shavell 1987) and our generalization of that model. In each figure, the horizontal axis represents the injurer's level of care (x), while the vertical axis represents costs (monetized to dollars). Following the modified Hand formula (*United States v. Carroll Towing Co*., 159 F.2d 169 [2d Cir. 1947]), the court defines reasonable care, x^*, by comparing the marginal benefits of additional precaution with the marginal costs borne by the injurer in undertaking further precaution. Marginal benefits (MBs) are assumed to be constant, while marginal costs (MCs) are increasing in x. For bilateral accidents, MB is a function of both x and y (where y is the victim's level of care). In the standard model, the injurer's marginal cost is assumed to depend only on his own precaution (that is, MC = MC(x)), as in Figure 1. The major innovation in this paper is quite simple—it is to allow for the possibility that the injurer's (and victim's) marginal cost can depend on both parties' care, as in Figure 2 where the injurer's MC equals MC($x; \ y$). The implications of this innovation for the ability of conventional tort rules to induce socially optimal behavior are analyzed below in Sections 3 and 4.

One of the motivating examples in this paper (introduced in Section 1) concerns the effects of SUVs and other heavy vehicles on other road users' cost of precaution. This involves conceptualizing one aspect of a driver's choice of precaution as being the choice of technology (in this case, buying either an SUV or a car). The objection may be raised that this choice involves an activity level rather than a level of care (with the driving of cars and SUVs being viewed as different "activities"). Of course, it is well known that the optimality results in the torts literature apply only to the choice of care by injurers and victims; the choice of activity level will not generally be optimal under any standard tort rule (for example, Shavell 1980). From this perspective, our results may not appear quite so surprising. However, while the issue is to some extent semantic, we believe that the crucial analytical issue is the following. In the existing literature (for example, Shavell 1980), an activity level is conceptualized as affecting only the expected accident loss; it does not affect the cost of either party's care. For instance, in this standard formulation, how much drivers drive affects the number of accidents that occur but not the cost associated with satisfying a given negligence standard. Thus, the phenomenon that we identify is analytically distinct from activity levels as they are usually conceived.

This emphasis on precaution costs distinguishes our model from the otherwise closely related work of Hindley and Bishop (1983). They develop a model of accidents that focuses entirely on the choice of activity level and assume that there are two different types of cars that are intrinsically more or less prone to accidents. Their setting is one that is analogous to bilateral harm in that drivers can both hit other drivers and be hit by them. Two distinct externalities are identified: one is due to the effect of the total number of cars (that is, the activity level) on the probability of accidents, while the other is due to the composition of the stock of cars (in terms of the two types of cars). They argue that a rule that requires each party to an accident to pay the full cost (termed the "Earl Thompson liability rule") can help correct the latter externality, although not the former.

In the sense that the two types of vehicles can be regarded as being

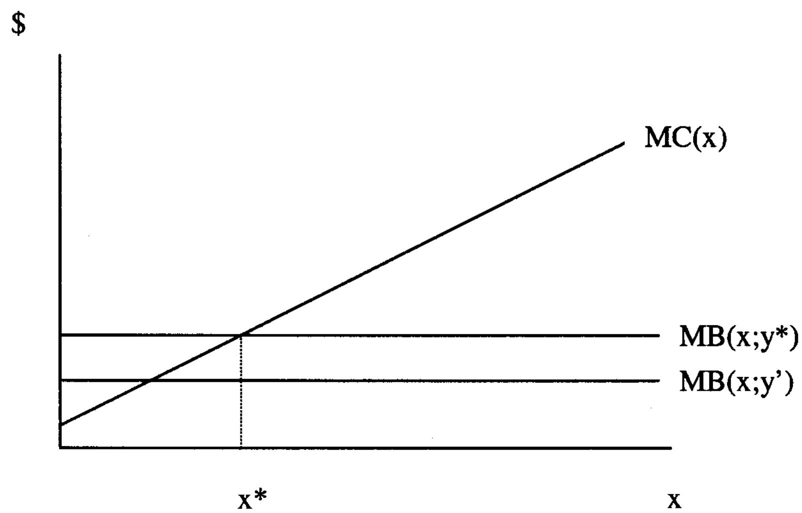

Figure 1. Marginal costs and benefits of precaution when MC equals MC(x)

analogous to cars and SUVs, Hindley and Bishop (1983) is related to the approach taken in our model. However, the focus is very different, as they abstract completely from issues of optimal care by assuming a fixed probability of accidents and a fixed magnitude of loss. In contrast, we ignore the choice of activity level and focus entirely on the choice of levels of care; in our model (as is typical in the literature), the expected loss from accidents depends on the choice of care by injurers and victims, while the activity level is implicitly held fixed. The reason for this choice is that inefficiency results for activity levels are well known, while our aim is to present novel inefficiency results for the choice of care.[9]

3. THE CASE OF UNILATERAL HARM

3.1. The Model

The model used in this paper follows the standard analysis of accidents between strangers with bilateral precaution, as presented in Shavell

9. Similarly, our focus is different from that of Meese (2001). That paper points out an externality that occurs because of the failure of tort rules to induce optimal activity levels—in choosing their activity level, injurers fail to take into account victims' expenditures on care, which creates the possibility that the former (even while conforming to a standard of due care) may choose a positive level of an activity when the socially optimal level is zero.

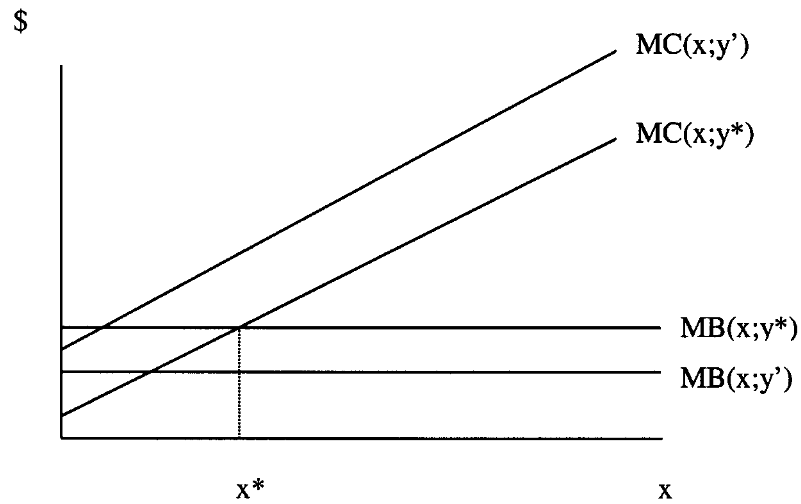

Figure 2. Marginal costs and benefits of precaution when MC equals MC($x; y$)

(1987, p. 36). All injurers (I) are assumed to be identical, as are all victims (V); all actors are assumed to be risk neutral. Each party can take precaution that reduces the expected loss from an accident (that is, reducing the probability of the accident, the harm if it does occur, or some combination of the two) and faces a cost of taking such precaution. In this section, a unilateral harm framework is assumed; thus, if an accident occurs in spite of these precautions, the losses are borne directly only by V. Depending on the liability rule that applies, I may or may not be required to compensate V. If such a payment is made, it is assumed to perfectly compensate V for the accident loss (thus, these losses are purely pecuniary in nature).

It is assumed that the parties have complete information about their payoffs and the applicable legal rules and standards, share common prior beliefs about the probability of the accident, and are not subject to error in their choice of actions. Parties are assumed to choose their level of care so as to minimize the sum of their own costs of precaution and expected liability from accidents given the governing tort rules. Courts are similarly assumed to have perfect information about costs, expected damages, and the relationships between care and expected damages. Where tort rules involve negligence, courts are assumed to set the due care standard at the level that minimizes social cost. We will refer to this as the socially optimal or efficient level of care.

Recall the SUV example with which we began the paper. The type of situation depicted there may be formalized as follows. Suppose that there are two (risk-neutral) parties, an injurer (I) and a victim (V). Suppose that the former can choose a type of vehicle, or "technology" $t \in \{\text{car, SUV}\}$, as well as a level of care (denoted x) with which to drive that vehicle. Assume initially that only I has available a choice of technology, while V's technology is fixed (that is, V drives a car), so V's only choice is a level of care in driving a car (denoted y). Note that the model can easily be extended to the case in which both parties can make a choice of t. The expected accident loss (which depends on each party's level of care and on I's choice of t) is assumed to be borne entirely by V. The more general case of bilateral harm is analyzed in Section 4 below.

For I, adopting the SUV technology can be assumed to shift down the function (denoted $f(x;\ t)$) that represents the utility cost of taking care. I's utility is

$$U_{\mathrm{I}} = u_{\mathrm{I}}^0 - f(x;\ t), \tag{1}$$

where u_{I}^0 is the exogenous utility from all other sources. It can be assumed that $f(x;\ \text{car})$ is greater than $f(x;\ \text{SUV})$ for any given x (for instance, it takes less effort to check for traffic in an SUV because the road is more easily visible, given that one is higher up).

