

## **A Neglected Interdependency in Liability Theory**

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July 2001 • Discussion Paper 01–13



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# **A Neglected Interdependency in Liability Theory: Bilateral Accidents where One Party's Precaution Shifts the Other's Cost of Care**

Dharmika Dharmapala, Sandra A. Hoffmann, and Warren F. Schwartz

## **Abstract**

The standard economic model of bilateral precaution concludes that (in the absence of uncertainty, misperception, or error) all negligence-based liability rules induce socially optimal behavior by both injurers and victims. This paper generalizes the standard model to consider situations in which one party's precaution affects not only expected accident loss, but also directly affects the other party's effort—or cost—of taking precaution. If the injurer's care affects the victim's precaution costs (but not vice versa), most of the standard results continue to hold (except for strict liability with a defense of contributory negligence). If the victim's precaution affects the injurer's costs of care (but not vice versa), only strict liability with a defense of contributory negligence leads to the social optimum, while the other negligence-based rules lead to suboptimal outcomes. In the general case (where each party's costs depend on both parties' levels of precaution), none of the standard liability rules induce socially optimal behavior in both parties.

The paper's other main result concerns the possibility of self-interested, negligent behavior in equilibrium. Under negligence with a defense of contributory negligence, the only equilibrium is in the mixed strategies of both injurer and victim. This involves the parties choosing (with strictly positive probability) to behave negligently, and gives rise to the possibility of successful litigation in equilibrium, even though there is no uncertainty, misperception, or error. The paper concludes by considering the implications of these results for the design of liability rules.

**Key Words:** law and economics; and tort law

**JEL Classification Numbers:** K13; K00

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# **A Neglected Interdependency in Liability Theory: Bilateral Accidents where One Party's Precaution Shifts the Other's Cost of Care**

Dharmika Dharmapala, Sandra A. Hoffmann, and Warren F. Schwartz

## **1. Introduction**

The standard economic model of accidents with bilateral precaution (e.g., Shavell, 1987) concludes that—with legal standards of care set at the socially optimal levels, and with no uncertainty, misperception, or error—all negligence-based liability rules induce socially optimal behavior by both injurers and victims. In this model, each party's cost of care depends directly only on its own level of precaution. The interdependency between the two parties' total expected accident costs occurs only via the effects of care on the expected loss from the accident. This paper analyzes situations in which a change in one party's level of care also directly influences the cost to the other party of taking any given level of care. In essence, in the standard model, parties interact only by affecting the victim's expected benefit from precaution. In the model presented in this paper, parties also interact by directly affecting (shifting) each other's precautionary expenditures.

In our model, there are two external effects from a party's precaution (or lack thereof): one on the other party's expected accident loss and the other on that party's cost of precaution. To the extent that tort rules focus solely on creating incentives to internalize expected accident loss, they may not be able to induce socially optimal care. As a consequence, in the most general case, where each party's care shifts the other's cost function, we find that none of the standard liability rules—no liability (NL), strict liability (SL), negligence (N), strict liability with a defense of negligence (SLdN), negligence with a defense of contributory negligence (NdN), and comparative negligence (CN)—induce socially optimal care. This is not true in all cases. In some cases, where only one party affects the other's cost of precaution, some negligence-based rules are able to induce the externalizing party to internalize both the impact of her care on the victim's expected loss and cost of precaution. In these cases, tort rules are able to induce socially efficient care taking by both parties, even though both externalities are present.

A second result from our model shows that when accidents involve both of these externalities, tort rules may not be able to induce injurers to comply with a due care standard. Under the standard model, in the absence of uncertainty, misperception, or error, parties who face negligence rules always satisfy the standard of care. Although there are some accidents, all parties are nonnegligent, and no successful litigation occurs in equilibrium. In our model—even if there is no uncertainty, misperception, or error—under certain rules parties will sometimes choose to behave negligently in equilibrium. Shavell (1986) found a similar result where defendants are insolvent. To the best of our knowledge, these are the only models in which it has been shown that tort rules are not able to generate compliance with due care standards in the absence of error, mistake, or misrepresentation.

While we find limited circumstances in which negligence-based tort rules are actually able to correct both externalities, this is not generally the case. This finding suggests that more complex mechanisms may be required to induce socially optimal care. If courts actually take the external impact on cost of precaution into account in deciding tort cases, they may be able to create incentives for parties to internalize both external effects. We find some evidence in the case law of courts taking the external impact on cost of precaution into account in deciding tort cases. But since in general, conventional tort rules cannot induce all parties to engage in socially optimal behavior, multiple instruments may be required to do so. The presence of this second external effect of precaution may, for example, help explain the widespread practice of using both regulation and liability to control the same accident loss.

Several examples of the phenomenon of interdependent precaution costs are described in detail in the next section. A brief review of the existing literature is provided in Section 3. The formal model is presented in Section 4, and the results are derived in Section 5. Section 6 discusses implications of the results, and also introduces case law that highlights the significance of the cost-based interdependency analyzed in this paper. Section 7 concludes the paper

## 2. Examples

Given the pervasiveness of externalities that affect costs of production and consumption, one would expect that the cost externalities examined in this paper would also be a common phenomena. In fact, it is more difficult than would be expected to think of examples in which

this applies. Yet there do seem to be situations that involve precaution having both an external impact on others' accident loss and on others' costs of precaution. To the extent that these situations arise, the results of this paper suggest they substantially affect the way conventional tort rules influence behavior. The examples presented here focus on auto accidents.

### ***2.1 Maintaining a Safe Following Distance***

One way that drivers take precaution is by maintaining a safe following distance. The effort (cost) of doing so depends on the behavior of other drivers. The precaution taken by other drivers on a multi-lane highway may take various forms: maintaining safe following distance behind other cars, signaling lane changes, observing maximum and minimum speed restrictions, and traveling at a speed consistent with the flow of traffic. Different types of precaution also involve different types of costs: delay in arriving at one's destination, the degree of attention one has to pay to driving, the level of tension experienced in paying attention, or the opportunity cost of not being able to pay attention to the scenery or planning future activities.

Consider the following scenario: one driver takes precaution by maintaining a safe following distance; the opportunity cost is the amount of productive thought that can be given to tomorrow's work activities. Another driver takes precaution by signaling lane changes and allowing sufficient distance between other vehicles before doing so; this is done at the cost of delay in arriving at her destination. The standard model recognizes that the level of precaution exercised by this driver in changing lanes affects the probability, and perhaps severity, of an accident. Our model recognizes that the level of precaution exercised by the driver changing lanes also affects the effort (cost) the other driver has to exercise in maintaining a given, safe, following distance. If the driver changes lanes with little precaution, weaving rapidly between lanes without signaling or cutting in closely in front of other cars in an effort to maintain a higher average speed, she also will affect the other drivers' costs of precaution. The driver trying to maintain a safe following distance has to shift more attention from planning the next day's activities to driving or may experience more tension in driving. In other words, the other driver's cost function has shifted out.

## **2.2. *The Aerodynamic Effect of Trucks***

Drivers also take precaution by driving in the center of their lane of traffic. Consider a small car that is being passed by a semi-trailer truck. Due to the difference in their sizes, the car can be pulled toward the truck as the truck passes the car. The car driver can compensate by steering away from the truck. This takes added attention and effort. The faster the truck travels, the stronger the aerodynamic effect and the more difficult it is for the car driver to keep her vehicle in the center of the lane. The standard model recognizes that the speed of the truck affects the probability of an accident. Our model also recognizes that it affects the effort (cost) required of the car driver to take precaution, here keeping her car in the middle of her lane. Our model reflects the fact that the choice of speed by the truck driver shifts the effort (cost) required by the car driver to keep the car in the center of the lane.

