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Victim or injurer, small car or SUV: Tort liability rules under role-type uncertainty

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Abstract

In this paper we modify the standard tort model by introducing role-type uncertainty. That is, we assume that neither party knows in advance whether she will be the victim or the injurer when an accident occurs. When the standards of care of the two parties are set at the socially optimal levels, only pure comparative negligence and the equal division rule guarantee efficiency, while the rules of simple negligence, contributory negligence, and comparative negligence with fixed division (other than a 50:50 split) may produce inefficient equilibria. Since pure comparative negligence splits liability between negligent parties according to each party's degree of fault, it makes the accident loss division independent of one's role-type. This produces its efficiency advantage.

We extend the model to the choice of vehicle size, as a factor determining who will be the injurer and who the victim in motor vehicle collisions. In the extension we analyze various standard negligence-based liability rules, and tax rules, as instruments to mitigate inefficiency resulting from the vehicle size "arms race." We also examine two strict liability rules, one of which incorporates a comparative negligence feature; this rule prevents inefficiency from both role-type uncertainty and from the "arms race."

JEL classification: K13; D61

Keywords: Role-type uncertainty; Negligence; Comparative negligence; Contributory negligence; Equal division rule; Motor vehicle collisions; Vehicle size

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1. Introduction

One of the stylized features of the standard economic model of tort law is that each party's potential role as a victim or an injurer in a possible accident is pre-determined. That is, each knows in advance the position – victim or injurer – she will be in if an event occurs that leads to a lawsuit. This set-up is consistent with some types of torts, such as product liability, medical malpractice, and slip and fall cases. But it may not fit some other types of torts. For example, when motor vehicles collide, there is great uncertainty about which party or parties will sustain serious injury. Since a seriously injured party is more likely to file a lawsuit than an uninjured or slightly injured party, which party will be plaintiff and which will be defendant (that is, which will be victim and which injurer) is extremely uncertain *ex ante*.[1] Hunting accidents may be similar: when A and B head to the woods, and A shoots B, mistaking him for a deer, they probably had no prior belief that B would be the victim and A the injurer. Similarly, if two fishing vessels collide and one sinks, the captains probably had no good knowledge beforehand about which vessel would sink and which would not, which party would be the victim and which would be the injurer.

Arlen (1990) extends the standard analysis, of one harmed party and advanced knowledge of who will be victim and who injurer, to the "bilateral risk" situation in which injurers as well as victims suffer accident damages.[2] She shows that if each party is allowed to sue her counterpart for her own damages, the main implications of the basic model remain intact. That is, various forms of negligence-based rules[3] induce both parties to take efficient levels of care if the standard of care for each party is set equal to the socially efficient level.

In her model, however, the proportion of total damages each party would suffer from an accident is *known in advance*. Landes and Posner (1987, p. 77) and Wittman, Friedman, Crevier, and Braskin (1997) make the same assumption in dealing with the theory of bilateral risk accidents.[4] But this does not capture the essential uncertainty about whether a party will be the victim or the injurer.

Our paper modifies the standard tort model by introducing *role-type uncertainty*. As in the standard model, we will assume that only one party will be harmed.[5] But we will also

[1] According to a study of the U.S. Department of Justice, Bureau of Justice Statistics, automobile accidents or property liability claims accounted for more than 75% of all tort filings in state courts between July 1, 1991 and June 30, 1992. Medical malpractice, product liability, and toxic substances together comprised about 10% of all the cases filed. See Cooter and Ulen (2000, pp.356–357). Huber (1988) estimated that traffic accident claims account for around 40% of all tort cases.

[2] Note that a unilateral risk model with role-type uncertainty is in essence similar to a bilateral risk model, if we assume that everyone is entitled to sue the other party for his own damages from an accident. In other words, the situation where we know that the victim suffers the whole damages but do not know who will be the victim, is analytically similar to the situation where we know both can suffer damages but do not know what the proportions will be.

[3] Arlen (1990) does not include comparative negligence in her analysis.

[4] White (1989) has a different approach for modeling automobile accidents cases, along the lines of Diamond (1974). Rather than considering gaming behavior between the two parties involved, she focuses on the representative driver's behavior, assuming that the other driver's care level is randomly chosen from a population. Her analysis also includes uncertainty in the court's decision-making.

[5] Alternatively we could assume both parties might be harmed, but with proportions falling on the two parties not known in advance. This makes the treatment more complex.

assume that the parties do not know in advance who will be the harmed party. With this kind of imperfect information, each party makes choices based on a subjective belief about the probability that she will be the victim.

Other tort uncertainties have been explored by other authors. Cooter and Ulen (1986) and Haddock and Curran (1985) argue that comparative negligence is superior to contributory negligence under *evidentiary uncertainty*, that is, uncertainty created by the imperfect ability of courts to evaluate care levels. However, Edlin (1994) argues that even with evidentiary uncertainty, if the standards of care are appropriately chosen (at levels different from the efficient levels), both negligence rules can lead to efficient outcomes. Various authors have modeled uncertainty created by *heterogeneous agents*. In particular, Rubinfeld (1987) and Emons (1990) introduce heterogeneity in individuals' care-taking costs. They show that a properly designed sharing rule (that is, a comparative negligence rule) can improve on all-or-nothing type negligence rules. But recently, Bar-Gill and Ben-Shahar (2003) critique these approaches, and show with simulations that comparative negligence may be less efficient that simple negligence or contributory negligence, depending on the degree of evidentiary uncertainty.

Our model abstracts from evidentiary uncertainty and heterogeneous agent uncertainty, and focuses instead on the uncertainty about which party will end up as the victim and which the injurer, that is, role-type uncertainty.

In Section 2 of this paper we show that, if the two parties' subjective victimization probabilities do not sum to 1, pure comparative negligence, and the equal division rule, have better efficiency properties than other standard negligence-based rules. We show that role-type uncertainty strengthens the efficiency claims of pure comparative negligence and the equal division rule, because they make the liability assignments between two negligent parties independent of their role-types. In contrast, the rules of simple negligence, negligence with contributory negligence as a defense, and comparative negligence with a fixed division other than 50:50, all allow the possibility of inefficient equilibria in which both parties take insufficient care.

In Section 3 of the paper we extend the model to a theory of liability rules and choice of motor vehicle size. We continue to assume role-type uncertainty, but this is also a theory of vehicle collisions, where one's probability of being the injurer depends on the size of one's vehicle. Drivers of big cars are more likely to be injurers, and drivers of small cars, victims. Our model here is similar in spirit to White's (2004) "arms race" paper. The general conclusion of Section 3 is that the standard negligence-based liability rules we examined in Section 2 of the paper produce efficient equilibria in terms of the parties' *care levels*, but all produce an inefficient "arms race" in terms of *vehicle size*. We indicate how adding a size-based standard of care could eliminate the inefficiency, and we compare that policy to the imposition of a vehicle size tax. We conclude by examining two variants of strict liability, one of which, strict liability with a defense of contributory negligence, eliminates the arms race in vehicle size, but may allow inefficiencies because of role-type uncertainty. The second, strict liability with a defense of comparative negligence, solves the arms race, and also, being a pure comparative negligence rule, guarantees efficiency in spite of role-type uncertainty. We briefly compare these proposed solutions to the legal remedies advocated by Latin and Kasolas (2002) and Case (2006).