V's disutility of precaution is also affected by I's choice of technology; for example, if I is in an SUV, it takes more effort for V to check for traffic, say, by craning her neck to look beyond the SUV. Let $g(y;\ t)$ denote V's disutility of precaution, with $g(y;\ \text{SUV}) > g(y;\ \text{car})$ for any given y. V also bears the losses if an accident occurs (implicitly, we are assuming a rule of no liability, but a similar exercise can be carried out for each of the liability rules analyzed in this paper). Let the expected accident loss be $L(x, y, t)$ (as it is natural to suppose that the loss to V if there is an accident will be larger when I is in an SUV; the inclusion of both x and y reflects the assumption of bilateral precaution). V's utility can then be expressed as

$$U_{\mathrm{V}} = u_{\mathrm{V}}^0 - g(y,\ t) - L(x,\ y,\ t), \tag{2}$$

where u_{V}^0 is the exogenous utility from all other sources.

Because both x and t are choices made by I, it is possible to represent them as different elements of an overall vector of care exercised by I. Let $\boldsymbol{x} = (x,\ t)$ denote this vector; then equations (1) and (2) above can be expressed using $\boldsymbol{x}$. Now, consider a simple social welfare function that is additive in the utilities of I and V. Then, maximizing social welfare is equivalent to minimizing

$$f(\boldsymbol{x}) + g(\boldsymbol{x},\ y) + L(\boldsymbol{x},\ y). \tag{3}$$

The standard model of bilateral accidents (for example, Shavell 1987) imposes the restriction that $g(\boldsymbol{x},\ y) = g(y)$. Representing the functions $f(\boldsymbol{x})$ and $g(y)$ as the costs of precaution for I and V, respectively (typically denoted $C^{\mathrm{I}}(x)$ and $C^{\mathrm{V}}(y)$), the social cost of accidents is thus

$$C^{\mathrm{I}}(\boldsymbol{x}) + C^{\mathrm{V}}(y) + L(\boldsymbol{x},\ y). \tag{4}$$

In our model, this restriction is not imposed, so the social cost of accidents is given by equation (3). For ease of comparison with the standard model, we label $f(\boldsymbol{x})$ and $g(\boldsymbol{x},\ y)$ as the costs of precaution for I and V, respectively (denoted $C^{\mathrm{I}}(\boldsymbol{x})$ and $C^{\mathrm{V}}(\boldsymbol{x},\ y)$). The social cost of accidents in our example is thus

$$C^{\mathrm{I}}(\boldsymbol{x}) + C^{\mathrm{V}}(y;\ \boldsymbol{x}) + L(\boldsymbol{x},\ y). \tag{5}$$

While we have motivated this formulation with an example in which I's care has two distinct dimensions (x and t), the results below are unaffected if we simplify equation (5) by assuming a one-dimensional level of care for I (where this dimension affects V's precaution costs). In addition, our motivating example is one in which I's precaution affects V's costs of care but not vice versa. In the interests of generality, we solve the general case (where both C^{I} and C^{V} each depend on both parties' precaution levels) in the analysis below. Thus, the social cost of accidents in our model can be expressed as[10]

$$C^{\mathrm{I}}(x;\ y) + C^{\mathrm{V}}(y;\ x) + L(x,\ y). \tag{6}$$

Our generalization of the standard bilateral precaution model raises two significant issues. The first concerns the way in which courts set due care standards. A conceptual distinction can be drawn between the level of care that is taken by a party (characterized in terms of that party's behavior) and the cost (whether a dollar amount or some nonmonetary

10. It is also possible to analyze two special cases, one in which C^{I} depends only on x while C^{V} depends on both x and y, and the other in which C^{I} depends on both x and y, while C^{V} depends only on y. These special cases are solved separately in Dharmapala, Hoffmann and Schwartz (2001). Note also that, in our example, I's precaution makes V's precaution more costly. It is also possible that one party's care may reduce the other party's cost of care; analogous results can be derived for this case.

cost) associated with that care. In the standard model, this distinction does not matter, as the cost (C) of care is used as the unit by which the level (x) of care is measured. However, where a party's cost of care may also depend on the other party's behavior, the distinction between levels and costs of precaution becomes significant. In practice, courts almost invariably describe standards of care in terms of the party's behavior (for example, the speed at which they were traveling) rather than in terms of the expenditure on care. Thus, we assume that while courts define reasonable care as a level of care such that the costs do not outweigh the benefits of taking care, the standard that an injurer faces is a standard of behavior, that is, a level of care, x.[11]

The second issue concerns the assumption that the court sets the standard of care for each party at the socially optimal level of care for that party to take, given that the other party takes socially optimal care. Under this assumption, a party that meets this standard of care will not be found negligent, even though the other party chooses to behave negligently (that is, the standard does not vary with the behavior of the other party). Of course, this conforms to what courts tend to do in practice;[12] however, given our assumptions about the court's information and capacities, the question naturally arises as to why courts do not set more complex rules where the standard of care, x^*, depends on the other party's behavior, so that $x^* = x^*(y)$. We note here that, while it greatly simplifies the analysis, our assumption of a fixed standard is not crucial to the results; the inefficiency results derived later in this section would continue to hold under a variable standard of care. This point is explained more fully in Section 3.3.

3.2. Assumptions

Following Shavell (1987, p. 36), we assume that the accident loss is nonnegative and decreasing at an increasing rate in both I's and V's

11. For instance, in the classic case of *United States v. Carroll Towing Co.* (159 F.2d 169), Judge Hand's assessment of whether the barge owner was negligent focused on whether or not a bargee was present on the barge, rather than on the wages that the bargee would have had to be paid. For a discussion of various issues that relate to what is meant by a standard of care, see Schwartz (1989).

12. There is a narrow area of exception to this under the "last clear chance" doctrine, where the defendant can be held liable despite the plaintiff's negligence if the defendant could have acted to avoid the accident given the plaintiff's negligent behavior—see *Dunn Bus Service v. McKinley* (130 Fla.778, 178 So. 865 [1937]). For an economic analysis of the last-clear-chance doctrine, see Wittman (1981).

precaution levels:

Assumption 1. (i) $L(x, y) \geq 0$; (ii) $L_x < 0$; (iii) $L_y < 0$; (iv) $L_{xx} > 0$; (v) $L_{yy} > 0$.

It will be assumed that each actor's cost is increasing and convex in her own level of precaution, so

Assumption 2. (i) $C_x^{\mathrm{I}} > 0$; (ii) $C_y^{\mathrm{V}} > 0$; (iii) $C_{xx}^{\mathrm{I}} > 0$; (iv) $C_{yy}^{\mathrm{V}} > 0$.

While it is possible that one party's care may render the other's precaution more costly, the focus here is on the case of positive externalities in costs of precaution. It is assumed that a higher level of care by one party lowers the other party's cost of care:

Assumption 3. (i) $C_y^{\mathrm{I}} \leq 0$; (ii) $C_x^{\mathrm{V}} \leq 0$.

This assumption changes only the direction of deviation of equilibrium care from socially optimal care, not the basic efficiency results of this paper.

A further assumption is that the accident losses L are "sufficiently large" relative to the costs of precaution, in the following sense:

Assumption 4. (i) For any y and any $x < x^*$, $L(x, y) > C^{\mathrm{I}}(x^*;\ y) - C^{\mathrm{I}}(y;\ x)$.

Thus, if courts impose a standard of care x^* on I, it is assumed that the cost savings that I can achieve by taking less care than required by the standard are always exceeded by the increase in the expected accident losses (and hence, under a negligence rule, in the expected liability). This assumption maintains the discrete jump between the injurer's expected losses for levels of precaution below and at or above the social optimum that the standard model depends on to assure that the injurer takes optimal precaution under negligence rules (Shavell 1987, p. 35).

It should be emphasized that this is not as restrictive an assumption as it may appear at first. Suppose that the court can impose, in addition to damages L that compensate V for the accident loss, a punitive penalty, represented by a nonnegative constant D, on I. Then, even if assumption 4i is not satisfied, it will always be possible to choose a D such that $D + L$ exceeds the right-hand side of the expression in assumption 4i.

An analogous assumption is made for V:

Assumption 4. (ii) For any x and any $y < y^*$, $L(x, y) > C^{\mathrm{V}}(y^*;\ x) - C^{\mathrm{V}}(y;\ x)$.

Assumptions 4i and 4ii may seem strong. However, it should be remembered that without these assumptions a party on which a negligence rule is imposed will not, in general, choose to satisfy that standard. The central results of this section are the nonoptimality of behavior under the standard tort rules, even when assumption 4 holds. Thus, relaxing assumption 4 would simply reinforce this basic result by making nonoptimal behavior even more pervasive.[13] In this sense, assumption 4 is a conservative assumption and makes the best possible case for the efficiency of standard tort rules.