## **2.3. *The Height and Size of Vehicles***

In recent years, sport utility vehicles (SUVs) have gained widespread popularity. One of the motivations for purchasing SUVs is that they are taller than most cars, as indicated by the data in Table 1.

**Table 1: Vehicle Size**

	<i>Weight (pounds)</i>	<i>Height</i>	<i>Width</i>	<i>Length</i>	<i>Retail Price (2001)</i>
Chevrolet Metro	1,900	4'6"	5'2"	12'5"	\$9,600
Toyota Camry	3,200	4'7"	5'10"	15'8"	\$23,600
Chevrolet Suburban	4,900	6'1"	6'7"	18'3"	\$27,000
Unimog*	12,500	9'7"	7'6"	20'1"	\$84,000

Source: [www.kellybluebook.net](http://www.kellybluebook.net) (Feb. 24, 2001).

\* The Feb. 21, 2001 New York Times announced Daimler-Chrysler plans to offer the Unimog, a sport utility vehicle weighing 12,500 pounds – more than two Chevrolet Suburban sport utility vehicles or four Toyota Camry sedans.



As a result, the SUV driver sits higher than surrounding vehicles and finds it easier to observe traffic. Consequently, it is less costly to see and anticipate other drivers' actions (i.e., to take precaution). The standard model would recognize that the purchase of an SUV shifts the owner's cost of precaution and, by affecting her level of precaution, affects expected accident loss. But those who continue to drive cars also find themselves behind taller, and sometimes wider, vehicles. It is now more costly for the car driver to observe and anticipate others' actions. For example, they may be forced to move to the edge of their lane to try to see around the larger vehicle. The precautionary activity of the SUV driver has shifted the car driver's cost of taking precaution. The standard model does not capture the impact of the SUV purchase on other drivers' cost of taking care; our model does.

### **3. Literature Review**

The basic model examining the efficiency of tort rules was first formalized in Brown (1973). Brown models torts involving bilateral precaution as a joint production process in which all parties take precaution that jointly determine expected accident damages. In Brown's paper, and in subsequent literature following his approach, it is assumed that parties' costs of precaution are independent of each other, and that their actions interact only through the loss function. The standard results for bilateral accidents were derived from a modification of Brown's model. Haddock and Curran (1985), Landes and Posner (1987), and Shavell (1987) showed that with full information, standards of care set equal to socially efficient levels, and full compensation of accident losses, all tort rules involving negligence can induce an equilibrium in which all parties take socially optimal care.

Several extensions of this basic model have been pursued. Cooter and Ulen (1986), Endres (1992), Edlin (1994), and Rea (1987) examine the impact of costly information, or court or parties' error on the efficiency of contributory and comparative negligence. The standard model assumes simultaneous action by the victim and injurer. Shavell (1983) and Winter (1994; 1997) examine models with sequential choice of care. Rubinfeld (1987) compares simple negligence and comparative negligence in a model in which injurers (or victims) differ in their

costs of precaution. Leong (1989) and Arlen (1990) extend the basic model by assuming that both the victim and the injurer can be harmed. Nowhere in this wide-range of extensions is there any discussion of the problem that one party's precaution may affect the other's cost of care.

The most notable results from these extensions concern efficiency of alternative tort rules and the circumstances that lead to litigation. Whenever error or incomplete information is introduced, the negligence-based rules are no longer efficient (Cooter and Ulen 1986; Endres 1992; Edlin 1994; Rea 1987; Winter 1994). Sequential choice of care undermines the efficiency of all rules except contributory negligence (Shavell 1983). Rubinfeld (1987) finds that where injurers (or victims) differ in cost of precaution, an individual standard of care is needed for each party in order to induce socially optimal care.<sup>1</sup> None of these results predict that a rational, fully informed actor would choose to violate a standard of care. Rather, this literature explains tort litigation as the result of error or lack of information.

Two broader themes arise in this literature. The first seeks to explain the widespread shift in the United States from contributory negligence to comparative negligence since the 1960s (Curran 1992). This literature explores the extent to which the shift to comparative negligence has been driven by efficiency concerns and the extent to which it has been driven by other concerns, such as fairness or rent seeking. A second theme addresses the puzzle of why litigation occurs, even though the basic theory predicts that negligence rules induce compliance with the standard of due care. The standard answer in the existing literature involves error or incomplete information. We will return to these themes in our discussion of results below.

#### 4. The Model

The model developed in this paper follows the standard analysis of accidents between strangers with bilateral precaution, as presented in Shavell (1987, p. 36f). In the standard model, there are two types of (risk-neutral) actors: injurers (hereafter denoted by I) and victims (denoted by V). All injurers are assumed to be identical, as are all victims. As a result, the analysis can

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<sup>1</sup> Emons (1990) and Emons and Sobel (1990) develop a fairly complex liability rule that can induce efficient behavior where the two parties differ in their costs of precaution.

proceed, without loss of generality, in terms of a representative I and V. Each party can take precaution that reduce the expected loss from an accident (i.e., 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. If an accident does occur 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 (though, of course, not for the costs of precaution).

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 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 social cost-minimizing level. We will refer to this as the socially optimal or efficient level of care.

In the standard bilateral precaution model, the social objective function is to minimize the sum of expected accident losses and the costs of precaution:

$$x + y + L(x, y) \tag{1}$$

where  $x$  denotes I's precaution,  $y$  denotes V's precaution, and  $L$  is the expected accident loss (Shavell 1987, p. 37). The notion of bilateral precaution is captured in the assumption that  $L$  is a function of both  $x$  and  $y$ . In this formulation, expenditures on precaution are used as the numeraire, so that Shavell sets  $C^I(x) = x$ , where  $C^I(x)$  is I's cost of taking precaution level  $x$ . Similarly,  $C^V(y) = y$ , where  $C^V(y)$  is V's cost of taking precaution level  $y$ . As long as costs of precaution are monotonically increasing in the level of care, as seems reasonable, Shavell's results carry through for the more general case where the cost of precaution is  $C(x)$  rather than  $x$ .

This paper examines how those results change when there are interdependencies between the two parties' costs of precaution. That is, one or both of the parties' costs depend not only on their own actions, but also on the other party's action, that is  $C^I = C^I(x; y)$  and  $C^V = C^V(y; x)$ . The social objective, as in Shavell (1987), is to minimize the sum of the costs of precaution and

expected accident loss. However, this now takes into account the possible interdependence between the victim and injurer's costs of precaution:

$$C^I(x; y) + C^V(y; x) + L(x, y) \quad (2)$$

Here,  $C^I$  denotes I's cost of precaution, and  $C^V$  denotes V's cost of precaution. The possible interdependence between them is captured by including both  $x$  and  $y$ , which now denote the levels of care taken by I and V, respectively, as arguments in each cost function.

#### 4.1. Further Assumptions

Following Shavell (1987, p. 36), we assume that the loss is non-negative and decreasing at an increasing rate in either I's or V's precaution:

**A1:** (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 that:

**A2:** (i)  $C^I_x > 0$ , (ii)  $C^V_y > 0$ , (iii)  $C^I_{xx} > 0$ , (iv)  $C^V_{yy} > 0$ .

While, as shown in the examples above, 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:

**A3:** (i)  $C^I_y \leq 0$ , (ii)  $C^V_x \leq 0$ .

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:

**A4:** (i) For any  $y$ , and any  $x < x^*$ ,  $L(x, y) > C^I(x^*; y) - C^I(y; x)$ .

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 entails  $L(x, y)$  being strictly bounded away from zero  $\forall y$ . 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. Suppose that, in addition to damages  $L$  that compensate  $V$  for the accident loss, the court can impose a punitive penalty, represented by a non-negative constant  $D$ , on  $I$ . Then, even if A4(i) 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 A4(i).