2. Efficient liability rules under role-type uncertainty

2.1. The model

Suppose that there are two risk-neutral people, X and Y, who engage in some activity that creates a risk of accidents. If an accident occurs, there is one victim, who suffers a monetary loss $L > 0$. The loss L is assumed to be constant.[6] But there is uncertainty regarding the roles of X and Y in the possible accident: neither knows in advance whether she will be the *victim* or the *injurer*. We assume that the uncertainty about the identity of the victim/injurer is independent of the uncertainty about whether or not an accident will occur. We assume that each party has a *subjective ex ante* belief about the likelihood that, if an accident occurs, she will be the victim. We define:

$\alpha \equiv$ Person X's probability that she will be the victim, if an accident occurs.
$\beta \equiv$ Person Y's probability that she will be the victim, if an accident occurs.

We assume that $0 \leq \alpha, \ \beta \leq 1$. We will call α and β the victimization probabilities, or role-type uncertainty parameters, depending on context. We assume that X and Y believe their probabilities of being the *injurer* are $1-\alpha$ and $1-\beta$, respectively.

Because the occurrence/non-occurrence of an accident is assumed independent of the identity of the victim/injurer, party X's subjective probability of being a victim in an accident is α times the accident probability, and her subjective probability of being an injurer in an accident is $1-\alpha$ times the accident probability.

Since α and β are subjective probabilities, formed before the fact, and not necessarily observable by the other party, the sum of α and β need not equal 1. That is, X and Y may form their beliefs about victimization probabilities in some *uncoordinated or inconsistent* way. They may not share the same information or beliefs. If they had the same information and beliefs, the subjective probabilities would sum to 1. The subjective probabilities are not generally the *true* probabilities that X or Y will be victim. If they were true probabilities, they would of course sum to 1. It will turn out that the value of $\alpha + \beta$ has a crucial role in determining game equilibria, and the efficiency or lack thereof, of some liability rules.[7]

Let x and y denote person X's and person Y's care levels, respectively, measured by their care expenditures. Following the standard modeling in tort liability literature since Brown (1973), we assume that each person can choose any level of care between 0 and ∞, that the care levels are observable by both, and that the probability of an accident, $p(x, y)$, is a continuous and differentiable function of the care levels, known to both. We assume that increasing care levels reduce the probability of an accident, and thus expected accident costs ($p_x < 0$, and $p_y < 0$). We also assume that, for all x and y, $p(x, y) > 0$, $p_{xx} > 0$, $p_{yy} > 0$, and $p_{xy} > 0$.

[6] The assumption of a constant L can also be relaxed, at the cost of greater complexity.

[7] For example, in the context of motor vehicle collisions, each driver's vehicle is different in terms of its weight, bumper height, etc. The drivers may not know the characteristics of the other party's vehicle in advance. A Hummer driver may expect that her probability of being the victim in a collision with another vehicle will be small. If two Hummer drivers are involved in a collision, $\alpha + \beta$ may be much less than one. If two motorcycle riders are involved in a collision, $\alpha + \beta$ may be much greater than 1.

To repeat, there are two levels of uncertainty in our model; the first is whether or not an accident will occur. This is treated in the standard fashion: the probability of an accident is a function of both care levels; care levels are money expenditures, easily observable; both parties know the care levels, and therefore both know the accident probabilities. The second is role-type uncertainty: if an accident occurs, who sustains the losses? This uncertainty is modeled with the subjective victimization probabilities α and β. For simplicity, we are assuming that the care levels do not affect α and β.[8] We allow these probabilities to be highly subjective: for instance, an *optimistic* person may know that she has a given probability of being involved in an accident with another person, but she may believe that if she is, *she has only a small chance* of being hurt. The subjective victimization probabilities are generally *not directly observable* by the other party, and they *may be inconsistent* in the sense that they do not sum to 1.

Total social cost (TSC) is defined as the sum of care-taking costs of both parties and expected accident costs. That is, $\mathrm{TSC} = x + y + p(x, y)L$. The social goal is, as usual, to minimize total social cost. Let (x^*, y^*) denote the solution to this TSC minimization problem. We will assume for the sake of clarity in this paper that (x^*, y^*) is unique.[9] We call (x^*, y^*) the *efficient*, or *socially optimal* care combination.

In our model, when an accident occurs the entire loss L is initially born by the victim. The court then enforces a *liability rule*, which determines where L ultimately falls: on the victim, on the injurer, or on both. A negligence-based liability rule is defined in terms of which parties are negligent, and if both are negligent, possibly their degrees of negligence. A party is *negligent* if her care expenditure falls short of the court-enforced *standard of care*. We assume that everyone, including the court, knows the expected loss function and the governing liability rule, that the court can solve the TSC minimization problem, and that everyone, including the court, can observe each party's care levels accurately. However, the parties and the court may not know the *true* probabilities that X or Y will be victim, and the subjective victimization probabilities may be known only to their owners. Note that knowledge of the true victimization probabilities is not necessary for the determination of (x^*, y^*) in our model, since we are assuming that whether the victim is X or Y, the loss L is the same. Finally, we assume that the standard of care for each party is set at the socially optimal level. That is, for instance, party X is found *negligent* by the court if and only if she spends $x < x^*$.[10]

In this section of the paper we will analyze and compare four standard negligence-based liability rules: simple negligence (Section 2.2 below), negligence with a defense of contributory negligence (Section 2.3), comparative negligence with fixed division (Section 2.4), and pure comparative negligence (Section 2.5). In Section 3 of the paper we will consider two more liability rules, both based on strict liability, which are significantly different from the four rules discussed in this section. Our four standard rules share the

[8] This assumption can also be relaxed without changing the main implications of the paper.

[9] Non-uniqueness creates considerable complication in the appropriate definition of the standard of care. See for instance Jain and Singh (2002). We prefer to avoid the complication.

[10] Note that the assumptions that the court knows the expected loss function, and sets the standards of care at the efficient levels, are exceedingly strong; we argue elsewhere that these assumptions, which are standard in the literature, are actually unrealistic. See Kim (2003) and Feldman and Kim (2005).

following properties:

(i) If both parties are non-negligent, all accident costs fall on the victim.
(ii) If one party is non-negligent and the other party is negligent, all accident costs fall on the negligent party.

The four rules differ as follows:

(iii.a) Simple negligence. If both parties are negligent, all accident costs fall on the injurer.
(iii.b) Negligence with contributory negligence as a defense. If both parties are negligent, all accident costs fall on the victim.
(iii.c) Comparative negligence with fixed division. If both parties are negligent, a fixed fraction of the accident costs fall on the victim, the balance on the injurer.
(iii.d) Pure comparative negligence. If both parties are negligent, the accident costs are split between victim and injurer, according to degree of fault.

From properties (i) and (ii) above, we can calculate person X's expected private cost function C_X under role-type uncertainty, which depends on both parties' care levels and on X's subjective victimization probability. Note that these equations hold for all four standard rules:

$$\text{If } x \geq x^* \text{ and } y \geq y^*, \text{ then } C_X = x + \alpha\, p(x, y)L \tag{1}$$

$$\text{If } x < x^* \text{ and } y \geq y^*, \text{ then } C_X = x + p(x, y)L \tag{2}$$

$$\text{If } x \geq x^* \text{ and } y < y^*, \text{ then } C_X = x \tag{3}$$

Eq. (1) says that if neither party is negligent, then party X's expected cost equals her care expenditure x, plus L times the probability of an accident in which she is the victim. Eq. (2) says that if X is negligent and Y is not, then party X's expected cost equals her care expenditure x, plus L times the probability of *any accident*. Eq. (3) says that if X is non-negligent and Y is negligent, then party X's expected cost equals her care expenditure x. Note that β does not appear in Eqs. (1)–(3).