3.3. Results

This section analyzes the behavior of I and V under six different tort liability rules: no liability (NL), strict liability (SL), simple negligence (N), strict liability with a defense of contributory negligence (SLdN), negligence with a defense of contributory negligence (NdN), and comparative negligence (CN). We follow standard definitions of these rules (Shavell 1987, chap. 2; Cooter and Ulen 1997). In the case of CN, we assume that when both parties are negligent, liability is shared; however, we do not specify a particular sharing rule.[14] In each of the rules that involves a negligence standard, we follow the previous literature and assume that the court sets the standard of care at the socially optimal level of care, $x = x^*$ and/or $y = y^*$, as applicable, with no uncertainty or error.[15]

Minimizing the social loss of accidents (equation [6]) with respect to x and y, the first-order conditions (FOCs) are

$$C_x^{\mathrm{I}}(x, y) + C_x^{\mathrm{V}}(x, y) + L_x(x, y) = 0 \tag{7}$$

13. Additional assumptions to ensure that the second-order conditions for the minimization of equation (6) are satisfied are discussed in the Appendix.

14. Various sharing rules have been used with CN over time. Early admiralty cases split liability 50/50, while some variants only require sharing of liability when the victim's actions have contributed at least 50 percent to the probability of the accident. We follow the more common case of applying comparative negligence whenever both parties are negligent (the most widely used approach apportions liability relative to fault). In the standard full-information rational actor model, CN is efficient regardless of the apportionment rule (Rea 1987).

15. Following the standard assumption about causality rules, it is assumed that when a negligence standard is imposed on I, I is assumed to have caused the entire accident loss suffered by V, rather than just the amount attributable to I's negligence. See Grady (1984) and Kahan (1989) for a discussion of this issue.

and

$$C_y^{\mathrm{I}}(x;\ y) + C_y^{\mathrm{V}}(y;\ x) + L_y(x,\ y) = 0. \tag{8}$$

Assuming an interior solution, these FOCs define the socially optimal x^* and y^*, given the social loss function above. The results of this section can be summarized as follows.[16] None of the standard tort rules induce socially optimal behavior (x^*, y^*) by both I and V. Consider, for instance, rule N. As in the standard model, I will always satisfy the standard of due care x^* in order to avoid the discontinuous leap in accident liability that results from failing to satisfy it. Given that I satisfies x^*, V will anticipate bearing all of her own accident losses; thus V will minimize the sum of expected accident losses and her own precaution costs. However, V will not take into account the precaution costs faced by I (which are affected by V's choice of y). This leads V to take a lower level of care than is socially optimal. I will thus satisfy the standard, but will incur a higher cost in doing so than if V were behaving optimally.

This intuition can also be represented in terms of the simple diagrams in Figures 1 and 2. Suppose that the victim takes less than socially optimal care ($y' < y^*$). In both figures, this shifts the MB curve downward. In the standard model, the victim's action has no effect on the injurer's MC function (Figure 1), but in our model the change in y also shifts the injurer's MC function upward (Figure 2). In neither case does y affect the standard of care x^* to which the injurer is held, and in both models the injurer always satisfies the standard of care x^* under a negligence rule, regardless of the victim's action. In the standard model, should the victim choose to exercise less than socially optimal care, the injurer will still meet the due care standard x^* and the injurer's total cost of precaution will not change with the victim's action. What does change is that the total social benefit (expected accident loss) that results from both parties' care is reduced (see Figure 1). Now consider our model, in which the victim's care affects the injurer's costs of care (Figure 2). Suppose that the injurer continues to meet the standard of care x^*. Now, should the victim decide to take less than socially optimal care, not only is total social benefit reduced, but the injurer's total (and marginal) cost of taking socially optimal care also increases.

These results imply that in the unilateral harm case with intrinsically interdependent costs of care, no tort rule induces socially optimal be-

16. A more formal statement of these results is presented in proposition 1 in the Appendix.

havior. For instance, N provides I with incentives to take optimal precautions but does not confront the V with either the external impact of her precaution on I's cost of precaution or with the necessity of complying with a legal standard of care in order to avoid bearing the accident cost. Similarly, under SLdN, V must comply with the negligence standard to avoid bearing the accident cost. However, under SLdN, I is motivated only to minimize her own cost of precaution and the accident cost. I therefore ignores the external impact of her action on V's cost of precaution and fails to take socially optimal precaution. Under CN, V neither faces this external impact nor can fully avoid bearing accident costs by meeting a court-determined standard of care. As a result, V will not take socially optimal precaution, and CN cannot induce socially optimal precaution from both parties.

It may appear at first that the results are simply due to our assumptions about the level of damages set by the court. In particular, it might seem that the inefficiency could be corrected simply by the court adjusting the amount of damages awarded in order to account for the cost interdependency. However, it can be shown that it is not in fact possible to do so within the limitations of traditional tort rules. Optimality requires that the legal rule force the victim to internalize the externality imposed by her choice of y on the injurer's costs $C^{\mathrm{I}}(x;\ y)$. In principle, it is possible to do this by setting a damages award (denoted A) that does not simply equal the accident loss $L(x, y)$; A could, rather, be set to punish the victim for suboptimal precaution. However, this will impair the incentives for the injurer to take optimal care. To illustrate this point, suppose that (under rule N) V takes optimal care ($y = y^*$); then I faces costs

$$C^{\mathrm{I}}(x;\ y^*) + A. \tag{9}$$

Clearly, setting any A other than $A = L(x, y^*)$ will lead I to choose an x that differs from x^*; conversely, of course, if A is set so that I chooses x^*, V will not find it privately optimal to choose y^*. Thus, manipulating the level of damages under rule N cannot induce socially optimal behavior by both parties. This point can be reiterated for each of the standard tort rules (in Section 3.5, however, we characterize more general tort-like mechanisms that implement the social optimum).

Finally, we return to an issue that was raised in Section 3.1—the assumption of a fixed standard of due care independent of the other party's behavior. The important point to stress here is that the inefficiency results of this section are not crucially dependent on this assumption. To see the intuition for this, suppose that the court were to set the standard of care under rule N as a function $x^*(y)$ (note that this does not change the social optimum, which is $[x^*(y^*), y^*]$). Then if V were to choose y^*, I's best response would be to choose $x^*(y^*)$; however, if I chooses $x^*(y^*)$, V will choose a suboptimal level of y less than y^*, for essentially the same reasons as in the model with a fixed standard. In particular, V does not internalize I's precaution costs and so faces a different program than does the social planner when I sets x equal to $x^*(y^*)$. Thus, the social optimum $[x^*(y^*), y^*]$ cannot be a Nash equilibrium, even if the court were to set a variable rather than fixed standard of care.

3.4. Equilibria in Mixed Strategies

In the case of NdN, there is no pure-strategy Nash equilibrium. It can be shown, however, that there exists a (unique) equilibrium in mixed strategies under NdN. Note first that, from the proof of the nonexistence of pure-strategy equilibria in proposition 1 (see the Appendix), I's best responses to any of V's pure strategies involve taking precaution level x equal to either x^* or zero. Similarly, V's best responses to any of I's pure strategies involve taking precaution level y equal to y^* or y^N. Thus, it is possible to simplify the game induced by the NdN rule to one with a finite number of strategies (that is, two) for each player. The existence of an equilibrium in mixed strategies follows straightforwardly from Nash's existence theorem.

Given the above simplification, any pair of mixed strategies can be represented by the parameters $r, q \in [0, 1]$, where r is the probability that I plays x^* and q is the probability that V plays y^*. It follows that the probability that I plays zero is $(1 - r)$ and the probability that V plays y^N is $(1 - q)$. Proposition 3 in the Appendix establishes the existence of a unique equilibrium in which each party randomizes over its possible pure strategies, sometimes satisfying the legal standard of due care and at other times failing to do so. The most interesting implication of this result is the possibility of trials in equilibrium. In the standard model of liability under perfect information, the legal standard is always satisfied by the party on whom it is imposed; thus, no party is ever negligent in equilibrium, so litigation never occurs. Of course, accidents do occur in equilibrium, but they are never the result of negligent behavior. This also extends to the previous analysis of this paper—for instance, under N, as analyzed above, I always satisfies the standard x^*, so there is no litigation in equilibrium.