An analogous assumption is made for  $V$ :

**A4:** (ii) For any  $x$ , and any  $y < y^*$ ,  $L(x, y) > C^V(y^*; x) - C^V(y; x)$ .

The assumptions A4(i) and A4(ii) 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 paper are the nonoptimality of behavior under the standard tort rules, even when A4 holds. Thus, relaxing A4 would simply reinforce this basic result, by making nonoptimal behavior even more pervasive.<sup>2</sup> In this sense, A4 is a conservative assumption, making the best possible case for the efficiency of standard tort rules.

#### **4.2. An Example of the Intuition for the Model**

A number of real-world scenarios that correspond to aspects of this model were introduced in Section 2. The intuition for the model (and for the results of the next section) can also be illustrated by a somewhat fanciful example. Following Emons (1990) and Emons and Sobel (1990), “cost of precaution” is represented directly as opportunity cost, that is, as changes in each party’s utility. Consider a world in which  $I$  is a driver and  $V$  a cyclist, and suppose that each party’s utility depends on its speed relative to that of the other party. Each party can take precaution to avoid an accident by reducing speed. However, even if the probability of an accident is zero, each party still cares (directly) about the other’s level of precaution (i.e., speed). Moreover, the parties’ precaution costs are directly interdependent, in the sense that, when the cyclist slows down, the driver suffers less disutility from any given reduction in her own speed.

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<sup>2</sup> Additional assumptions to ensure that the SOCs for the minimization of Eq (2) are satisfied, are discussed in the Appendix.

Thus, the lower the cyclists speed, the less costly it is for the driver to take precaution by reducing her own speed.

Now consider a negligence rule. Suppose the law requires the driver to drive no faster than the socially optimal speed in order to avoid liability. Further, suppose the expected accident liability is sufficiently large to induce the driver to satisfy this standard of care. In the standard analysis, the cyclist would then internalize all accident losses, and take socially optimal care. However, in our scenario, the cyclist's care (i.e., reduction in speed) has two distinct effects—one is to reduce the expected accident loss, and the other is to reduce the cost to the driver of satisfying the legal standard. The cyclist will take the former fully into account, but has no incentive to consider the latter. Therefore, the cyclist will ride faster than is socially optimal, while the driver will satisfy the standard, but will have to incur a greater cost to do so than if the cyclist were behaving in a socially optimal manner.

## 5. 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 (see Shavell 1987, Ch. 2; and 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.<sup>3</sup> 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.<sup>4</sup>

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<sup>3</sup> 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).

<sup>4</sup> Following the standard assumption about causality rules, it is assumed that, when a negligence standard is imposed on I, then 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).

The model specified in equation (2) represents the general case, in which I's precaution affects V's costs and V's precaution affects I's costs. In carrying out the analysis in this section, however, it proves more illuminating to begin with two special cases of that model, before returning to the general case (Section 5.3). The first of these (Section 5.1) is the case where the injurer's level of care affects the victim's cost of taking precaution, but not vice versa. The second (Section 5.2) is where the victim's precaution affects the injurer's cost of precaution, but not vice versa.

### 5.1. Injurer's level of care affects victim's precaution costs

We start with the case in which I's level of care affects V's cost of precaution, but V's action has no impact on I's costs because the standard results on optimality are least affected by the externality in this case. Here, the social cost of accidents can be represented as:

$$C^I(x) + C^V(y;x) + L(x,y) \quad (3)$$

This is a special case of A3, with  $C_y^I = 0$ . The first order conditions for the minimization of social cost are:

$$C_x^I(x) + C_x^V(y;x) + L_x(x,y) = 0 \quad (4)$$

$$C_y^V(y;x) + L_y(x,y) = 0 \quad (5)$$

which (assuming interior solutions) result in socially optimal levels of care,  $x^*(y^*)$  and  $y^*(x^*)$ . It should be noted that the optimal  $x^*$  and  $y^*$  here will, in general, differ from those derived in the general case, using Eq (2); however, no confusion should result from the use of the same notation, as we will not be undertaking any comparisons across different cases (all comparisons will refer to different liability rules, given particular assumptions about the direction of the externality).

The results of this section can be summarized as follows:

**Proposition 5.1:** *Suppose that A1-A4 hold, and that  $C_y^I = 0$  (in accordance with Eq (3)). Then,*

- (i) *the unique Nash equilibrium outcome under rules N and NdN is the social optimum  $(x^*, y^*)$ ;*

- (ii) *the unique (nonoptimal) equilibrium under NL is  $(0, y^{NL})$ , where*  

$$y^{NL} \equiv \operatorname{argmin} C^V(y; 0) + L(0, y);$$
- (iii) *the unique (nonoptimal) equilibrium under SL is  $(x^{SL}, 0)$ , where*  

$$x^{SL} \equiv \operatorname{argmin} C^I(x) + L(x, 0);$$
- (iv) *the unique (suboptimal) equilibrium under SLdN is  $(x^S, y^*)$ , where*  

$$x^S \equiv \operatorname{argmin} C^I(x) + L(x, y^*) < x^*;$$
- (v) *the social optimum  $(x^*, y^*)$  is an equilibrium under CN; however, there may exist other (suboptimal) equilibria.*

**Proof:** See Appendix

As long as A4 holds, the results from a model in which the injurer's precautionary activity affects the victim's cost of taking precaution closely resemble those for the standard model of bilateral accidents. In particular, the negligence based rules N, NdN, and CN lead to the social optimum. The central intuition for the optimality results is that, under N, NdN, and CN, V faces the same problem, of minimizing  $C^V(y; x^*) + L(x^*, y)$ , as the social planner does in choosing y. The major exception to the general pattern of optimal behavior is in the case of SLdN. V takes socially optimal precaution,  $y^*$ , because it is the court-imposed standard of care. Given that V satisfies  $y^*$ , I will internalize the accident damages (for which she is strictly liable); but she does not have an incentive to take into account the impact of her actions on V's costs of precaution. Thus, as the external effect is positive, I will take suboptimal care because the optimal level of care  $x^*$  would involve lowering V's costs of taking precaution  $y^*$ , without conferring any private benefit on I. The outcome is that V takes optimal precaution, but because of I's suboptimal precaution, is forced to incur a higher cost to meet the legal standard than is the case under the social optimum.

## 5.2. The Victim's Precaution affects the Injurer's Costs

Now consider the case where the victim's precaution affects the injurer's cost of taking precaution. In this case, the social problem is to minimize total social cost defined as:

$$C^I(x; y) + C^V(y) + L(x, y) \quad (6)$$



This is a special case of A3, with  $C_x^V = 0$ . The social minimization problem leads to first order conditions:

$$C_x^I(x;y) + L_x(x,y) = 0 \quad (7)$$

$$C_y^I(x;y) + C_y^V(y) + L_y(x,y) = 0 \quad (8)$$

which result in socially optimal levels of care  $x^*(y^*)$  and  $y^*(x^*)$ . Once again, these values differ from the optimal values in the general case and in Section 5.1.