Person Y's expected private cost function C_Y is derived in a similar way. Eqs. (1)–(3) enable us to establish that, as in the standard model with pre-determined role-type, the social optimum (x^*, y^*) is a Nash equilibrium even with role-type uncertainty, under the four standard liability rules. We call this Result 1 below. Closely related Result 2 says that under the four liability rules, there is no Nash equilibrium that involves either party taking *more* than due care, that is, spending more than her efficient x^* or y^*. Proofs of both results are omitted.

Result 1. *With role-type uncertainty, the social optimum* (x^*, y^*) *is a Nash equilibrium under the rules of simple negligence, contributory negligence, comparative negligence with fixed division, and pure comparative negligence*.

Result 2. *With role-type uncertainty, nobody takes more than due care, at any possible Nash equilibrium, under the rules of simple negligence, contributory negligence, comparative negligence with fixed division, and pure comparative negligence.*

Results 1 and 2 do not rule out the possibility of a Nash equilibrium in which *both* parties take *less* than due care. Since each negligence-based rule specifies a different liability assignment in this case, the parties' expected cost functions vary from rule to rule. If any of the four liability rules could successfully rule out the possibility of an insufficient-care-equilibrium, then (x^*, y^*) would turn out to be the *unique* equilibrium of the game, and we would conclude that the rule is efficient in the presence of role-type uncertainty. With this in mind, we examine each of the four rules in turn.

2.2. Simple negligence

Under the simple negligence rule, if both parties are negligent, all accident costs fall on the injurer. This gives:

$$\text{If } x < x^* \text{ and } y < y^*, \text{ then } C_X = x + (1-\alpha)\, p(x, y)L \tag{4.a}$$

The equation says that if both parties are negligent, party X's expected cost equals her care expenditure x, plus L times the probability of *an accident in which she is the injurer*. Note that β does not appear in equation (4.a).

When facing a negligent counterpart, person X's best response for minimizing her own expected cost may be either to take due care, or to choose negligence. The intuitive reason for the latter possibility is this: X may believe that she will be victim with high probability. That is, α may be close to 1. In this case the probability of an accident in which she is injurer (and liable) will be low. She will then be likely to choose an $\tilde{x}$ smaller than the efficient x^*.

In fact, the simple negligence rule under role-type uncertainty allows the possibility of inefficient equilibria, in which both parties are choosing negligent behavior. In addition to the efficient equilibrium at (x^*, y^*), the game has an inefficient equilibrium at $(\tilde{x}, \tilde{y})$, where $\tilde{x} < x^*$ and $\tilde{y} < y^*$, if the following conditions are satisfied simultaneously:

$$\tilde{x} \text{ minimizes } x + (1-\alpha)\, p(x, \tilde{y})L, \text{ and } \tilde{y} \text{ minimizes } y + (1-\beta)\, p(\tilde{x}, y)L \tag{5}$$

$$\tilde{x} + (1-\alpha)\, p(\tilde{x}, \tilde{y})L \le x^* \tag{6}$$

$$\tilde{y} + (1-\beta)\, p(\tilde{x}, \tilde{y})L \le y^* \tag{7}$$

Expression (5) says that the chosen expenditure levels minimize the respective expected private cost expressions C_X and C_Y, contingent on both parties choosing to be negligent. Expressions (6) and (7) permit the parties to rationally choose a negligent $\tilde{x} < x^*$ (and $\tilde{y} < y^*$), at a cost less than or equal the cost of being non-negligent.

Here is a simple, if extreme, example: Suppose that party X believes that she will be the victim, and that Y believes *she* will be the victim (i.e., both are extreme pessimists; $\alpha = \beta = 1$). In this case, the simple negligence game has two Nash equilibria; (0, 0) and (x^*, y^*). One possible outcome in the game is an inefficient equilibrium, where neither party takes any precaution. Note that this outcome does not require irrational behavior: at (0, 0) each party is minimizing her expected costs, given the care level of the other party and given the legal rule. Nor are we assuming that that party X is so silly she thinks her probability of being victim, plus her probability of being injurer, add up to something other than 1. The odd thing about the (0, 0) equilibrium is that it is based on extreme and highly uncoordinated subjective victimization probabilities. However, the victimization probabilities need not be as extreme as we assumed ($\alpha = \beta = 1$), in fact α and β might both be substantially less than 1, and we might still have an insufficient-care Nash equilibrium. The crucial assumption in the example, as we will see in the next result, is that the two parties X and Y do not have coordinated or consistent views about the probabilities of who will be victim and who injurer; because if their views were coordinated, we would have $\alpha + \beta = 1$.

A subtle objection might be made to the (0, 0) Nash equilibrium: If party X sees party Y choosing care level $y = 0$, X can infer that Y's β must be 1. Similarly, if party Y sees party X choosing care level $x = 0$, Y can infer that X's α must be 1. That is, the two parties can infer that their subjective victimization probabilities are inconsistent; that $\alpha + \beta > 1$. (The inference about the other person's subjective victimization probability can generally be made if they are at an inefficient Nash equilibrium, but not if they are at the efficient Nash equilibrium.) But it is unclear what they would do with this information: Should party X, after having calculated what β must be based on her observation of y, abandon her own belief about α? Should the two parties modify their victimization probabilities in some Bayesian fashion? The answers to these questions are not obvious, and we will therefore make the simplest assumption: Party X, if she is able to compute party Y's β from an observation of Y's care level, will neither modify nor abandon her own α in the interest of making the victimization probabilities consistent. Our model can therefore be viewed as one with *friction* in beliefs about victimization probabilities; X and Y are quick to see and act on each other's care levels, but they are slow to discover and act on inconsistencies in beliefs about victimization probabilities.

Result 3 below provides a necessary condition for the existence of an inefficient equilibrium, in terms of the sum of two subjective victimization probabilities.

Result 3. $\alpha + \beta > 1$ *is a necessary condition for the simple negligence rule to produce an inefficient equilibrium under role-type uncertainty.*

Proof. Let $(\tilde{x}, \tilde{y})$ be an inefficient equilibrium. We will show $\alpha + \beta > 1$. By adding together inequalities (6) and (7), we have $\tilde{x} + \tilde{y} + (2 - (\alpha + \beta))p(\tilde{x}, \tilde{y})L \leq x^* + y^*$. But since x^* and y^* solve the total social cost minimization problem, $x^* + y^* < x^* + y^* + p(x^*, y^*)L \leq \tilde{x} + \tilde{y} + p(\tilde{x}, \tilde{y})L$. Therefore $\tilde{x} + \tilde{y} + (2 - (\alpha + \beta))p(\tilde{x}, \tilde{y})L \leq x^* + y^* < \tilde{x} + \tilde{y} + p(\tilde{x}, \tilde{y})L$, which implies $1 < \alpha + \beta$. Q.E.D.

2.3. Contributory negligence

Under the rule of negligence with contributory negligence as a defense, the victim recovers damages from a negligent injurer, unless the victim is also negligent, in which case the losses stay with the victim. Therefore, if both parties are negligent, all accident costs fall on the victim. This gives:

$$\text{If } x < x^* \text{ and } y < y^*, \text{ then } C_X = x + \alpha\ p(x, y)L \tag{4.b}$$

The equation says that if both parties are negligent, party X's expected cost equals her care expenditure x, plus L times the probability of *an accident in which she is the victim*. Note that β does not appear in equation (4.b).