However, the analysis of NdN in this paper yields substantially different implications. There is now a positive probability that, in equilibrium, one or both of the parties will fail to satisfy the standard. In some of these circumstances, trials will occur in equilibrium. In particular, consider the case where I plays $x = 0$ and V plays $y = y^*$. The equilibrium strategy specified in proposition 2 involves I playing zero with probability $(1 - r^0)$ and V playing y^* with probability q^0. Thus, there is a probability $(1 - r^0)q^0$ that I will be negligent, while V satisfies the standard required to avoid contributory negligence. This situation could result in V successfully suing I to recover the accident loss and thus involves a trial in which I is correctly found to have been negligent.

3.5. Optimal Tort Rules

The basic result above was that, when the structure of social costs is given by equation (6), none of the standard tort rules induce optimal behavior by both I and V. This naturally leads to the question of whether there exist some other mechanisms that can induce optimal behavior. In fact, there is a large class of mechanisms that can implement the social optimum, namely, those involving regulation. All that is needed is that the regulator requires I to choose x^* and V to choose y^* and that the regulation is backed by sufficient enforcement to dissuade I and V from deviating from these levels of care. However, such regulatory mechanisms have stringent information requirements, generally involve high enforcement costs, and do not provide ex post compensation to injured parties. As a result, there are reasons why society would want a tort rule instead of or in addition to a regulatory mechanism (for analyses of the relationship between regulation and tort law, see, for instance, Kolstad, Ulen, and Johnson [1990] and Schmitz [2000]).

An important question thus remains—are there tortlike mechanisms that can induce optimal behavior? Our goal is to find mechanisms that retain as many features of tort rules as possible while implementing the social optimum. Two basic conditions that distinguish the tort rules that we have used in this paper from regulatory mechanisms are the following:

Condition 1. It is triggered only ex post: that is, transfers are made only in states of the world in which an accident has occurred. In contrast, regulation applies ex ante to all states of the world.

Condition 2. There is a balanced budget: that is, transfers are made only between the parties (I and V); no fines, taxes, or subsidies are imposed or provided by the government. In contrast, regulation requires an enforcement budget and a system of fines or other punishments, so regulatory mechanisms may run either a budget surplus or deficit.

Of these, it may be argued that only condition 1 is essential to tort remedies because decoupling is used in certain tort contexts. Decoupling involves a liability rule where the payment made by one party differs from the amount received by the other party, with the difference taking the form of a fine or subsidy paid to or by the government (see Polinsky and Che [1991] for an analysis).[17]

When decoupling is permitted (that is, only condition 1 is imposed), it is fairly straightforward to characterize tort rules that induce socially optimal levels of care, even in the presence of multiple externalities. Recall that L captures both the probability and the severity of an accident; thus, it can also be written as follows: $L(x, y) = p(x, y)H(x, y)$, where p is the probability of an accident and H is the harm that results if an accident occurs (note that each of these depends on both x and y). Consider the following rule: whenever an accident occurs, I pays a fine of

$$\frac{C^V(x;\ y^*) + L(x;\ y^*)}{p(x,\ y^*)} \tag{10}$$

and V pays a fine of

$$\frac{C^I(x^*;\ y) + L(x^*;\ y)}{p(x^*,\ y)} \tag{11}$$

(note that the fines are not fixed dollar amounts but rather payment schedules, which are conditioned on the party's choice of level of care and on the socially optimal level of care for the other party). It is clear that this rule leads to socially optimal behavior by both I and V (given risk neutrality)—note simply that I and V are each confronted with a program that is identical to that of a social planner choosing x and y, respectively.

When we restrict attention to mechanisms that satisfy both conditions 1 and 2, it is somewhat more difficult to characterize optimal rules. Such mechanisms do exist, however. For example, consider a rule that we will call negligence with compensation for increased costs of precaution (NCC). This is a simple negligence rule augmented by the payment by

17. Note that the existence of positive litigation costs in itself creates a certain degree of decoupling.

V to I of compensation for I's increased costs of precaution. The rule can be specified as follows:

NCC. If an accident occurs and I is negligent (that is, $x < x^*$), then I pays damages $L(x, y)$ to V. If I is nonnegligent (that is, $x \geq x^*$), then V bears her own accident losses and also pays I an amount $[C^I(x^*; y)/p(x^*, y)]$.

Given the assumption of risk neutrality, NCC leads to socially optimal behavior by both I and V. (A formal statement and proof of this result are provided in the Appendix.) The basic intuition is as follows. When I takes care x and V takes care y, the probability of an accident is $p(x, y)$. If I chooses x^*, she receives a payoff of zero, regardless of V's choice of y (note that the probability of being involved in an accident $p(x^*, y)$ and the denominator of the transfer from V if there is an accident cancel out). In expectation, I bears zero precaution costs and no accident liability. However, if I were to take suboptimal precaution, she would face both her own precaution costs and the expected accident losses. Thus, I will always satisfy the standard of due care. Given this, V not only faces her own precaution costs and the accident losses but also bears the expected value of I's precaution costs (through the transfers made when accidents occur). Thus, V's decision problem is aligned with the social planner's, so V chooses the socially optimal level of precaution y^*.

Clearly, although it is tortlike in the sense that we have defined, NCC bears little resemblance to real-world liability rules and is an unlikely candidate for actual adoption by courts. This simply underlines the point that it requires some unusual mechanisms to induce socially optimal behavior by both parties under circumstances of cost externalities.

4. THE CASE OF BILATERAL HARM

In real-world accidents, it is often the case that harm is suffered by both parties rather than only by V (Leong 1989; Arlen 1990a, 1990b, 1992). This section of the paper extends the unilateral harm model of Section 3 to the case of bilateral harm. Thus, the model in this section involves both bilateral precaution and bilateral cost externalities (as in Section 3) as well as bilateral harm. To facilitate comparisons with our earlier results, the notation with I and V will be retained, although these terms are less meaningful when both parties suffer harm. The standard tort rules will be assumed to generalize straightforwardly to the bilateral harm context (as in Arlen 1990b); thus, under a negligence rule (N) I can sue V to recover her accident losses if V is negligent and V can sue I when I is negligent.

The social cost of accidents in the bilateral harm context can be represented as

$$C^{I}(x;\ y) + C^{V}(y;\ x) + L^{I}(x,\ y) + L^{V}(x,\ y), \tag{12}$$

where $L^{V}(x, y)$ is the expected accident loss faced by V and $L^{I}(x, y)$ is the expected accident loss faced by I. The set of assumptions required is closely analogous to that in Section 3, and these are specified formally in the Appendix (assumptions 5–9). These assumptions require that the accident losses L^{I} and L^{V} are sufficiently large relative to the costs of precaution (or, more specifically, to the precaution costs that a party can avoid by failing to take care). Thus, they are straightforward generalizations of those in Section 3.

The court imposes social-cost-minimizing standards of care $x^*(y^*)$ and $y^*(x^*)$ on both parties. The basic result (stated formally in proposition 4 in the Appendix) is that all of the standard negligence-based tort rules—N, SLdN, NdN, and CN—induce each party to take this socially optimal level of care. The intuition can be clarified by considering the basic negligence rule N. Each party faces a choice between satisfying the standard of due care (x^* for I and y^* for V) and thereby avoiding all liability for the other party's accident losses or failing to satisfy the standard and bearing all of the other party's accident losses. Provided that the other party's losses are sufficiently large, relative to the savings in precaution costs by failing to take care, each party will find it in her interest to satisfy the standard, regardless of the behavior of the other party. There is thus a unique equilibrium in dominant strategies (x^*, y^*); moreover, this coincides with the social optimum. Analogous (although somewhat more complicated) reasoning establishes that each of the other negligence-based rules also induces socially optimal behavior.

It is important to stress that the intrinsic interdependency between the costs of precaution of the two parties does not lead to suboptimal behavior in the bilateral harm case. This is because each party faces a standard of due care, which, by assumption, is defined by the court so as to take into account the cost externality. A party that fails to satisfy this standard will face a discontinuous jump in its expected costs, as it will be forced to bear the accident losses of the other party. This results in the cost externality being internalized by each party (along with the accident externality). The lesson of this section is thus that, in the bilateral harm case (in contrast to the unilateral harm case) traditional tort rules are robust to the introduction of cost externalities.

5. DISCUSSION

Having analyzed both the unilateral and bilateral harm cases, it remains to review the paper's results and to draw some more general conclusions concerning the design of tort liability rules. The results from Sections 3 and 4 are summarized in Table 1, along with results from the existing literature.

The first two of these are the results of the standard models with independent costs of precaution, for the unilateral harm and bilateral harm cases (as discussed, for instance, in Shavell [1987] and Arlen [1990b], respectively). The next two, which are explicitly derived in Dharmapala, Hoffman, and Schwartz (2001), are special cases of the results in proposition 1 (discussed in Section 3).