The basic results of this section can be summarized as follows:

**Proposition 5.2:** *Suppose that A1-A4 hold, and that  $C_x^V = 0$  (in accordance with Eq (6)). Then,*

- (i) *the social optimum  $(x^*, y^*)$  is the (unique) Nash equilibrium outcome under SLdN; it is not an equilibrium under any other liability rule*
- (ii) *the unique (nonoptimal) outcome under NL is  $(0, y^{NL})$ , where*  

$$y^{NL} \equiv \operatorname{argmin} C^V(y) + L(0, y)$$
- (iii) *the unique (nonoptimal) outcome under SL is  $(x^{SL}, 0)$ , where*  

$$x^{SL} \equiv \operatorname{argmin} C^I(x;0) + L(x,0)$$
- (iv) *the unique (suboptimal) outcome under N is  $(x^*, y^N)$ , where*  

$$y^N \equiv \operatorname{argmin} C^V(y) + L(x^*, y) < y^*$$
- (v)  *$(x^*, y^*)$  is not an equilibrium under CN; there will exist suboptimal equilibria  $(x^{CN}, y^{CN}) \neq (x^*, y^*)$  under CN if there exist  $x^{CN}$  and  $y^{CN}$  that (simultaneously) satisfy the following conditions:*

$$C^I(x^{CN}; y^{CN}) + \alpha(x^{CN}, y^{CN})L(x^{CN}, y^{CN}) \leq C^I(x; y^{CN}) + \alpha(x, y^{CN})L(x, y^{CN})$$

$$\forall x \neq x^{CN} \quad (va)$$

$$C^V(y^{CN}) + (1 - \alpha(x^{CN}, y^{CN}))L(x^{CN}, y^{CN}) \leq C^V(y) + (1 - \alpha(x^{CN}, y))L(x^{CN}, y)$$

$\forall y \neq y^{CN}$  (vb) where  $\alpha(x, y) \in [0, 1]$  is the fraction of liability borne by I when I takes precaution  $x \leq x^*$  and V takes precaution  $y \leq y^{*5}$

(vi) there is no pure-strategy Nash equilibrium under NdN.

**Proof:** See Appendix

Now, even when A4 holds, the standard result that all forms of negligence rules lead to socially optimal behavior fails to hold in most cases. In the case of N, NdN, and CN, if the injurer takes optimal care,  $x^*$ , the externalizing party, V, is motivated to minimize  $C^V(y) + L(x^*, y)$ , not by a legal standard of care, but by her own private interest. Since V is not responding to a legal standard of care and ignores the impact of her precaution on I, V will not take socially optimal care. By focusing on I's precaution, most traditional rules of negligence do not provide adequate incentives to induce optimal behavior in a victim whose precaution affects the injurer's cost of precaution.

The only tort rule that successfully does this is SLdN. Here, unlike in the case of NdN, I cannot avoid bearing the accident loss as long as V meets the legal standard of care,  $y^*$ . As long as A4(ii) holds, V will take  $y^*$  to avoid bearing the accident loss (note that V takes socially optimal precaution to satisfy the legal standard of care, and would not do so in the absence of the contributory negligence defense). The asymmetry in the ability of tort rules to account for external impacts on cost of precaution follows from the general result that the externalizing party takes optimal precaution in order to satisfy the court's standard of care, rather than because the tort rule forces her to face a private choice in which she explicitly internalizes the externalized cost or benefit of their precaution. Where I affects V's cost of precaution, all of the rules that force I to face a negligence standard induce I to take socially optimal care. Where V affects I's cost of precaution, only SLdN induces socially optimal care by V, because only under SLdN is V motivated by the court's legal standard of care.<sup>6</sup>

<sup>5</sup> This is the most general formulation. In fact, CN entails that  $\alpha(x^*, y) = 0$ .

<sup>6</sup> At first glance, it may appear that V would be responding to the court's standard under NdN and CN; however, this is not the case. Under NdN and CN, a victim who affects I's cost of precaution chooses her own precaution

Finally, it is noteworthy that there is no equilibrium in pure strategies under NdN. Section 5.4 below characterizes the unique mixed-strategy equilibrium under NdN in the general case. There also exists a unique mixed-strategy equilibrium under NdN in this case, and the characterization is a straightforward special case of that in Proposition 5. below, so it is not specified in detail here.

### 5.3. The General Case

The previous sections discussed two scenarios in which the costs of precaution were subject to unilateral externalities. In this section, we consider the general case, in which I's precaution lowers V's cost of care and V's precaution lowers I's cost of care. The social loss from accidents can be expressed as follows:

$$C^I(x; y) + C^V(y; x) + L(x, y) \quad (9)$$

Minimizing this social loss with respect to  $x$  and  $y$ , the FOCs are:

$$C_x^I(x, y) + C_x^V(x, y) + L_x(x, y) = 0 \quad (10)$$

$$C_y^I(x; y) + C_y^V(y; x) + L_y(x, y) = 0 \quad (11)$$

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:

**Proposition 5.3:** *Suppose that A1-A4 holds. 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  $y^N \equiv \operatorname{argmin} C^V(y; x^*) + L(x^*, y) < y^*$*
- (iii) *the unique (nonoptimal) equilibrium under  $NL$  is  $(0, y^{NL})$ , where*

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without reference to the legal standard of care. This is because these rules also impose a standard of due care on I, and V anticipates that I will always satisfy this standard. Since they can ignore their impact on I, they do not take socially optimal precaution.

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

(iv) *the unique (nonoptimal) equilibrium under SL is  $(x^{SL}, 0)$ , where*

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

(v) *the unique (suboptimal) equilibrium under SLdN is  $(x^S, y^*)$ , where  $x^S \equiv \operatorname{argmin} C^I(x; y^*) + L(x, y^*) < x^*$*

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

$$C^I(x^{CN}; y^{CN}) + \alpha(x^{CN}, y^{CN})L(x^{CN}, y^{CN}) \leq C^I(x; y^{CN}) + \alpha(x, y^{CN})L(x, y^{CN})$$

$$\forall x \neq x^{CN} \quad (va)$$

$$C^V(x^{CN}; y^{CN}) + (1 - \alpha(x^{CN}, y^{CN}))L(x^{CN}, y^{CN}) \leq C^V(x^{CN}; y)$$

$+ (1 - \alpha(x^{CN}, y))L(x^{CN}, y) \quad \forall y \neq y^{CN} \quad (vb)$  *where  $\alpha(x, y) \in [0, 1]$  is the fraction of liability borne by I when I takes precaution  $x \leq x^*$  and V takes precaution  $y \leq y^*$ <sup>7</sup>*

(vii) *there is no pure-strategy Nash equilibrium under NdN.*

**Proof:** *See Appendix*

In the case where each party's precaution affects the other's cost of precaution, no tort rule induces socially optimal behavior. The tort rules do not induce a party to take optimal care by directly confronting the party with the external impact of her precaution on the other party's cost of precaution. Rather, optimal precaution is induced only by the desire to avoid liability for accident damages if a due care standard is met. This can happen only when courts, with perfect knowledge, set the legal standard of care under negligence at the level that minimizes total social costs. Since both parties must take optimal care for tort rules to reward optimal behavior, the asymmetry seen in the impact of tort rules on victims and injurers works against the

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<sup>7</sup> This is the most general formulation. In fact, CN entails that  $\alpha(x^*, y) = 0$ .

effectiveness of torts in inducing socially optimal behavior where both parties' precaution affect the other party's costs of precaution. The negligence rule still provides the cost-externalizing injurer with incentive to take optimal precaution. It does not, however, confront the cost externalizing victim with either the external impact of their 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, the externalizing victim must comply with the negligence standard to avoid bearing the accident cost. However, under SLdN, the externalizing injurer is motivated only to minimize his or 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. The asymmetry in tort treatment of V and I repeats itself under CN. As in the case where V's precaution affects I's cost of precaution, V neither faces this external impact nor can fully avoid bearing accident cost 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. In the case of NdN, there is no pure strategy Nash equilibrium, as in Section 5.2; the following subsection characterizes the unique mixed-strategy equilibrium.

#### **5.4. Characterizing the Mixed-Strategy Equilibrium under NdN**

Recall the result in Propositions 5.2 and 5.3 that no Nash equilibrium in pure strategies exists under NdN. In this section, we show that there exists a unique equilibrium in mixed strategies under NdN. This is characterized for the general case of Section 5.3, but the corresponding characterization of the equilibrium for the special case of Section 5.2 follows directly from the general case.