By the same logic as was used in the preceding section, one can derive conditions for the existence of an inefficient equilibrium at $(\tilde{x}, \tilde{y})$, where $\tilde{x} < x^*$ and $\tilde{y} < y^*$. The conditions are similar to conditions (5)–(7) above, and will not be given here.

Like the simple negligence rule, the contributory negligence rule does not necessarily lead to an efficient outcome under role-type uncertainty. Since the accident costs fall on the victim when both are negligent, the contributory negligence rule may produce an insufficient-care equilibrium when both parties believe they have high probabilities of becoming an injurer, that is, low probabilities of becoming a victim. Here is another simple, extreme, example: Suppose that party X is sure she will be the injurer, and that Y is sure that *she* will be the injurer (i.e., $\alpha = \beta = 0$). In this case, the contributory negligence game has two Nash equilibria (0, 0) and (x^*, y^*), and in one neither party takes any precaution. Note that the (0, 0) is not irrational: it minimizes each party's expected costs, subject to what the other party is doing and subject to the legal rule. As in the simple negligence example discussed above, the victimization probabilities are uncoordinated or inconsistent, but we assume that even if the parties can infer that $\alpha + \beta < 1$, they do not revise their own subjective probabilities. The important thing about this example is that it is based on uncoordinated or inconsistent beliefs about victimization probabilities; if the beliefs were coordinated we would have $\alpha + \beta = 1$.

Based on the same kind of logic as used in the proof of Result 3, we have the following:

Result 4. $\alpha + \beta < 1$ *is a necessary condition for the contributory negligence rule to produce an inefficient equilibrium under role-type uncertainty.*

Result 4 makes it clear why Arlen (1990) and Wittman et al. (1997) conclude that efficiency is guaranteed under the contributory negligence rule. In their bilateral risk models, both parties suffer losses and each party's expected loss function is separable and known to everyone. Accordingly, the condition $\alpha + \beta = 1$ (in our context) is always satisfied, and the possibility of an insufficient-care equilibrium is eliminated.

Before proceeding, we will make some final remarks about Results 3 and 4. To establish each, we ask whether or not it is possible for both parties, simultaneously, to want to choose negligence. For this to happen, X must be opting for negligence while Y is being negligent, and *vice versa*. This requires that the expected cost to X under (X negligent, Y negligent) must be less than or equal to the expected cost to X under (X non-negligent, Y negligent), and *vice versa*. Since the latter expected cost is x^* (or y^*, respectively), we get conditions like (6) and (7) (for simply liability, with similar conditions, not shown, for contributory negligence.) We then add the two conditions together, as in the proof of Result 3, to produce our necessary condition for an inefficient equilibrium. The crucial step in that adding together is $\tilde{x} + (1 - \alpha)p(\tilde{x}, \tilde{y})L + \tilde{y} + (1 - \beta)p(\tilde{x}, \tilde{y})L \leq x^* + y^*$ in Result 3, with a similar inequality (used but not shown) in Result 4. What allowed this inequality to be possible for some pair $(\tilde{x}, \tilde{y})$ was the fact that the terms $1 - \alpha$ and $1 - \beta$ did not have to sum to 1; if they did sum to 1, the inequality would be impossible because (x^*, y^*) is total social cost minimizing. In this case there could be no inefficient Nash equilibrium. In short, it was the latitude created by the inclusion of the role-type uncertainty parameters, not constrained to sum to 1, in conditions (6) and (7), that led to Result 3; and similar conditions (not shown) led to Result 4. As we will see below, if the role-type uncertainty parameters could not work their way into conditions analogous to (6) and (7), that latitude would disappear, and so would the inefficient Nash equilibria.

2.4. Comparative negligence with fixed division

In contrast to "all-or-nothing" rules like simple negligence or contributory negligence, the comparative negligence rule with fixed division splits accident damages between two negligent parties, in some fixed proportion.[11] Let γ denote the fraction of accident damages borne by the victim when both parties are negligent ($0<\gamma<1$). In particular, if $\gamma = 1/2$, this is "the equal division rule." The equal division rule was once the dominant doctrine in admiralty law, until it was replaced by the pure comparative negligence system.[12]

Under the comparative negligence rule with fixed division, when both parties are negligent person X's expected cost function is:

$$\text{If } x < x^* \text{ and } y < y^*,\; C_X = x + [\alpha\gamma + (1-\alpha)(1-\gamma)]p(x, y)L \tag{4.c}$$

The equation says that if both parties are negligent, party X's expected cost equals her care expenditure x, plus γL times the probability of *an accident in which she is the victim*, plus $(1-\gamma)L$ times the probability of *an accident in which she is the injurer*. Note that β does not appear in equation (4.c).

It is easy to see that this rule may not preclude an insufficient-care equilibrium, for certain values of α, β, and γ. The conditions for the existence of an inefficient equilibrium at $(\tilde{x}, \tilde{y})$, where $\tilde{x} < x^*$ and $\tilde{y} < y^*$, analogous to expressions (5)–(7), are as follows:

$$\begin{aligned}&\tilde{x} \text{ minimizes } x + [\alpha\gamma + (1-\alpha)(1-\gamma)]p(x, \tilde{y})L, \text{ and}\\ &\tilde{y} \text{ minimizes } y + [\beta\gamma + (1-\beta)(1-\gamma)]p(\tilde{x}, y)L\end{aligned} \tag{8}$$

$$\tilde{x} + [\alpha\gamma + (1-\alpha)(1-\gamma)]p(\tilde{x}, \tilde{y})L \leq x^* \tag{9}$$

$$\tilde{y} + [\beta\gamma + (1-\beta)(1-\gamma)]p(\tilde{x}, \tilde{y})L \leq y^* \tag{10}$$

However, note that if $\gamma = 1/2$, the role-type uncertainty parameters α and β disappear in the above expressions. Moreover, under the equal division rule condition (4.c) is

[11] Note that the loss-splitting property of the comparative negligence with fixed division rule works only as a "defense". So this rule is different from what Shavell (1987) defines as the rule of "strict division of accident losses". Strict division of accident losses implies that the fraction of losses borne by the injurer and the victim is assumed to be independent of their levels of care, and, in particular, independent of whether someone was negligent. It is straightforward that strict division of accident losses does not provide the parties with correct incentives, even in the standard model without role-type uncertainty.

[12] By about 1700 English courts were consistently applying the equal division rule in admiralty collision cases. This doctrine was replaced in 1911 in Great Britain by a statute providing for division of damages in proportion to the degree of fault of each vessel. The U.S. Supreme Court adopted the equal division rule in 1854, in a ship collision case, *The Schooner Catharine v. Dickinson* (58 U.S. (17 how.) 170, 15L. Ed. 233). In turn, the equal division rule was replaced by the pure comparative negligence rule in U.S. admiralty cases as a result of a 1975 U.S. Supreme Court case, *United States v. Reliable Transfer Co.* (421 U.S. 397, 44 L. Ed. 2d 251, 95 S. Ct. 1708). See Keeton et al. (1984) and Schwartz (1994).

transformed to:

$$\text{If } x < x^* \text{ and } y < y^*, \text{ then } C_X = x + 0.5p(x, y)L \tag{4.d}$$

That is, if both parties are negligent, then party X's expected cost equals her care expenditure x, plus one half times L times the probability of *any accident*.