Model 3 considers the case in which, within a unilateral harm framework, V's precaution costs are affected by I's level of care, but in which I's cost of care is independent of V's precaution. In these circumstances, courts can set a negligence standard for I that takes into account the external effects of I's precaution on V's costs. Given that the accident loss is sufficiently large, I will always choose to adhere to this standard, as failing to do so entails a large discontinuous jump in expected liability. Given that I takes the socially optimal level of care, V's problem (of choosing y to maximize $C^{V}(y;\ x^{*}) + L^{V}(x^{*},\ y)$) is identical to the social planner's program in choosing y. Thus, all of the negligence-based tort rules lead to optimal behavior by both I and V.

The fourth model is also one of unilateral harm and involves the case in which I's precaution costs are affected by V's level of care but in which V's cost of care is independent of I's precaution. Once again, I will adhere to the standard of care imposed by the court. Anticipating this, V knows that she will bear her accident losses and her own costs of precaution; however, she does not bear I's precaution costs, although these depend in part on her actions, and so will not choose the socially optimal level of care (this is essentially the same intuition as that in Section 3). Thus, the standard tort rules do not induce both parties to behave optimally (although NCC, the rule developed in Section 3, does so).

Table 1 summarizes these results, along with those of this paper.

Table 1. Summary of Results

Model	Example	Social Loss Function	Liability Rule						
			NL	SL	N	SLdN	NdN	CN	NCC
Independent costs:									
1. Unilateral harm	Shavell (1987, p. 37)	$C^{I}(x) + C^{V}(y) + L^{V}(x, y)$			*	*	*	*	*
2. Bilateral harm	Arlen (1990a)	$C^{I}(x) + C^{V}(y) + L^{I}(x, y) + L^{V}(x, y)$			*	*	*	*	*
Unilateral harm:									
3. I affects V's costs	Dharmapala, Hoffman, and Schwartz (2001)	$C^{I}(x) + C^{V}(x, y) + L^{V}(x, y)$			*	*	*	*	*
4. V affects I's costs	Dharmapala, Hoffman, and Schwartz (2001)	$C^{I}(x, y) + C^{V}(y) + L^{V}(x, y)$							*
Interdependent costs:									
5. Unilateral harm	Section 3	$C^{I}(x, y) + C^{V}(x, y) + L^{V}(x, y)$							*
6. Bilateral harm	Section 4	$C^{I}(x, y) + C^{V}(x, y) + L^{I}(x, y) + L^{V}(x, y)$			*	*	*	*	*

Note. NL: no liability, SL: strict liability, N: simple negligence, SLdN: strict liability with a defense of contributory negligence, NdN: negligence with a defense of contributory negligence, CN: comparative negligence, and NCC: negligence with compensation for increased costs of precaution. Note that these results rely on assumptions stated in the text and in the cited works (for example, assumptions 1–4 for model 5 and assumptions 5–9 for model 6). An asterisk indicates that the rules induces both the injurer (I) and the victim (V) to undertake the socially optimal levels of care.

Model 5 is simply the unilateral harm framework analyzed in Section 3, while model 6 is the bilateral harm model from Section 4. For each of these models, the table shows which tort rules lead to socially optimal behavior by both I and V. Note that, in addition to the standard rules considered in the literature, the table includes NCC, the hypothetical rule derived in Section 3. This is purely for purposes of comparison and is not intended to suggest that NCC is necessarily an appropriate rule to adopt in practice. While NCC induces optimal behavior under all the circumstances considered, it should be noted that for models 1–3 it involves an arbitrary wealth redistribution from victims to injurers, without having any behavioral effects.

Consider the first two rows of Table 1. In model 1, there is only one externality (I's effect on V's accident loss); this externality can be internalized by imposing a negligence standard on I and enabling V to sue I to recover her accident losses when this standard is not met. Model 2 extends this idea to the case of two externalities (I's effect on V's accident loss and V's effect on I's accident loss). Here, the externalities can be internalized by imposing a negligence standard on each party and enabling each to sue the other to recover accident losses when the standard is not met. Thus, it would seem from the existing literature that tort liability rules succeed in internalizing externalities by creating a cause of action for each external effect (in contrast, Leong [1989] is a model in which there are two externalities and only one cause of action, which leads to nonoptimal behavior).

The results of this paper, however, tend to cast some doubt on this generalization. Note, for example, that model 6 involves four externalities—each party's effect on the other's accident loss and each party's effect on the other's precaution costs. However, liability rules that involve only two causes of action—that is, that impose a negligence standard on each party and enable the other to sue for accident losses (but not precaution costs) when the standard is violated—are sufficient to internalize all four externalities. Similarly, in model 3, there are two externalities (I's effect on C^{V} and her effect on L^{V}), but they can both be internalized by imposing a negligence standard on I and enabling V to sue to recover L^{V}.

From Table 1, it appears that tort liability rules can internalize externalities when the following two conditions are imposed on each party that generates externalities:

1. the party faces a negligence standard that takes into account all the externalities created by a party, and
2. if the standard is violated, the party is held liable for accident losses.

This holds true regardless of the number of externalities that the party creates. Consequently, there do not need to be as many causes of action as externalities in order for a tort rule to induce both parties to take optimal precaution.

Moreover, something fundamental about the way in which torts functions to induce optimal precaution is revealed by comparing the results in the unilateral and bilateral harm cases where parties affect each other's costs of precaution. The critical features of a socially optimal tort system are that there is a cause of action against each externalizing party and that in setting that party's standard of care the court takes into account all external impacts, including impacts on injury and on cost of precaution. Negligence rules that govern torts involving bilateral harm can induce socially optimal behavior even in the presence of external effects on the costs of precaution because there is always a cause of action available against the externalizing party. This is not so in the case of torts involving unilateral harm.

This formulation explains the results of the previous literature (models 1 and 2). Note in particular that in Leong (1989) there are two parties—I and V—that generate externalities, but a negligence standard and liability for damages are imposed only on I; thus, there is an externality-generating party (V) who does not face liability. Essentially similar explanations can be given for why models 4 and 5 lead to suboptimal behavior: V imposes an externality on I's precaution costs but faces no liability for damages.

At first glance, this formulation may seem to run counter to the basic intuition from public economics that one policy instrument is needed to achieve each policy objective. Here the objectives appear to be internalizing each party's loss from accidents and internalizing each party's impact on the other's cost of precaution. In this case, one might think that four policy instruments are needed. However, the comparison of results from the unilateral and bilateral harm cases shows that the objective is actually to induce each party to internalize the costs (whether in terms of harm or increased cost of precaution) that they impose on the other party. Thus, with the objectives properly defined, it is apparent that only two instruments are needed. The two causes of action involved in torts with bilateral harm provide the two needed instruments. Similarly, the optimal mechanism derived above in the unilateral harm case also makes use of two policy instruments. It should be emphasized that both elements that are highlighted above—the negligence standard and the liability for damages—are important in the internalization of externalities. For instance, consider model 5. Rule NdN (contributory negligence) imposes negligence standards on both I and V, but a cause of action exists only for V. That is, only V is able to recover damages. Thus, as V creates an externality but does not face liability for damages, NdN is incapable of inducing both parties to behave in a socially optimal manner.

6. CONCLUSION

In conclusion, this paper has analyzed the consequences that ensue when parties in accidents have intrinsically interdependent costs of precaution. This generalization of the standard economic analysis of tort rules enables a better understanding of the conditions under which torts rules can induce socially optimal precaution. The results show conditions under which standard tort rules can fail to induce socially optimal behavior and result in successful tort litigation (even where there is no error, misperception, incomplete information, or wealth constraints). We characterize tortlike rules that induce socially optimal precaution under even these conditions. While these rules are unlikely to be functional, they help illustrate the elements necessary for a tort system to induce socially optimal precaution. The larger contribution of this analysis is to show that, in order to induce socially optimal behavior, all that is required of a tort system is that a cause of action be available against every externalizing party and that the cause of action impose a standard of care that accounts for all external costs caused by that party.

APPENDIX: SECOND-ORDER CONDITIONS

The following establishes a sufficient set of conditions for the second-order conditions (SOCs) for the social problem in the general case (equation [2]). The SOCs for the various other programs considered in the paper will be satisfied under very similar circumstances.

Let

$$f \equiv C^{\mathrm{I}}(x;\ y) + C^{\mathrm{V}}(y;\ x) + L(x,\ y).$$

The SOCs require that the Hessian is positive semidefinite (that is, the principal minor determinants are all positive). The first principal minor is

$$f_{xx} = C^{\mathrm{I}}_{xx}(x;\ y) + C^{\mathrm{V}}_{xx}(y;\ x) + L_{xx}(x,\ y).$$

Note that, by assumption, $C^{\mathrm{I}}_{xx}(x;\ y) > 0$ and $L_{xx}(x,\ y) > 0$; thus, imposing the restriction that $C^{\mathrm{V}}_{xx}(y;\ x) > 0$ is sufficient to ensure that $f_{xx} > 0$.