Note first that, from the proof of the nonexistence of pure-strategy equilibria in Propositions 5.2 and 5.3, I's best responses to any of V's pure strategies involve taking precaution level  $x$  equal to  $x^*$  or 0. 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 (i.e., two) for each player. The existence of an equilibrium in mixed strategies follows directly 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 0 is  $(1 - r)$  and the probability that V plays  $y^N$  is  $(1 - q)$ . For sake of convenience, the proof below is developed in terms of each player's payoff, rather than cost, where the payoff is simply taken to be the negative of the cost.

The basic result under NdN is the following:

**Proposition 5.4:** *Suppose that A1-A4 hold. Then, there exists a unique Nash equilibrium*

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

$(r^0, q^0)$  under NdN, where:

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:** *See Appendix.*

This proposition 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 upon whom it is imposed; thus, no party is ever negligent in equilibrium, so that 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 that 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 4.4 involves I playing 0 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.

## 6. Discussion

The standard result from the previous literature on the efficiency of alternative tort rules is that—with full information, no error, and the due care standard set at socially optimal care—all negligence-based tort rules induce socially optimal precaution by both injurers and victims (Shavell, 1987). In our model, incorporating external impacts of care on cost of precaution and joint production of accident damages, these results break down (even with full information, and with due care standards set at socially optimal care). The results of our analysis, and those of the previous literature, are summarized in Table 2.

<b>Table 2. The Impact of Externalities in Costs of Precaution on the Optimality of Tort Liability Rules.<sup>o</sup></b>				
	No Externality	Cost Externality Present: Form of Externality		
		Unilateral on V's Cost	Unilateral on I's Cost	Bilateral on Both
	$C^I(x), C^V(y)^{\circ\circ}$	$C^I(x), C^V(y;x)$	$C^I(x;y), C^V(y)$	$C^I(x;y), C^V(y;x)$
Negligence	*	*		
Comparative Negligence	*	*		
Negligence with Defense of Contributory Negligence	*	*		
Strict Liability with Defense of Contributory Negligence	*		*	
Strict Liability				
No Liability				
* = liability rule induces socially optimal care				
<sup>o</sup> These results rely on assumptions A4(i) and A4(ii) holding. If these assumptions do not hold, then no liability rule will create incentives for a socially optimal outcome where parties' precautionary activities affect other parties' costs of precaution.				
<sup>oo</sup> Results from Shavell (1987) pp. 9-21.				



The impact of cost externalities on the efficiency of tort rules depends on the form of the externality and the asymmetric ways in which tort law treats victims and injurers. Where the externality is unilateral, with I affecting V's costs of precaution (but not vice versa), most of the standard results continue to hold. Most of the negligence-based rules, negligence, negligence with a defense of contributory negligence, and comparative negligence, induce I to internalize the impact of her care on both accident damages and the victim's cost of precaution by creating adequate incentives to meet the due care standard. However, because it is only the threat of liability if the due-care standard is not met that induces I to account for the impact of his or her care on V's cost of care, neither of the rules involving strict liability induce optimal care from the injurer. Under all tort rules, V takes the impact of I's actions on her costs into consideration, just as the fully informed court does. The incentives for V essentially parallel those provided in the standard model with no externalities. Negligence, negligence with a defense of contributory negligence, and comparative negligence all induce both parties to take optimal precaution.

Where the externality is unilateral, but V's care affects I's cost of precaution and not vice versa, conventional tort rules (apart from SLdN) are ineffective in inducing optimal care by both parties. Here, the problem is to induce the victim to internalize both the impact of her care on both accident loss and the injurer's cost of precaution. Under strict liability with a defense of contributory negligence, the contributory negligence defense motivates the victim to do this. The injurer takes socially optimal precaution because her objective in choosing her optimal level of care,  $x$ , is identical to the court's in setting  $x$  to minimize social cost. The capacity of tort rules to force all parties to internalize both their external impact on accident losses and other parties' costs of care is thus severely limited where the victim is externalizing part of her cost of precaution. One explanation for this is that tort law has focused on the injurer as externalizer and therefore is not well designed to force internalization of the impacts of victims' actions.

In the bilateral cost externality case, where both injurer's and victim's precaution affects the other party's cost of precaution, none of the conventional tort rules are capable of inducing socially efficient caretaking by both parties. This is true even though parties and courts are fully informed, make no errors in their decisions, and courts set due care at the socially optimal level of care for each party. A negligence rule does induce socially optimal care in the injurer, and strict liability with a defense of contributory negligence does so in the victim. Essentially, none

of the tort rules are adequate to force two parties to internalize two external impacts of their actions.

The following subsections elaborate on the implications of the results summarized above.

### **6.1. *Litigation in Equilibrium***

The standard model cannot explain why, in the real world, successful trials occur under negligence-based rules, since the system theoretically induces non-negligent care from all parties. Several possible explanations have been explored in the literature, including: court error of fact or standard; costliness of parties determining legal rules; parties' misperception of risks of accidents or error in executing care; or the involvement of judgment-proof defendants (see Rea, 1987). In this study, we show that even without incomplete or costly information or error, when parties externalize part of their cost of precaution, one should expect to see negligent behavior in equilibrium under the two most widely used rules in the United States, negligence with a defense of contributory negligence and comparative negligence. Thus, one of the central contributions of our paper is to demonstrate the possibility of equilibrium negligence and therefore successful litigation even when there is full information and no error.

The mixed-strategy equilibrium under negligence with a defense of contributory negligence was characterized in Section 5.4. Essentially, this equilibrium gives rise (with a strictly positive probability) to cases in which I chooses suboptimal care, while V chooses to satisfy the legal standard  $y^*$ . In these circumstances, I behaves negligently, and cannot use the defense that V was contributorily negligent; thus, V can successfully sue I for damages when an accident occurs.

Recall that in Propositions 5.2 and 5.3, pure strategy equilibria under comparative negligence were characterized. However, to guarantee the existence of these equilibria, it was necessary to impose more stringent assumptions than those made in the rest of the analysis. If these more restrictive conditions hold, then I will take optimal care, but V will take suboptimal care under comparative negligence. Thus, equilibrium negligence will occur, in the sense that V fails to meet the legal standard of care. However, this will not lead to litigation when accidents occur, as I is non-negligent and V will thus be unable to recover damages. If, on the other hand, the extra assumptions required for pure-strategy equilibria under comparative negligence are not

satisfied, the outcomes will be analogous to those under negligence with a defense of contributory negligence: there will be no pure-strategy equilibria under comparative negligence. The mixed strategy equilibria will resemble that characterized in Proposition 5.4. In these circumstances, comparative negligence (like NdN) will give rise to a strictly positive probability that I will behave negligently, and hence lead to litigation (whether or not V is also negligent).

## **6.2 The Choice of Negligence Standards by Courts**

When courts seek to define negligence standards in particular contexts, they must take into account all of the social effects of the care-taking activity of the party on whom the standard is to be imposed. Thus, under the assumptions of the standard model of bilateral precaution, the only factors that courts need to take into account in determining the negligence standard are the effects of care on expected harm and on the party's own cost of care. On the other hand, under the assumptions of the model, in this paper, it is necessary for the court to consider the impact of care taken not only on expected harm and the party's own cost of care, but also on the other party's cost of care. The factors considered by courts in their choice of negligence standards thus provides an 'empirical' test of the applicability of the two models to various circumstances.