When $\gamma = 1/2$, conditions (9) and (10) become $\tilde{x} + (1/2)p(\tilde{x}, \tilde{y})L \leq x^*$ and $\tilde{y} + (1/2)p(\tilde{x}, \tilde{y})L \leq y^*$, respectively. But these two conditions cannot be satisfied simultaneously, because adding the two inequalities together yields $\tilde{x} + \tilde{y} + p(\tilde{x}, \tilde{y})L \leq x^* + y^* < x^* + y^* + p(x^*, y^*)L$, which is not possible, since (x^*, y^*) is by assumption social cost minimizing. Therefore, the equal division rule guarantees efficiency. Note that among all fixed division rules, the equal division rule is the only one that makes one party's expected cost, assuming both parties are negligent, independent of her role-type. That is, only the equal division rule makes α and β disappear in expressions (9) and (10), and therefore eliminates the latitude that would make an inefficient equilibrium possible.

All other fixed division rules allow the possibility of insufficient-care equilibria. By logic similar to that used in the proof of Result 3, we can derive a necessary condition for such equilibria:

Result 5. *Either* (*i*) $\alpha + \beta > 1$ *and* $\gamma < 1/2$, *or* (*ii*) $\alpha + \beta < 1$ *and* $\gamma > 1/2$, *is a necessary condition for the comparative negligence rule with fixed division to produce an inefficient equilibrium under role-type uncertainty.*

At this point we can compare simple negligence, contributory negligence, and comparative negligence with fixed division (excepting the 50:50 split) in terms of social efficiency. We find that if $\alpha + \beta = 1$, then all three rules are efficient, but if $\alpha + \beta \neq 1$, none of these three rules guarantees efficiency, and, furthermore, none dominates the others on efficiency grounds.

2.5. Pure comparative negligence

Under the pure comparative negligence rule, if both parties are negligent, accident damages are split according to degree of fault. In the context of continuous care models, the proportions of accident damages persons X and Y should bear are generally defined using the extent of each party's deviation from her due care level. That is, X's degree of fault is most naturally measured by $(x^* - x)/(x^* - x + y^* - y)$, and similarly for Y's.

Now, person X's expected cost function when both parties are negligent is:

$$\text{If } x < x^* \text{ and } y < y^*, \; C_X = x + \frac{x^* - x}{x^* - x + y^* - y} p(x, y)L \tag{4.e}$$

The equation says that if both parties are negligent, party X's expected cost equals her care expenditure x, plus her degree of fault times L times the probability of *any accident*.

Since neither α nor β appears in equation (4.e), when both take less than due care, each party's expected cost function is independent of the role-type uncertainty parameters. When both are negligent, one party's damage share depends only on the actual care levels, and on (x^*, y^*). As before, the social optimum (x^*, y^*) is a Nash equilibrium under the pure comparative negligence rule. Most important, it is the *unique* equilibrium of the game, by an argument similar to the argument for the efficiency of the equal division rule. We leave the details to the reader. The intuition is that the degree-of-fault term in equation (4.e), pre-multiplying $p(x, y)L$, has no α in it; the corresponding term for party Y has no β, and the sum of the two terms, for X and Y, equals 1.

In conclusion, the pure comparative negligence rule guarantees efficiency even with role-type uncertainty, as long as the standards of care are set at the socially efficient levels. Since the pure comparative negligence rule splits liability between negligent parties according to each party's degree of fault, it makes the accident loss division independent of one's role-type. No matter what α and β are, the rule produces the efficient outcome as the unique equilibrium of the game.

Our main findings so far are summarized in:

Proposition 1. *Suppose that the standard of care for each party is set at the socially optimal level. In the standard tort model, with role-type uncertainty, under which each party forms a subjective belief regarding her probability of becoming an injurer or a victim*:

(i) *If $\alpha + \beta = 1$, the four standard negligence rules we have examined all guarantee efficiency.*
(ii) *For arbitrary α and β, the pure comparative negligence rule and the equal division rule both guarantee efficiency.*
(iii) *However, for arbitrary α and β, the rules of simple negligence, contributory negligence, and comparative negligence with fixed division* (*other than the 50:50 split*) *all produce the possibility of an inefficient equilibrium in which both parties take less than due care. Among these three rules, no rule dominates others in terms of efficiency.*

3. Applying the model to collisions of different-sized vehicles

At this stage we add other dimensions to the analysis. We will assume the losses stem from motor vehicle accidents. We will relate the subjective victimization probabilities α and β to the true victimization probabilities, which we will assume are based on vehicle size.

Note that adding the dimension of vehicle size to our model at this point is similar to the addition of *activity level*, as a choice independent of, and perhaps prior to, the choice of *care level*, in the standard literature.[13] When activity level can vary, standard negligence-based liability rules may fail to be efficient, because they do not provide incentives to careful parties to limit the extent of their activities. On the other hand, strict liability may provide such incentives. The difference between adding activity level in the standard tort model, and adding vehicle size in our role-type uncertainty model, is this: Activity level is assumed to affect expected losses, or at least expected losses per unit time. In contrast, we assume that vehicle size has no impact on $p(x, y)$ or on L, but only affects the (true) probabilities of who will be victim and who injurer. (We will elaborate on our use of this assumption

[13] See for example Polinsky (1983), Chapter 6.

below; see footnote 14.) The interesting similarity is this: just as consideration of activity level in the standard model points toward strict liability, the problem of vehicle size in our model is solved by certain strict liability rules.

With the burgeoning use of SUV's and pickup trucks as passenger vehicles in recent years, it has become apparent that many people are choosing large vehicles to reduce the likelihood that, in the event of a collision, they will be victims. If your Hummer H1 collides with my Honda Civic, whose vehicle is totaled? More important, who goes to the hospital, or worse? The auto companies don't advertise it explicitly, but it's implicit: Drive our big SUV, and *you'll* walk away from the crash; the *guy in the other car* (*or his spouse or children*) will be injured or killed.

White (2004) provides compelling evidence about the negative effects created by vehicle size in the United States. (See also Latin and Kasolas, 2002 and Case, 2006.) Among the statistical results she reports are these: Consider a traffic collision between vehicles A and B. If A is a car, then the probability of a fatality in A is 38% lower if B is a car rather than a light truck. If A is a light truck, then the probability of a fatality in A is 55% lower if B is a car rather than a light truck. If A is a motorcycle, then the probability of a fatality on A is 125% higher if B is a light truck rather than a car. White also provides similar data on serious injuries. White's data indicate that if 1 million light trucks on US highways were replaced by cars, traffic fatalities would fall by between 34 and 93 per year. White also discusses, in general terms, the failure of liability rules, insurance, and traffic rules to solve this externality problem.

The model we present below is obviously in the same spirit as White's paper. However, we differ from her by emphasizing the game theoretic outcomes when persons X and Y are responding to each other's vehicle sizes, and are simultaneously playing the care choice liability game.