The second principal minor determinant is $f_{xx}f_{yy} - f_{xy}f_{yx}$; assuming that $C^{\mathrm{I}}_{yy}(x;\ y) > 0$ is sufficient to ensure that $f_{yy} > 0$. In addition, assuming that the cross-partials $C^{\mathrm{I}}_{xy}(x;\ y)$, $C^{\mathrm{I}}_{yx}(x;\ y)$, $C^{\mathrm{V}}_{xy}(y;\ x)$, $C^{\mathrm{V}}_{yx}(y;\ x)$, $L_{xy}(x,\ y)$, and $L_{yx}(x,\ y)$ are all sufficiently small ensures that $f_{xx}f_{yy} - f_{xy}f_{yx} > 0$. Under those conditions, the SOCs for equation (2) are satisfied.

Proposition 1. Suppose that assumptions 1–4 hold. Then,

i) The social optimum $(x^*,\ y^*)$ is not a Nash equilibrium under any liability rule.

ii) The unique (suboptimal) equilibrium under N is $(x^*,\ y^N)$, where $y^N \equiv \operatorname{argmin} C^{\mathrm{V}}(y;\ x^*) + L(x^*,\ y) < y^*$.

iii) The unique (nonoptimal) equilibrium under NL is $(0,\ y^{\mathrm{NL}})$, where

$$y^{\mathrm{NL}} \equiv \operatorname{argmin} C^{\mathrm{V}}(y;\ 0) + L(0,\ y).$$

iv) The unique (nonoptimal) equilibrium under SL is $(x^{\mathrm{SL}},\ 0)$, where

$$x^{\mathrm{SL}} \equiv \operatorname{argmin} C^{\mathrm{I}}(x;\ 0) + L(x,\ 0).$$

v) The unique (suboptimal) equilibrium under SLdN is $(x^S,\ y^*)$, where

$$x^S \equiv \operatorname{argmin} C^{\mathrm{I}}(x;\ y^*) + L(x,\ y^*) < x^*.$$

vi) Under CN, $(x^*,\ y^*)$ is not an equilibrium; there will exist suboptimal equilibria $(x^{\mathrm{CN}},\ y^{\mathrm{CN}}) \neq (x^*,\ y^*)$ under CN if there exist x^{CN} and y^{CN} that (simultaneously) satisfy the following conditions:

$$\begin{aligned} &C^{\mathrm{I}}(x^{\mathrm{CN}};\ y^{\mathrm{CN}}) + \alpha(x^{\mathrm{CN}},\ y^{\mathrm{CN}})L(x^{\mathrm{CN}},\ y^{\mathrm{CN}}) \\ &\le C^{\mathrm{I}}(x;\ y^{\mathrm{CN}}) + \alpha(x,\ y^{\mathrm{CN}})L(x,\ y^{\mathrm{CN}}) \quad \forall x \neq x^{\mathrm{CN}} \end{aligned} \tag{vi-a}$$

and

$$\begin{aligned} &C^{\mathrm{V}}(x^{\mathrm{CN}};\ y^{\mathrm{CN}}) + [1 - \alpha(x^{\mathrm{CN}},\ y^{\mathrm{CN}})]L(x^{\mathrm{CN}},\ y^{\mathrm{CN}}) \\ &\le C^{\mathrm{V}}(x^{\mathrm{CN}};\ y) + [1 - \alpha(x^{\mathrm{CN}},\ y)]L(x^{\mathrm{CN}},\ y) \quad \forall y \neq y^{\mathrm{CN}}, \end{aligned} \tag{vi-b}$$

where $\alpha(x, y) \in [0, 1]$ is the fraction of liability borne by I when I takes precaution $x \le x^*$ and V takes precaution $y \le y^*$.[18]

vii) There is no pure-strategy Nash equilibrium under NdN.

18. This is the most general formulation. In fact, CN entails that $\alpha(x^*,\ y)$ equals zero.

Proof of Proposition 1.

i) It will be apparent from the reasoning below that (x^*, y^*) is not an equilibrium under any of the rules considered here.

ii) Consider N: by satisfying the legal standard of care x^*, I avoids all liability and faces cost $C^{I}(x^*; y)$, while taking $x < x^*$ leads to costs $C^{I}(x; y) + L(x, y)$. Given assumption 4i, $L(x, y) > C^{I}(x^*; y) - C^{I}(x; y)$, I's dominant strategy (for any y) will be to satisfy the standard. Given that I satisfies x^*, V faces $C^{V}(y; x^*) + L(x^*, y)$; the first-order condition (FOC) for V's minimization problem differs from the FOC for the social planner's problem in equation (8). V will take precaution of y^N. Thus, (x^*, y^N) is an equilibrium; uniqueness follows as x^* is a dominant strategy and y^N is the unique maximizer of V's program.

To show that $y^N < y^*$, recall the FOC for the socially optimal choice of y, y^* (equation [8]). As $C^{I}_{y}(\cdot) < 0$ by assumption, it follows that

$$C^{V}_{y}(y^*;\ x^*) + L_y(x^*,\ y^*) > C^{V}_{y}(y^N;\ x^*) + L_y(x^*,\ y^N).$$

By assumption, $C^{V}_{yy}(\cdot) > 0$ and $L_{yy}(\cdot) > 0$. Thus, both the left-hand side and right-hand side of the expression above represent an increasing function of y, say, $f(y)$, where $f(y) \equiv C^{V}_{y}(y;\ x^*) + L_y(x^*,\ y)$ and $f'(y) > 0$. It follows that, as $f(y^*) > f(y^N)$, it must be true that $y^N < y^*$.

iii) Under NL, I never faces liability for V's loss, so her costs are only her cost of precaution, $C^{I}(x; y)$, which is minimized by taking $x = 0$. Since $C^{I}_{x} < 0$, this is true for all y. Given I's choice of $x = 0$, V faces cost $C^{V}(y; 0) + L(0, y)$, which is minimized by y^{NL}. Since the FOC for this optimization problem, $C^{V}_{y}(y; 0) + L_y(0, y) = 0$, differs from that of the social planner (equation [8]), the victim will not choose the socially optimal level of precaution, $y^{NL} \neq y^*$. The outcome $(0, y^{NL})$ will be a unique equilibrium, but it will not be socially optimal.

iv) Under SL, V is always compensated and bears only his cost of precaution, $C^{V}(y; x)$, regardless of I's precaution. V minimizes $C^{V}(y; x)$ by taking no precaution ($y = 0$). I in turn, faces costs, $C^{I}(x; 0) + L(x, 0)$, which he will minimize by taking precaution x^{SL}. The FOC for this minimization problem, $C^{I}_{x}(x; 0) + L_x(x, 0) = 0$, differs from that for the social problem (equation [7]). As a result, I's precaution, x^{SL}, will differ from the socially optimal precaution x^*. The outcome $(x^{SL}, 0)$ will be a unique equilibrium, but it will not be socially optimal.

v) Under SLdN, regardless of I's action, V can avoid bearing the expected accident loss only by taking the socially optimal level of care y^*. V can either avoid liability by meeting the social standard of care y^* and face only the cost of precaution, $C^{V}(y^*; x)$, or can take care $y < y^*$ and bear both the cost of precaution and the accident loss, $C^{V}(y; x) + L(x, y)$. As long as assumption 4ii is satisfied, V will meet the social standard of care y^*. Given that V takes precaution y^*, I will choose x to minimize both costs of precaution and accident loss, $C^{I}(x; y^*) + L(x, y^*)$ by the choice of x^S. The FOC for this minimization problem differs from that of the social planner's problem in equation (7). To show that $x^S < x^*$: as $C^V_x(\cdot) < 0$ by assumption, it follows that

$$C^I_x(x^*;\ y^*) + L_x(x^*,\ y^*) > C^I_x(x^S;\ y^*) + L_x(x^S,\ y^*)$$

and therefore (as $C^I_{xx}(\cdot) > 0$ and $L_{xx}(\cdot) > 0$) that $x^S < x^*$.

vi) Consider CN: to show that $(x^*,\ y^*)$ is not an equilibrium, suppose that I plays x^*. V faces $C^V(y;\ x^*) + L(x^*,\ y)$ and takes precaution y^N. Therefore, $(x^*,\ y^*)$ is not an equilibrium.