When justifying the imposition of a particular negligence standard, courts have explicitly referred in their opinions to the effects of a party's care on the other party's cost of care. For instance, care that is optimal in the sense of cost-effectively reducing expected harm might, nevertheless, be suboptimal because of its effect on the cost of care or utility of the other actor. Moreover, care that might not be optimal if viewed solely from the perspective of reducing expected harm might, nevertheless, be optimal because of its effect in reducing the costs of care or increasing the utility of the other actor. In *Andrews v. United Airlines*<sup>8</sup>, the question was whether the airline had been negligent in failing to prevent a briefcase from falling from an overhead compartment and striking the plaintiff. The plaintiff's theory was that the airline should

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<sup>8</sup> *Andrews v. United Airlines*, 24 F-3d 39 (9<sup>th</sup> Cir. 1984).

have installed netting in the overhead bins to reduce the probability that an object would fall and hurt someone. In reversing a summary judgment for defendant the court said:

United has demonstrated neither that retrofitting overhead bins with netting (or other means) would be prohibitively expensive, *nor, that such steps would grossly interfere with the convenience of its passengers.* (Emphasis supplied)

In the terms of our analysis, the court recognized that even if installation of the netting would be a cost-effective way to reduce expected harm it might not be optimal behavior because of the associated increase in the inconvenience experienced by passengers. This highlights the significance of cost interdependencies in certain contexts.<sup>9</sup>

### **6.3. Controlling Two Externalities with One Instrument**

So far, we have interpreted our results in the light of the previous literature on the economic analysis of torts. From this perspective, what is most striking about our results is the failure of the standard tort rules to induce socially optimal behavior in the general case (Proposition 5.3). However, when the issue is approached through the prism of the economic theory of externalities, the nonoptimality results are not at all surprising. In essence, our model involves two distinct externalities (the accident losses and the interdependency between costs of care), and the government is permitted to use only one policy instrument to control both externalities. Moreover, the policy instrument in question, tort liability, is itself highly constrained—it relies purely on *ex post* shifting of the accident losses among the parties. From this standpoint, it is surprising that there are some circumstances in which both externalities can be successfully internalized through the use of this one instrument (Proposition 5.1).

To understand this point more fully, note that we have followed standard practice by labeling the party who bears the accident loss (in the absence of liability) the ‘victim’ and the

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<sup>9</sup> Note that what courts are doing in these cases is trying to define  $x^*$  to maximize social welfare. Of course, our results show that even defining  $x^*$  ‘properly’ will not, in general, induce socially optimal behavior.

other party the “injurer.” However, consider the situation where a negligence rule applies and I satisfies  $x^*$ , but V takes suboptimal care (as in Sections 5.2 and 5.3). In these circumstances, V is imposing costs on I by failing to take care  $y^*$ . It is thus possible to describe I as the economic victim of V’s failure to take sufficient care (although this failure is, of course, not generally a valid cause of legal action). In this sense, it is possible to distinguish between the “economic” and the “legal” victims. Using this terminology, Proposition 5.1 represents a situation in which the economic and legal victims coincide (i.e., I imposes external costs on V, both through the accident losses and the costs of care). Thus (as long as A4(i) holds), affecting I’s behavior through rule negligence is sufficient to cause I to internalize both externalities. On the other hand, Propositions 5.2 and 5.3 represent scenarios where the identity of the economic and legal victims differ. In such circumstances, the tort system cannot optimally control both externalities.

It should be emphasized that our basic claim regarding nonoptimality applies to the standard tort rules that are explicitly considered in the paper. It may be theoretically possible for courts or legislatures to adopt a tort rule that would induce socially optimal behavior by both parties (for instance, requiring I and V each to satisfy  $x^*$  and  $y^*$ , respectively, on pain of suffering a substantial penalty). However, such mechanisms will not, in general, resemble conventional tort rules in the sense of being budget-balanced, loss-shifting instruments.<sup>10</sup>

#### **6.4. Tort Liability versus Regulation**

Another question relevant to our results is raised by a related literature: why, if tort liability can induce socially efficient care, do we observe regulation and tort liability being used simultaneously to induce care taking (Kolstad, Ulen, and Johnson 1990; Shavell 1984; Wittman 1987; Rose-Ackerman 1991; Schmitz 2000).<sup>11</sup> The standard model of bilateral precaution

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<sup>10</sup> It is worth pointing out that imposing strict liability on both parties—which generally induces optimal behavior in the standard model—in the absence of collusive behavior, will not do so in our model. The parties will take suboptimal care because of the cost externality, even when each faces the full losses from accidents.

<sup>11</sup> Kolstad, Ulen, and Johnson (1990) assume that liability is inefficient because of uncertainty about the court’s behavior. Regulation then complements the liability rule and corrects its inefficiencies. Schmitz (2000) notes that what is not clear in the Kolstad *et al.* model is why liability is needed at all since, in their model, regulation could costlessly implement the social optimum. Shavell (1984) posits a model in which both liability and regulation are imperfect. Liability is inefficient because defendants are judgment proof, while regulation is inefficient because the

suggests that optimal deterrence can be achieved solely through the tort system. However, in many areas, such as automobile safety, both regulation and liability are used to induce precaution. Speed limits, drunk driving laws, and numerous criminal and civil laws governing driving care all create incentives for precaution in addition to the incentive provided by tort liability. This model suggests a possible rationale for multiple instruments being used to induce precaution in a single situation, which has not been examined in the existing literature. A single accident situation may involve multiple externalities and therefore may require multiple instruments to create correct incentives for socially optimal care. If courts or legislatures were unable to adopt novel tort rules that do induce socially optimal behavior, then conventional negligence-based rules would be unable, in general, to induce efficient precaution. In this case, a combination of regulation and liability may be more socially efficient than liability alone. This is an area for future research.

### **6.5. From Contributory to Comparative Negligence**

The standard bilateral precaution model predicts that contributory negligence and comparative negligence both induce efficient care, and thus provides no basis to explain why one rule might be preferred to another. In particular, the overwhelming shift from contributory negligence to comparative negligence in the United States since the 1960s is difficult to understand within the standard framework. The shift often has been justified on fairness grounds, but the question of whether a desire for efficient precaution played a role in the shift remains. Several papers demonstrate that comparative negligence results in more efficient (though nonoptimal) care than negligence with a defense of contributory negligence where there is incomplete information or error.<sup>12</sup> Empirical studies of automobile accidents by White (1989)

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same regulatory standard applies to all injurers even though they have differing costs of compliance. Schmitz (2000) criticizes this model for basing a “theory on the assumption that the same kind of error persistently occurs” (Schmitz 2000, 372). Our model introduces a situation in which liability is inefficient even with no uncertainty and no error. The question of whether regulation could induce socially optimal behavior and achieve desired transfers without the use of a liability system remains for future research.

<sup>12</sup>Cooter and Ulen (1986) show that with court error in evaluating whether the standard of care is met, CN is better at inducing efficient care than NdN. Rea (1987) shows that, when some parties do not respond to incentives, CN Pareto dominates other tort rules in terms of incentives for efficient care. Endres (1992) shows how, in the case of

and Sloan et al. (1994) provide ambiguous evidence about which rule has a stronger deterrence effect.<sup>13</sup> Edlin (1994) finds that an efficient switch to comparative negligence—where courts cannot perfectly observe care taking—requires stricter standards of care for both potential victims and injurers, which, arguably has occurred. Curran (1992) finds empirical support for an alternative hypothesis that the shift to comparative negligence was driven more by political economy considerations, such as rent-seeking, than by efficiency concerns. Our results suggest that the efficiency explanation for the shift may be more complex than previously thought.

## 7. Conclusion

This paper has sought to extend the economic analysis of bilateral accidents by considering a hitherto neglected interdependency among precaution costs. Specifically, we have analyzed situations in which a change in one party's level of care shifts the other party's cost-of-care function. We model this interdependency using a generalization of the standard bilateral precaution model, with no uncertainty, misperception, or error. In the case where the injurer's level of care affects the victim's precaution costs (but not vice versa), we found that most of the standard results continue to hold. However, strict liability with a defense of contributory negligence no longer leads to socially optimal behavior. In the case where the victim's precaution affects the injurer's costs of care (but not vice versa), our results showed that only strict liability with a defense of contributory negligence leads to the social optimum, while the other negligence-based rules lead to suboptimal outcomes. In the general case where each party's costs depend on both parties' levels of precaution, none of the standard liability rules induce socially optimal behavior by both parties.