Moreover, White (2004) goes far beyond claiming that the vehicle size arms race is a matter of vehicle owners attempting to throw *fixed* costs on the other party. In fact, she presents evidence that the upsizing of vehicles results in substantially higher totals of deaths and injuries in the US. In our model, in contrast, we assume (perhaps unrealistically) that accident probabilities, and losses when accidents occur, are not affected by vehicle size. We assume that vehicle size merely impacts on the probabilities of *who will be victim*. We do assume that size is costly, but only in the sense that the consumer pays a higher price for purchasing a larger vehicle. And under these quite limited assumptions, we establish that, in theory, the arms race will be very costly.[14]

We now assume that there is a one-dimensional property that is chosen by each of the potential parties to accidents, which we call "size." We call this "size" following White (2004) and others; however, what we mean is weight (that is, mass). (In reality, motor vehicles obviously have a number of characteristics that impact on the probability that

[14] For the sake of simplicity we are assuming vehicle size has no impact on accident probabilities, and losses when accidents occur. White (2004) presents much evidence to the contrary (see also Latin and Kasolas (2002), and Case (2006)). In our theoretical model, we infer substantial social costs resulting from the vehicle size "arms race." If larger vehicles also produce greater accident probabilities and greater losses per accident, as the evidence suggests, the social costs figured in our model *underestimate* the true social costs. That is, our estimate of "arms race" social costs provides a *lower bound* for the true costs.

their occupants will be victims or injurers, including weight, bumper and frame height, horsepower, body reinforcements and rigidity, crumple zones, airbags, and so on.)

Weight is a particularly important characteristic affecting which parties in an accident may be harmed, simply because of physical laws, particularly the law of conservation of linear momentum. For instance, suppose an 8000 lb light truck collides precisely head on with a 2000 lb car, both traveling at 50 miles per hour (in opposite directions). Suppose the wrecked vehicles travel together as a single unit (rather than bouncing apart like elastic billiard balls). The resulting 2-vehicle tangle will continue to travel in the direction of the truck, at 30 m.p.h., by conservation of momentum. The occupants of the light truck will have experienced a 20 m.p.h. deceleration in the brief period of the crash, whereas the occupants of the car will have experienced an 80 m.p.h. deceleration. It is no surprise that, when a train and a car collide, the occupants of the car die much more often than the occupants of the train; the explanation is that the train is the very much more massive object.

We now assume that size is a non-negative number; and we normalize the units so the smallest vehicle has size 0. (A more realistic normalization would put the minimum at 1, but this would make some of our equations later on unnecessarily complex.) We assume that person X chooses size s, and that person Y chooses size t. Note that vehicle size is a continuous variable ranging from 0 to infinity in our model. Therefore person X's vehicle size s can range continuously from Mini Cooper to Hummer H1 and beyond, and so can person Y's vehicle size t. We assume that the following equations determine the *true victimization probabilities*, which we will call $\bar{\alpha}$ and $\bar{\beta}$:

$$\bar{\alpha} = \frac{t}{s+t} \text{ and } \bar{\beta} = \frac{s}{s+t} \tag{11}$$

Note that $\bar{\alpha} + \bar{\beta} = 1$, as should be the case for the true probabilities. To put it another way, the true probability that person X is the *injurer* is given by $s/(s+t)$, the fraction of total vehicle size comprised by X's vehicle. The big cars rule! To complete the specification of the victimization probabilities, we assume that if $(s, t) = (0, 0)$, the probabilities are both 1/2.

We will assume that party X knows her vehicle size s, and that party Y knows her vehicle size t. We will assume that both know the equations determining the true victimization probabilities. However, X may or may not know Y's vehicle size, and vice versa. If each party knows the other's vehicle size, then the subjective probabilities must equal the true probabilities. Otherwise, the subjective probabilities may differ from the true probabilities. In Sections 3.1–3.4 below, we will assume that the parties *do* know the other person's vehicle size, and so the subjective probabilities are also true probabilities. In Section 3.5, we will assume that the parties *may not* know the other person's vehicle size.

3.1. Incorporating vehicle size in the decision process

As a first simple case, assume that X and Y have *fixed, pre-determined* vehicle sizes, that the sizes s and t are known to both, and that they are choosing care levels x and y, subject to one of the negligence-based rules analyzed above. Since X and Y know both vehicle sizes, $\alpha = \bar{\alpha}$ and $\beta = \bar{\beta}$, and therefore $\alpha + \beta = 1$. Therefore, under Results 3–5 above, no matter which standard negligence-based rule is in effect, the unique Nash equilibrium care levels are at (x^*, y^*).

When (x^*, y^*) is the Nash equilibrium for the care levels, both parties are taking adequate care, and therefore under all the standard negligence-based rules, all of the accident losses fall on the victim. We conclude, therefore, party X's expected cost is:

$$C_X = x^* + \frac{t}{s+t}\, p(x^*, y^*)L \tag{12}$$

Next, we continue to assume that the sizes s and t are known to both. But now we *allow party X to adjust her vehicle size s*, while taking party Y's vehicle size t as given. We let r represent the cost per unit of vehicle size, so that a vehicle of size s costs rs.

By the arguments in Section 2 above, any Nash equilibrium requires that the care levels be at the efficient (x^*, y^*).

Anticipating a Nash equilibrium in the care levels at (x^*, y^*), and deciding what sized vehicle to choose, party X wants to choose s to minimize

$$C_X + rs = x^* + \frac{t}{s+t}\, p(x^*, y^*)L + rs$$

The first order condition for a minimum leads easily to

$$s = \left(\frac{t}{r} p(x^*, y^*)L\right)^{1/2} - t \tag{13}$$

3.2. *Nash equilibrium in vehicle size*

We are continuing to assume that the sizes s and t are visible to both. But now we assume that both parties, X and Y, are minimizing expected private costs plus vehicle size costs, each taking the other's (optimal) care as a given, and each taking the other's vehicle size as a given. We wish to find a Nash equilibrium in vehicle sizes (which lies on top of the Nash equilibrium in care levels). Party X is solving Eq. (13), and party Y is solving an analogous equation. It is then easy to show that the resulting vehicle size choices, s^*, t^*, are given by[15]

$$s^* = t^* = \frac{1}{4r} p(x^*, y^*)L \tag{14}$$

Total expenditure on vehicle size is of course a pure social waste in this model, since it has no function other than to throw fixed damages on the *other* party in the event of an accident. We will call this social cost *vehicle size waste*, and abbreviate it VSW; it is of course an addition to the previously defined TSC, which only comprises care costs plus expected accident costs. The vehicle size waste is trivially derived from equation (14) above, as follows:

$$\mathrm{VSW} = rs^* + rt^* = \tfrac{1}{2} p(x^*, y^*)L \tag{15}$$

[15] Note that we are using the * notation in a different sense for vehicle sizes than for care levels. For care levels, a * designates a total-social-cost-minimizing level of care for a party, which she might (or might not) choose. For vehicle sizes, a * designates a chosen size, which normally will not be total-social-cost-minimizing, since the social-cost-minimizing sizes in the model will both be zero.

Equation (15) buttresses White's (2004) findings about the cost of the "arms race." White provides empirical evidence that large vehicles actually result in more deaths and injuries than would otherwise occur. (Latin and Kasolas (2002) and Case (2006) also argue that large SUV's produce carnage on the roads.)

Our theoretical model indicates that even if there are *no* additional accidents from the use of large vehicles, and even if large vehicles *do not* result in more costly accidents, the wasted expenditure on upsizing amounts to *fully half of the expected accident losses*.