To show that $(x^{CN},\ y^{CN}) \neq (x^*,\ y^*)$ may be an equilibrium: suppose that condition (vi-a) holds. Then, x^{CN} is I's best response to V playing y^{CN}. Suppose that condition (vi-b) holds. Then, y^{CN} is V's best response to I playing x^{CN}. Thus, if $\exists(x^{CN},\ y^{CN})$ such that conditions (vi-a) and (vi-b) are simultaneously satisfied, then $(x^{CN},\ y^{CN})$ is an equilibrium. Furthermore, note that if $(x^{CN},\ y^{CN})$ is an equilibrium, then $(x^{CN},\ y^{CN}) \neq (x^*,\ y^*)$, as $(x^*,\ y^*)$ is not an equilibrium.

vii) Consider NdN: suppose $x = x^*$: V faces $C^V(y;\ x^*) + L(x^*,\ y)$ and thus takes precaution $y^N < y^*$. Thus, $(x^*,\ y^*)$ is not an equilibrium. Moreover, if V takes any level of care below y^*, I will face no liability and will thus take no care $(x = 0)$. Thus, there cannot be an equilibrium in which I takes x^* and V takes $y < y^*$.

Suppose $x < x^*$: if assumption 4ii holds, V will take y^*. Thus, there cannot be an equilibrium in which both parties take suboptimal care. Moreover, if V takes y^*, I (given assumption 4i) will take x^*; thus, there cannot be an equilibrium in which I takes $x < x^*$ and V takes y^*.

This exhausts all the possibilities, so there is no equilibrium in pure strategies.

Proposition 2. Suppose that assumptions 1–4 hold. Then there exists a unique Nash equilibrium $(r^0,\ q^0)$ under NdN, where

$$r^0 = \frac{C^V(y^*;\ 0) - C^V(y^N;\ 0) - L(0,\ y^N)}{C^V(y^N;\ x^*) + L(x^*,\ y^N) - C^V(y^*;\ 0) - C^V(y^N;\ 0) - L(0,\ y^N)}$$

and

$$q^0 = \frac{C^I(x^*;\ y^N) - C^I(0;\ y^N)}{C^I(x^*;\ y^N) + C^I(0;\ y^*) + L(x^*,\ y^N) - C^I(x^*;\ y^N) - C^I(0;\ y^N)}.$$

Proof of Proposition 2. Consider I's expected payoff from playing r, given that V plays q

$$-rqC^I(x^*;\ y^*) - r(1-q)C^I(x^*;\ y^N)$$
$$-(1-r)(1-q)C^I(0;\ y^N) - (1-r)q[C^I(0;\ y^*) + L(0,\ y^*)].$$

Simplifying, the expected payoff is

$$r[-qC^{\mathrm{I}}(x^*;\ y^*) - C^{\mathrm{I}}(x^*;\ y^N) + qC^{\mathrm{I}}(x^*;\ y^N) + qC^{\mathrm{I}}(0;\ y^*)$$
$$+qL(0,\ y^*) + C^{\mathrm{I}}(0;\ y^N) - qC^{\mathrm{I}}(0;\ y^N)]$$
$$-q[C^{\mathrm{I}}(0;\ y^*) + L(0,\ y^*)] - (1-q)C^{\mathrm{I}}(0;\ y^N).$$

Setting the coefficient of r in the above expression equal to zero and rearranging yields q^0 (note that, using assumptions 1–4, it follows that $q^0 \in (0, 1)$). If $q > q^0$, then I's payoff is increasing in r, so I's best response $r^*(q)$ equals one (that is, playing the pure-strategy x^*). If $q < q^0$, then I's payoff is decreasing in r, so $r^*(q)$ equals zero (that is, playing the pure-strategy zero). If $q = q^0$, then I's payoff is constant in r, so any r is a best response to V playing $q = q^0$.

Now consider V's expected payoff from playing q, given that I plays r

$$q\{-r[C^{\mathrm{V}}(y^*;\ x^*) + L(x^*,\ y^*)] - C^{\mathrm{V}}(y^*;\ 0) + rC^{\mathrm{V}}(y^*;\ 0)$$
$$+r[C^{\mathrm{V}}(y^N;\ x^*) + L(x^*,\ y^N)] + C^{\mathrm{V}}(y^N;\ 0) + L(0,\ y^N) - r[C^{\mathrm{V}}(y^N;\ 0) + L(0,\ y^N)]\}$$
$$-qC^{\mathrm{V}}(y^*;\ 0) - C^{\mathrm{V}}(y^N; 0) - L(0,\ y^N).$$

Setting the coefficient of q in the above expression equal to zero and rearranging yields r^0 (note that, using assumptions 1–4, it follows that $r^0 \in (0, 1)$). If $r > r^0$, then V's payoff is decreasing in q, so V's best response $q^*(r)$ equals zero (that is, playing the pure-strategy y^N). If $r < r^0$, then V's payoff is increasing in q, so $q^*(r)$ equals one (that is, playing the pure-strategy y^*). If $r = r^0$, then V's payoff is constant in q, so any q is a best response to I playing $r = r^0$.

In particular, q^0 is a best response by V when I plays r^0; moreover, from above, r^0 is a best response by I when V plays q^0. Thus, (r^0, q^0) is a Nash equilibrium.

To show uniqueness, suppose that there exists an equilibrium (r', q'), where $q' \neq q^0$. If $q' > q^0$, then $r^*(q') = 1$. Moreover, $q^*(1) = 0$, so $(r', q') = (1, 0)$. But this cannot be an equilibrium (see proof of proposition 1). If $q' < q^0$, then $r^*(q') = 0$. Moreover, $q^*(0) = 1$, so $(r', q') = (0, 1)$. But, this cannot be an equilibrium (see proof of proposition 1). Similar reasoning holds for $r' \neq r^0$. Thus, (r^0, q^0) is the unique Nash equilibrium.

Proposition 3. Given assumptions 1–4 and the risk neutrality of I and V, the unique Nash equilibrium outcome under NCC is (x^*, y^*).

Proof of Proposition 3. I's payoff from satisfying x^* (for any choice y by V) is

$$[p(x^*,\ y)/p(x^*,\ y)]C^{\mathrm{I}}(x^*;\ y) - C^{\mathrm{I}}(x^*;\ y) = 0 \quad \text{(for any } y\text{)},$$

while I's payoff from failing to satisfy x^* is

$$-C^{\mathrm{I}}(x;\ y) - L(x^*;\ y) < 0.$$

Thus, I always satisfies x^*. Given this, V faces costs

$$[p(x^*, y)/p(x^*, y)]C^{\mathrm{I}}(x^*; y) + C^{\mathrm{V}}(y; x^*) + L(x^*, y)$$
$$= C^{\mathrm{I}}(x^*; y) + C^{\mathrm{V}}(y; x^*) + L(x^*, y).$$

But this is identical to the social planner's problem in choosing y. Thus, V will choose $y^*(x^*)$, which is unique by assumption. It follows that (x^*, y^*) is the unique Nash equilibrium outcome.

Assumption 5.
i) $L^{\mathrm{V}}(x, y^*) > [C^{\mathrm{I}}(x^*; y^*) + L^{\mathrm{I}}(x^*, y^*)] - [C^{\mathrm{I}}(x; y^*) + L^{\mathrm{I}}(x, y^*)]\ \forall x < x^*$.
ii) $L^{\mathrm{I}}(x^*, y) > [C^{\mathrm{V}}(x^*; y^*) + L^{\mathrm{V}}(x^*, y^*)] - [C^{\mathrm{V}}(x^*; y) + L^{\mathrm{V}}(x^*, y)]\ \forall y < y^*$.

Assumption 6.
i) $L^{\mathrm{V}}(x, y) > [C^{\mathrm{I}}(x^*; y) - C^{\mathrm{I}}(x; y)]\ \forall x < x^*$ and $\forall y < y^*$.
ii) $L^{\mathrm{I}}(x, y) > [C^{\mathrm{V}}(x; y^*) - C^{\mathrm{V}}(x; y)]\ \forall x < x^*$ and $\forall y < y^*$.

Assumption 7.
i) $L^{\mathrm{I}}(x, y^*) > [C^{\mathrm{I}}(x^*; y^*) + L^{\mathrm{V}}(x^*, y^*)] - [C^{\mathrm{I}}(x; y^*) + L^{\mathrm{V}}(x, y^*)]\ \forall x < x^*$.
ii) $L^{\mathrm{V}}(x^*, y) > [C^{\mathrm{V}}(x^*; y^*) + L^{\mathrm{I}}(x^*, y^*)] - [C^{\mathrm{V}}(x^*; y) + L^{\mathrm{I}}(x^*, y)]\ \forall y < y^*$.

Assumption 8.
i) $L^{\mathrm{I}}(x, y) > [C^{\mathrm{I}}(x^*; y) - C^{I}(x; y)]\ \forall x < x^*$ and $\forall y < y^*$.
ii) $L^{\mathrm{V}}(x, y) > [C^{\mathrm{V}}(x; y^*) - C^{\mathrm{V}}(x; y)] \forall x < x^*$ and $\forall y < y^*$.