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SLdN, error in the legal standard induces strategic behavior among parties, but that this behavior can actually help to correct court error in setting the legal standard. Rubinfeld (1987) shows that, where injurers (or victims) differ in their costs of care, CN is more efficient than N because it allows injurers (victims) to vary the degree of care they take.

<sup>13</sup> Using data from rear-end automobile accident cases, White (1989) finds that the shift to CN actually reduced incentives for careful driving. In contrast, Sloan et al. (1994) find that the trend away from NdN to CN had no effect on deterrence of automobile accidents, but that for drivers over 25 years of age, tort liability and increased insurance premiums had a more significant deterrence affect than increases in the price of alcohol.

Another important result of this paper concerns the possibility of negligent behavior in equilibrium, even with perfect information and no error. We found that, under a contributory negligence regime, there is no Nash equilibrium in pure strategies. The mixed strategy equilibrium involves parties choosing (with strictly positive probability) to behave negligently. This gives rise to the possibility of successful litigation in equilibrium. Earlier literature has explained litigation by invoking uncertainty, misperception, or error; ours is the first full-information, rational-actor model that generates equilibrium negligence.

This paper also has discussed case law that highlights the significance of the interdependency among precaution costs we have analyzed. We also have considered the implications of our results for such issues as the design of liability rules, the shift from contributory to comparative negligence, and the relative merits of regulation and tort liability.



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## Appendix

### *Second Order Conditions:*

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

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

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

$$f_{xx} = C^I_{xx}(x, y) + C^V_{xx}(x, y) + L_{xx}(x, y).$$

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

The second principal minor determinant is  $f_{xx}f_{yy} - f_{xy}f_{yx}$ ; assuming that  $C^I_{yy}(x, y) > 0$  is sufficient to ensure that  $f_{yy} > 0$ . In addition, assuming that the cross-partials  $C^I_{xy}(x, y)$ ,  $C^I_{yx}(x, y)$ ,  $C^V_{xy}(x, y)$ ,  $C^V_{yx}(x, y)$ ,  $L_{xy}(x, y)$ , 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 Eq. 2 are satisfied.

### ***Proof of Proposition 5.1:***

(i) Consider N: by satisfying the legal standard of care  $x^*$ , I avoids all liability, and faces cost  $C^I(x^*)$ , while taking  $x < x^*$  leads to costs  $C^I(x) + L(x, y)$ . Given A4(i),  $L(x, y) > C^I(x^*) - C^I(x)$ , I's dominant strategy (for any  $y$ ) will be to satisfy the standard. Since  $C^I_x(x) > 0$ , a cost minimizing I will never choose  $x > x^*$ . Given that I satisfies  $x^*$ , V faces  $C^V(x^*, y) + L(x^*, y)$ ; the first order condition (FOC) for V's minimization problem is identical to the FOC for the social planner's problem in Eq (5), which gives the socially optimal  $y$ ,  $y^*$ . Thus, V takes  $y^*$ , and  $(x^*, y^*)$  is an equilibrium; uniqueness follows as  $x^*$  is I's dominant strategy, and  $y^*$  is the unique maximizer of Eq (3).

Consider NdN: Suppose I satisfies  $x^*$ ; then, V faces  $C^V(y; x^*) + L(x^*, y)$ . The FOC for this problem is the same as that of the social planner, Eq (5). V will take the socially optimal level of care,  $y^*$ .

Suppose V takes  $y^*$ ; then, I faces  $C^I(x^*)$  by taking  $x^*$ , and  $C^I(x) + L(x, y)$  by taking  $x < x^*$ . By A4(i), I takes  $x^*$ . Thus,  $(x^*, y^*)$  is an equilibrium.

From above, it also follows that there cannot be an equilibrium in which one party takes optimal care and the other does not. Furthermore, suppose that I takes  $x < x^*$ ; then, V takes  $y^*$  by A4(ii). Thus, there cannot be an equilibrium in which both parties take suboptimal care. This establishes the uniqueness of  $(x^*, y^*)$ .

(ii) Under NL, I never faces liability for V's loss, regardless of V's actions, so her costs are only her cost of precaution,  $C^I(x)$ , which is minimized by taking  $x = 0$ . 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,  $C^V_y(y; 0) + L_y(0, y) = 0$ , is different from that of the social planner (Eq. 5), 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.

(iii) 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,  $C^I(x) + L(x, 0)$ , which he will minimize by taking precaution  $x^{SL}$ . The FOC for this minimization problem,  $C^I_x(x) + L_x(x, 0) = 0$ , differs from the social problem (Eq (4)). 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 will not be socially optimal.

(iv) Under SLdN, V can avoid bearing the expected accident loss only by taking the socially optimal level of care,  $y^*$ . As long as A4(ii) is satisfied, V takes precaution  $y^*$ . Given V's choice of  $y^*$ , I faces full liability, and will minimize cost of  $C^I(x) + L(x, y^*)$  by taking precaution of level  $x^S$ . Since the first order condition for this minimization problem,  $C^I_x(x) + L_x(x, y^*) = 0$ , differs from that of the social planner (Eq. 4), the victim will not choose the socially optimal level of precaution.

To show that  $x^S < x^*$ , compare the FOC for the social problem (Eq (5)) with the FOC for I's problem,  $C^I_x(x^S) + L_x(x^S, y^*) = 0$ . As  $C^V_x(\cdot) < 0$ , it follows that:

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

Define  $g(x) \equiv C^I_x(x) + L_x(x, y^*)$ . As (given A2(iii) and A1(iv)),  $C^I_{xx} > 0$  and  $L_{xx} > 0$ ,  $g_x > 0$  (i.e.,  $g$  is monotonically increasing in  $x$ ). Therefore,  $g(x^*) > g(x^S) \Leftrightarrow x^* > x^S$ .

(v) Consider CN: Suppose that I takes  $x^*$ ; then, V faces  $C^V(y; x^*) + L(x^*, y)$ , so that V's best response is  $y^*$ . Given that V takes  $y^*$ , I faces full liability,  $C^I(x) + L(x, y^*)$ , if she takes  $x^0 < x^*$ , and faces only precautionary cost,  $C^I(x^*)$ , by taking  $x = x^*$ . Since  $C^I_x(x) > 0$ , a cost minimizing I will never choose  $x > x^*$ . Given A4(i), I will take  $x^*$ . Thus,  $(x^*, y^*)$  is an equilibrium.

As I's best response to  $y^*$  is  $x^*$ , there can be no equilibria of the form  $(x^0, y^*)$ ; as V's best response to  $x^*$  is  $y^*$ , there can be no equilibria of the form  $(x^*, y^0)$ , where  $y^0 < y^*$ . However, suppose that I takes  $x^0 < x^*$ ; if  $C^V(y^*; x^0) < C^V(y^0; x^0) + \alpha L(x^0, y^0)$  for all  $y^0 < y^*$ , then  $y^*$  is V's best response. If there exists some  $y^0$  such that  $C^V(y^*; x^0) > C^V(y^0; x^0) + \alpha L(x^0, y^0)$ , then this  $y^0$  is a best response to  $x^0$ . Moreover, if, for such a  $y^0$  and  $x^0$ , it is also the case that  $C^I(x^0; y^0) < C^V(y^0; x^*) + (1-\alpha)L(x^*, y^0)$ , then  $(x^0, y^0)$  will be an equilibrium.