3.3. Solving the size problem—making large size per se negligence, or taxing size

If the vehicle size arms race is wasteful, what policies might be adopted to reduce the waste? Vehicle size *per se* is not a negligence issue under the legal rules with which we are familiar. However, in theory, it could be. If the designer of a judicial system were to establish standards for both care levels x, y, *and* vehicle sizes s and t, our model at this point would work as follows: Vehicle size costs would be added to the previously defined TSC, producing a redefined total social cost of:

$$\text{TSC.1} = x + y + p(x, y)L + rs + rt.$$

This is minimized at $(x, s) = (x^*, 0)$ and $(y, t) = (y^*, 0)$. The court would set party X's standard of care at $(x^*, 0)$ and party Y's standard of care at $(y^*, 0)$. Failure to meet *either* the care expenditure standard *or* the size standard would result in a party's being found negligent.

Now consider whether or not party X would want to deviate from $(x^*, 0)$, if party Y were at $(y^*, 0)$. If X maintains s at 0, by the assumptions of this section $\alpha + \beta = \bar{\alpha} + \bar{\beta} = (1/2) + (1/2) = 1$, and the analysis of the previous section goes through, with (x^*, y^*) comprising a Nash care-level equilibrium, for any fixed s and t, under any of the standard negligence-based liability rules. We need to show party X would also choose size $s = 0$. She might be tempted to choose $x = x^*$ and $s = \varepsilon > 0$, in order to throw the accident damages on the other party, with her larger vehicle. But if she does so she becomes negligent, and under any of the standard negligence-based rules, all the damages get thrown back on her. Therefore, she resists the temptation. It is also clear that no Nash equilibrium would be possible if party Y were at (y^*, t), with $t > 0$, because X would then choose $(x^*, 0)$; this would result in X, in the small vehicle, becoming the victim with probability 1, but the damages would always be thrown back on Y, whose too-large vehicle makes her negligent. The results of this section to this point are summarized in:

Proposition 2. *Suppose that parties X and Y choose both care levels x and y, and vehicle sizes s and t. Assume the parties can observe the vehicle sizes, and can infer the true probabilities of their being accident victims, as per Eq.* (11) *above. Assume that standards of care for x and y are set at the socially optimal levels. Under the rules of simple negligence, contributory negligence, comparative negligence with fixed division, and pure comparative negligence:*

(1) *If the court imposes no size standard, all four negligence-based rules produce efficient Nash equilibria in terms of care levels, but they produce social waste from a vehicle size "arms race," equal to one half of expected accident losses.*

(2) *If the court also imposes a standard of care for size, at the optimal level of zero, all the rules produce efficient Nash equilibria in terms of both care levels and vehicle size.*

The principal drawback of Proposition 2's positive second part is that it is only a faint theoretical possibility. It's not likely that driving a large vehicle will ever be *per se* evidence of negligence, at least not in this Era of Excess. (However, see Case (2006).) A more plausible possibility is a tax on vehicle size, which could be easy to implement (state motor vehicle departments in the US already know vehicle weights, and some states impose higher registration fees on heavier vehicles), and for which there are precedents. We now model such a tax.

We continue to assume that both parties, X and Y, are minimizing expected accident costs plus vehicle size costs, each taking the other's (optimal) care as a given, and each observing the other's vehicle size, and taking it as given in her calculations. We assume that negligence is defined only in terms of x^* and y^*. We assume that there is an *ad valorem* tax τ on vehicle size, and therefore the cost of a unit of vehicle size, inclusive of the tax, is $(1+\tau)r$. We assume that each dollar of tax revenue produces a dollar's worth of social value, so the tax itself does not create its own social loss. The result is that each party replaces r with $(1+\tau)r$ in her calculations regarding what vehicle size to choose. Eqs. (14) and (15) are replaced with the following:

$$s^* = t^* = \frac{1}{4r(1+\tau)} p(x^*, y^*)L. \tag{16}$$

$$\text{VSW} = rs^* + rt^* = \frac{1}{2(1+\tau)} p(x^*, y^*)L. \tag{17}$$

The conclusion is this: all the negligence-based liability rules produce efficient Nash equilibria in terms of care levels x and y. There remains a vehicle size "arms race" loss VSW as shown in Eq. (17), but society can reduce this below any (positive) threshold by choosing the tax τ large enough.

3.4. Solving the size problem—strict liability with contributory negligence

To this point in this paper we have examined four standard negligence-based liability rules: simple negligence, negligence with a defense of contributory negligence, comparative negligence with fixed division, and pure comparative negligence. All have the property that, if both parties are non-negligent in care levels, accident losses fall on the victim. We have seen above that when vehicle size is an additional choice variable available to the parties, distinct from care level, vehicle owners may opt to use wastefully large vehicles in order to thrust victimization probabilities on the other party. The inefficiency could be mitigated by making the use of a large vehicle *per se* negligence, a very unlikely policy, or by taxing large vehicles, a somewhat unlikely policy. We now offer a third and a fourth choice.

Consider the rule Brown (1973) calls strict liability with a defense of contributory negligence, and Calabresi and Hirschoff (1972) call the reverse Learned Hand rule. It works as follows:

(iv) If both parties are non-negligent, all accident costs fall on the injurer.
(ii) If one party is non-negligent and the other party is negligent, all accident costs fall on the negligent party.
(iii.b) If both parties are negligent, all accident costs fall on the victim.

Note that property (iv) is new, and is what makes this a "strict liability" rule. Property (ii) is the same as in the four standard rules, and (iii.b) is the same as in the negligence with contributory negligence rule. Calabresi and Hirschoff call this the "reverse" Hand rule because it is, in a sense, the mirror image of the simple negligence rule. Simple negligence makes the victim bear the costs of accidents if and only if the injurer is non-negligent; this rule makes the injurer bear the cost of accidents if and only if the victim is non-negligent. Switch the words "victim" and "injurer" in (iv), (ii) and (iii.b) above and you have simple negligence.

Ignoring vehicle size for a moment, and focusing only on care levels as was done in Section 2, the equations for party X's expected cost functions are as follows:

$$\text{If } x \geq x^* \text{ and } y \geq y^*, \text{ then } C_X = x + (1 - \alpha)\, p(x, y)L \tag{18}$$

$$\text{If } x < x^* \text{ and } y \geq y^*, \text{ then } C_X = x + p(x, y)L \tag{2}$$

$$\text{If } x \geq x^* \text{ and } y < y^*, \text{ then } C_X = x \tag{3}$$

$$\text{If } x < x^* \text{ and } y < y^*, \text{ then } C_X = x + \alpha\, p(x, y)L \tag{4.b}$$

Eq. (18) is new, and characterizes "strict liability." It says that if neither party is negligent, then party X's expected cost equals her care expenditure x, plus L times the probability of an accident in which she is the injurer. Eqs. (2) and (3) are the same as for the standard rules; and Eq. (4.b) comes from contributory negligence. The reader can verify that these are identical to the corresponding equations for the simple negligence rule, except that X's subjective probability of being the *injurer* is switched around with her subjective probability of being the *victim*. And it turns out that the conclusions of Results 1 and 2 hold for this rule, as does an analog of Result 3: $\alpha + \beta < 1$ is the necessary condition for the existence of an inefficient equilibrium in care levels.

We are continuing to assume in this subsection that the parties can observe each other's vehicle sizes. Therefore they know the true victimization probabilities, which sum to 1. Therefore (x^*, y^*) is the unique Nash equilibrium in care levels. Both parties will be non-negligent.