It is assumed that under CN, if an accident occurs and both parties are deemed to be negligent, then I bears a fraction $\alpha \in [0, 1]$ of the total accident losses, while V bears $(1 - \alpha)$. Then the following assumptions are required:

Assumption 9.
i) $\alpha[L^{\mathrm{I}}(x, y) + L^{\mathrm{V}}(x, y)] > [C^{\mathrm{I}}(x^*; y) - C^{\mathrm{I}}(x; y)]\ \forall x < x^*$ and $\forall y < y^*$.
ii) $(1 - \alpha)[L^{\mathrm{I}}(x, y) + L^{\mathrm{V}}(x, y)] > [C^{\mathrm{V}}(x; y^*) - C^{\mathrm{V}}(x; y)]\ \forall x < x^*$ and $\forall y < y^*$.

Proposition 4. In the bilateral harm model with social costs given by equation (12), and given assumptions 5–9, the unique Nash equilibrium outcome under all negligence-based liability rules (N, SLdN, NdN, and CN) is (x^*, y^*).

Proof of Proposition 4.

N. Consider I's problem, assuming that V chooses y^*. Then I faces expected costs

$$C^{\mathrm{I}}(x^*; y^*) + L^{\mathrm{I}}(x^*, y^*) \quad \text{by choosing } x = x^*$$

and

$$C^{\mathrm{I}}(x; y^*) + L^{\mathrm{I}}(x, y^*) + L^{\mathrm{V}}(x, y^*) \quad \text{by choosing } x < x^*.$$

Given assumption 5i, I will choose $x = x^*$. Now suppose that V chooses $y < y^*$; then I faces costs $C^{\mathrm{I}}(x^*; y)$ by choosing $x = x^*$ and $C^{\mathrm{I}}(x; y) + L^{\mathrm{V}}(x, y)$ by choosing $x < x^*$. Given assumption 6i, I will choose $x = x^*$. Thus, $x = x^*$ is a dominant strategy for I. By the symmetry of the problem, and given assumptions 5ii and 6ii, V will choose $y = y^*$. Hence, the unique equilibrium outcome is (x^*, y^*).

SLdN. Consider I's problem, assuming that V chooses $y = y^*$. Then I faces expected costs

$$C^{\mathrm{I}}(x^*;\ y^*) + L^{\mathrm{V}}(x^*,\ y^*) \quad \text{by choosing } x^*$$

and

$$C^{\mathrm{I}}(x;\ y^*) + L^{\mathrm{I}}(x,\ y^*) + L^{\mathrm{V}}(x,\ y^*) \quad \text{by choosing } x < x^*.$$

Given assumption 7i, I will choose x^*. Now suppose that V chooses $y < y^*$; then I faces costs $C^{\mathrm{I}}(x^*;\ y)$ by choosing $x = x^*$ and $C^{\mathrm{I}}(x;\ y) + L^{\mathrm{I}}(x,\ y)$ by choosing $x < x^*$. Given assumption 8i, I will choose $x = x^*$. Thus, $x = x^*$ is a dominant strategy for I. By the symmetry of the problem, and given assumptions 7ii and 8ii, V will choose $y = y^*$. Hence, the unique equilibrium outcome is (x^*, y^*).

NdN. Consider I's problem, assuming that V chooses $y = y^*$. Then I faces expected costs

$$C^{\mathrm{I}}(x^*;\ y^*) + L^{\mathrm{I}}(x^*,\ y^*) \quad \text{by choosing } x^*$$

and

$$C^{\mathrm{I}}(x;\ y^*) + L^{\mathrm{I}}(x,\ y^*) + L^{\mathrm{V}}(x,\ y^*) \quad \text{by choosing } x < x^*.$$

Given assumption 5i, I will choose x^*. Now suppose that V chooses $y < y^*$; then I faces costs $C^{\mathrm{I}}(x^*;\ y)$ by choosing $x = x^*$ and $C^{\mathrm{I}}(x;\ y) + L^{\mathrm{I}}(x,\ y)$ by choosing $x < x^*$. Given assumption 8i, I will choose $x = x^*$. Thus, $x = x^*$ is a dominant strategy for I. By the symmetry of the problem, and given assumptions 5ii and 8ii, V will choose $y = y^*$. Hence, the unique equilibrium outcome is (x^*, y^*).

CN. Consider I's problem, assuming that V chooses $y = y^*$. Then I faces expected costs

$$C^{\mathrm{I}}(x^*;\ y^*) + L^{\mathrm{I}}(x^*,\ y^*) \quad \text{by choosing } x^*$$

and

$$C^{\mathrm{I}}(x;\ y^*) + L^{\mathrm{I}}(x,\ y^*) + L^{\mathrm{V}}(x,\ y^*) \quad \text{by choosing } x < x^*.$$

Given assumption 5i, I will choose x^*. Now suppose that V chooses $y < y^*$; then I faces costs $C^{\mathrm{I}}(x^*;\ y)$ by choosing $x = x^*$ and $\alpha[L^{\mathrm{I}}(x;\ y) + L^{\mathrm{V}}(x, y)]$ by choosing $x < x^*$. Given assumption 9i, I will choose $x = x^*$. Thus, $x = x^*$ is a dominant strategy for I. By the symmetry of the problem and given assumptions 5ii and 9ii, V will choose $y = y^*$. Hence, the unique equilibrium outcome is (x^*, y^*).

REFERENCES

Arlen, Jennifer H. 1990a. Reconsidering Efficient Tort Rules for Personal Injury: The Case of Single Activity Accidents. *William and Mary Law Review* 32: 41–103.

———. 1990b. Re-examining Liability Rules When Injurers as Well as Victims Suffer Losses. *International Review of Law and Economics* 10:233–39.

———. 1992. Liability for Physical Injury When Injurers as Well as Victims Suffer Losses. *Journal of Law, Economics, and Organization* 8:411–26.

Brown, John Prather. 1973. Toward an Economic Theory of Liability. *Journal of Legal Studies* 2:323–49.

Cooter, Robert, and Thomas Ulen. 1997. *Law and Economics*. 2d ed. Reading, Mass.: Addison-Wesley.

Craswell, Richard, and John E. Calfee. 1986. Deterrence and Uncertain Legal Standards. *Journal of Law, Economics, and Organization* 2:279–303.

Dharmapala, Dhammika, Sandra A. Hoffmann, and Warren F. Schwartz. 2001. A Neglected Interdependency in Liability Theory: Bilateral Accidents Where One Party's Precaution Shifts the Other's Cost of Care. Discussion Paper No. 01–13. Resources for the Future, Washington, D.C.

Grady, Mark. 1984. Proximate Cause and the Law of Negligence. *Iowa Law Review* 69:363–449.

Hindley, Brian, and Bill Bishop. 1983. Accident Liability Rules and Externality. *International Review of Law and Economics* 3:59–68.

Kahan, Marcel. 1989. Causation and Incentives to Take Care under the Negligence Rule. *Journal of Legal Studies* 18:427–47.

Kolstad, Charles D., Thomas S. Ulen, and Gary V. Johnson. 1990. Ex Post Liability for Harm vs. Ex Ante Safety Regulation: Substitutes or Complements? *American Economic Review* 80:888–901.

Leong, Avon K. 1989. Liability Rules When Injurers as Well as Victims Suffer Losses. *International Review of Law and Economics* 9:105–11.

Meese, Alan J. 2001. The Externality of Victim Care. *University of Chicago Law Review* 68:1201–34.

Ordover, Janusz A. 1978. Costly Litigation in the Model of Single Activity Accidents. *Journal of Legal Studies* 7:243–61.

Polinsky, A. Mitchell, and Yeon-Koo Che. 1991. Decoupling Liability: Optimal Incentives for Care and Litigation. *RAND Journal of Economics* 22:562–70.

Rea, Samuel A., Jr. 1987. The Economics of Comparative Negligence. *International Review of Law and Economics* 7:149–62.

Schmitz, Patrick W. 2000. On the Joint Use of Liability and Safety Regulation. *International Review of Law and Economics* 20:371–82.

Schwartz, Warren F. 1989. Objective and Subjective Standards of Negligence: Defining the Reasonable Person to Induce Optimal Care and Optimal Populations of Injurers and Victims. *Georgetown Law Journal* 78:241–79.

Shavell, Steven. 1980. Strict Liability versus Negligence. *Journal of Legal Studies* 9:1–25.

———. 1986. The Judgment Proof Problem. *International Review of Law and Economics* 6:45–58.

———. 1987. *Economic Analysis of Accident Law*. Cambridge, Mass.: Harvard University Press.

White, Michelle J. 2004. The "Arms Race" on American Roads: The Effect of Sport Utility Vehicles and Pickup Trucks on Traffic Safety. *Journal of Law and Economics* 47:333–55.

Wittman, Donald. 1981. Optimal Pricing of Sequential Inputs: Last Clear Chance, Mitigation of Damages, and Related Doctrines in the Law. *Journal of Legal Studies* 10:65–91.