***Proof of Proposition 5.2:***

(i) Under SLdN, V can avoid bearing the expected accident loss only by satisfying the legal standard  $y^*$ . As long as A4(ii) is satisfied, V takes precaution  $y^*$ . Given V's choice of  $y^*$ , I faces full liability, and will minimize  $C^I(x; y^*) + L(x, y^*)$ . The FOC for this minimization problem is identical to that in the social planner's problem, Eq. 10. A cost minimizing I will take the socially optimal level of care,  $x^*$ . Thus,  $(x^*, y^*)$  is an equilibrium; uniqueness follows because  $y^*$  is V's dominant strategy, and  $x^*$  is the unique maximizer of I's program. It is apparent from the reasoning below that  $(x^*, y^*)$  is not an equilibrium under any other rule.

(ii) 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  $C^V(y) + L(0, y)$ , which is minimized by  $y^{NL}$ . Since the FOC for this optimization problem,  $C^V_y(y) + L_y(0, y) = 0$ , is different from that of the social planner (Eq. 11), 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.

(iii) Under SL, V is always compensated and bears only his cost of precaution,  $C^V(y; x)$ , regardless of I's precaution. V minimizes  $C^V(y)$  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 the social problem (Eq (10)). 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 will not be socially optimal.

(iv) 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 A4(i),  $L(x, y) > C^I(x^*; y) - C^I(x; y)$ , I's dominant strategy (for any  $y$ ) will be to satisfy the standard. Given that I satisfies  $x^*$ , V faces  $C^V(y) + L(x^*, y)$ ; the FOC for V's minimization problem differs from the FOC for the social planner's problem in Eq (11) V will take precaution of  $y^N$ . Thus,  $(x^*, y^N)$  is an equilibrium.

To show that  $y^N < y^*$ : V's FOC is  $C_y^V(y^N) + L_y(x^*, y^N) = 0$ . Comparing this to the FOC for the social optimum, Eq. 11, and noting that  $C_y^I < 0$  by assumption, it follows that:

$$C_y^V(y^*) + L_y(x^*, y^*) > C_y^V(y^N) + L_y(x^*, y^N).$$

Noting that  $C_y^V(y) + L_y(x^*, y)$  is monotonically increasing in  $y$ , it follows (by a similar argument to that in the proof of Proposition 4.1(iv)) that  $y^N < y^*$ .

(v) Consider CN: To show that  $(x^*, y^*)$  is not an equilibrium, suppose that I plays  $x^*$ . V faces  $C^V(y) + L(x^*, y)$  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 (va) holds. Then,  $x^{CN}$  is I's best response to V playing  $y^{CN}$ . Suppose that Condition (vb) holds. Then,  $y^{CN}$  is V's best response to I playing  $x^{CN}$ . Thus, if  $\exists (x^{CN}, y^{CN})$  such that Conditions (va) and (vb) 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.

(vi) Consider NdN: Suppose I takes  $x^*$ ; V faces  $C^V(y) + L(x^*, y)$  and takes precaution  $y^N$ . Thus,  $(x^*, y^*)$  is not an equilibrium. Moreover, if  $y$  takes  $y^0 < y^*$ , I will face no liability, and will choose  $x = 0$ . Thus,  $(x^*, y^0)$  (including  $(x^*, y^N)$ ) is not an equilibrium. Suppose I takes  $x^0 < x^*$ ; V can avoid the accident loss by taking  $y^*$ , and (given A4(ii)) will do so. Thus, there cannot be equilibria of the form  $(x^0, y^0)$ . But, if V takes  $y^*$ , I's best response (given A4(i)) is to take  $x^*$ ; thus, there cannot be equilibria of the form  $(x^0, y^*)$ .

This exhausts all the possibilities, so there is no pure-strategy Nash equilibrium.

***Proof of Proposition 5.3:***

(i) It will be apparent from the reasoning below  $(x^*, y^*)$  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 A4(i),  $L(x, y) > C^I(x^*; y) - C^I(x; y)$ , 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 FOC for V's minimization problem differs from the FOC for the social planner's problem in Eq (14) 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  $y$ ,  $y^*$ , above. As  $C_y^I(\cdot) < 0$  by assumption, it follows that:

$$C_y^V(y^*; x^*) + L_y(x^*, y^*) > C_y^V(y^N; x^*) + L_y(x^*, y^N).$$

By assumption,  $C_{yy}^V(\cdot) > 0$  and  $L_{yy}(\cdot) > 0$ . Thus, both the LHS and RHS of the expression above represent an increasing function of  $y$ , say,  $f(y)$ , where  $f(y) \equiv C_y^V(y; x^*) + L_y(x^*, y)$  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  $C_x^I < 0$ , 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,  $C_y^V(y; 0) + L_y(0, y) = 0$ , differs from that of the social planner (eq. 11), 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,  $C_x^I(x; 0) + L_x(x, 0) = 0$ , differs from the that for the social problem (Eq

(10)). 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 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 A4(ii) is satisfied, V will meet the social standard of care,  $y^*$ . Given that V takes precaution  $y^*$ , I will face and choose  $x$  to minimize both costs of precaution and accident loss,  $C^I(x; y^*) + L(x, y^*)$  by choice of  $x^S$ . The FOC for this minimization problem differs from that of the social planner's problem in Eq 13.

To show that  $x^S < x^*$ : As  $C_x^V(\cdot) < 0$  by assumption, it follows that:

$$C_x^I(x^*; y^*) + L_x(x^*, y^*) > C_x^I(x^S; y^*) + L_x(x^S, y^*)$$

and therefore (as  $C_{xx}^I(\cdot) > 0$  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 (va) holds. Then,  $x^{CN}$  is I's best response to V playing  $y^{CN}$ . Suppose that Condition (vb) holds. Then,  $y^{CN}$  is V's best response to I playing  $x^{CN}$ . Thus, if  $\exists (x^{CN}, y^{CN})$  such that Conditions (va) and (vb) 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 A4(ii) 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 A4(I)) 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.

***Proof of Proposition 5.4:***

Consider I's expected payoff from playing  $r$ , given that V plays  $q$ :

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

Simplifying, the expected payoff is

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

Setting the coefficient of  $r$  in the above expression equal to zero, and rearranging, yields  $q^0$  (note that, using assumptions A1-A4, it follows that  $q^0 \in (0,1)$ ). If  $q > q^0$ , then I's payoff is increasing in  $r$ , so that I's best response  $r^*(q) = 1$  (i.e., playing the pure strategy  $x^*$ ). If  $q < q^0$ , then I's payoff is decreasing in  $r$ , so that  $r^*(q) = 0$  (i.e., playing the pure strategy 0). If  $q = q^0$ , then I's payoff is constant in  $r$ , so that *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  $r$ :

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

Setting the coefficient of  $q$  in the above expression equal to zero, and rearranging, yields  $r^0$  (note that, using assumptions A1-A4, it follows that  $r^0 \in (0,1)$ ). If  $r > r^0$ , then V's payoff is decreasing in  $q$ , so that V's best response  $q^*(r) = 0$  (i.e., playing the pure strategy  $y^N$ ). If  $r < r^0$ , then V's payoff is increasing in  $q$ , so that  $q^*(r) = 1$  (i.e., playing the pure strategy  $y^*$ ). If  $r = r^0$ , then V's payoff is constant in  $q$ , so that *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 that  $(r', q') = (1, 0)$ . But, this cannot be an equilibrium (see proof of Proposition 5.3).

If  $q' < q^0$ , then  $r^*(q') = 0$ . Moreover,  $q^*(0) = 1$ , so that  $(r', q') = (0, 1)$ . But, this cannot be an equilibrium (see proof of Proposition 5.3).

Similar reasoning holds for  $r' \neq r^0$ . Thus,  $(r^0, q^0)$  is the unique Nash equilibrium.