Under strict liability, when both parties are non-negligent, it is costly for a party to be the *injurer*. With the four standard negligence-based rules previously discussed, it is costly for the party to be the *victim*. Therefore, a major difference between the four standard liability rules, on the one hand, and the strict liability with contributory negligence rule, on the other, is that strict liability makes even non-negligent parties want to avoid injuring others. This makes them want to use the smallest possible vehicles.

Formally, we now have the following:

Proposition 3. *Suppose that parties X and Y choose both care levels x and y, and vehicle sizes s and t. Assume the parties can observe the vehicle sizes, and can infer the true* *probabilities of their being accident victims, as per Eq.* (11) *above. Assume that standards of care for x and y are set at the socially optimal levels* (*but no standards are set for vehicle sizes*). *Assume the liability rule is strict liability with a defense of contributory negligence.*

Then (x^*, y^*) *is the unique Nash equilibrium for care levels, and the parties will also choose efficient vehicle sizes* $s^* = t^* = 0$.

Proposition 3 relies on the assumption that the parties can observe each other's vehicle sizes, and can therefore calculate the true victimization probabilities. This guarantees $\alpha + \beta = \bar{\alpha} + \bar{\beta} = 1$, which in turn guarantees that there cannot be an insufficient-care equilibrium. However, if the parties *cannot* observe each other's vehicle sizes, then (x^*, y^*) may no longer be a unique Nash equilibrium. In this case, there may also be an insufficient-care equilibrium $(\tilde{x}, \tilde{y})$, with $\tilde{x} < x^*$ and $\tilde{y} < y^*$. This would throw both parties X and Y onto Eq. (4.b), which makes it costly for a party to be a victim. And this, ironically, might encourage large vehicles![16]

3.5. Solving the size problem—strict liability with comparative negligence

We now introduce a new rule, which solves both the role-type uncertainty problem and the vehicle size problem. It is strict liability with a defense *comparative* negligence, and it works as follows:

(iv) If both parties are non-negligent, all accident costs fall on the injurer.
(ii) If one party is non-negligent and the other party is negligent, all accident costs fall on the negligent party.
(iii.d) If both parties are negligent, the accident costs are split between victim and injurer, according to degree of fault.

Formally these imply Eqs. (18), (2), (3), and, in the both-negligent case (4.e).

We now assume this liability rule, and we assume individuals know their own vehicle sizes, but *may not know* the other party's vehicle size. Therefore the subjective victimization probabilities need not equal the true probabilities. Therefore, $\alpha + \beta$ may not equal 1. We want to characterize the Nash equilibrium in care levels, and the choices of vehicle sizes.

Consider first whether or not (x^*, y^*) is a Nash equilibrium in care levels. The conclusions of Results 1 and 2 hold for this rule also; again, for the sake of brevity, we omit the proofs. Therefore (x^*, y^*) is a Nash equilibrium, and there exist no Nash equilibria in which one or both parties takes more than due care.

Next, suppose Y is at y^*. Could $(\tilde{x}, y^*)$ be an equilibrium, for some $\tilde{x} < x^*$? Note first that if X chooses the efficient level of care x^* the outcome for her is $C_X = x^* + (1 - \alpha)\, p(x^*, y^*)L \leq x^* + p(x^*, y^*)L$. But $x^* + p(x^*, y^*)L < \tilde{x} + p(\tilde{x}, y^*)L$, and the expression on the right is the expected cost to her if she chooses $\tilde{x}$. Therefore, $(\tilde{x}, y^*)$ cannot be an equilibrium.

[16] Here we do not have the well-defined "arms race" structure of Subsection 3.2 above; that structure was predicated on the assumption that each party knows the other's vehicle size, and reacts to that size. Absent that structure, we do not claim there is a Nash equilibrium of too-large vehicles.

Next we need to ask if there could be an insufficient-care Nash equilibrium $(\tilde{x}, \tilde{y})$ with both $\tilde{x} < x^*$ and $\tilde{y} < y^*$. If so, both X and Y are negligent, and their expected costs are, respectively, $C_X = \tilde{x} + ((x^* - \tilde{x})/(x^* - \tilde{x} + y^* - \tilde{y}))p(\tilde{x}, \tilde{y})L$, and $C_Y = \tilde{y} + ((y^* - \tilde{y})/(y^* - \tilde{y} + x^* - \tilde{x}))p(\tilde{x}, \tilde{y})L$. Since either party would escape liability by choosing her efficient care level (x^* or y^*, respectively), we must have $C_X \leq x^*$ and $C_Y \leq y^*$. Adding the two inequalities together then gives $\tilde{x} + \tilde{y} + p(\tilde{x}, \tilde{y})L \leq x^* + y^* < x^* + y^* + p(x^*, y^*)L$. But this would contradict the assumption that (x^*, y^*) is social cost minimizing. We have therefore shown that there cannot be a Nash equilibrium in care levels with both parties taking less than due care.

To this point we have shown that there is one and only one Nash equilibrium in care levels under the assumptions laid out in this subsection. Therefore, even if the parties do not know each other's vehicle sizes, and must rely on their subjective victimization probabilities α and β, they know they end up at care levels (x^*, y^*), and therefore each knows she will bear the burden of accidents in which she is the injurer. Therefore each attempts to minimize the probability of being injurer. The result is that X will choose $s^* = 0$, and Y will choose $t^* = 0$.

Our results of this section are summarized in:

Proposition 4. *Suppose that parties X and Y choose both care levels x and y, and vehicle sizes s and t. Assume X and Y cannot observe the other party's vehicle size, and must rely on subjective probabilities of their being accident victims. Assume that standards of care for x and y are set at the socially optimal levels. Assume the liability rule is strict liability with a defense of comparative negligence.*

Then (x^*, y^*) *is the unique Nash equilibrium for care levels, and the parties will also choose efficient vehicle sizes* $s^* = t^* = 0$.

Before leaving this section we will briefly comment on legal solutions to the large vehicle problem proposed by Latin and Kasolas (2002) and Case (2006). Latin and Kasolas argue that SUV's, particularly "behemoth" SUV's, create an enormous externality problem best attacked by design defect litigation. This would make the SUV *manufacturers* liable for injuries sustained by parties injured when their (smaller) vehicles are hit by SUV's. To do this it would be necessary to link two doctrines: (1) design defect liability and (2) bystander liability. As the law stands now, injured occupants of SUV's have successfully sued manufacturers for design defects which either caused accidents in which they were injured or exacerbated their injuries, but injured occupants of *other* vehicles (the "bystanders") have yet to succeed in suing SUV manufacturers for design defects of the SUV's that exacerbated their injuries but did not actually cause the accidents (e.g., excessive weight, dangerous bumper height, stiff frame). The Latin and Kasolas argument, while extremely interesting, goes beyond the scope of the model of this paper because it introduces a third party: the manufacturer.

Case (2006) endorses design defect litigation as a first approach, and then offers a second: This is to attack SUV use as an *ultra-hazardous* or *abnormally dangerous* activity, and make the *user* of the SUV strictly liable for injuries sustained by occupants of the other vehicle. Case argues for the second approach on the grounds that it has a more immediate bite than making manufacturers liable under the design defect theory. Case's ultra-hazardous strict liability would be much cruder and stronger than our strict liability rules discussed above;

transformed to the model of this paper it would say that if X and Y are involved in an accident, if s falls above some threshold (maximum "car" size), and if t falls at or below the threshold, then all accident costs must fall on X, no matter who is negligent or non-negligent in terms of the care levels x and y. Case does not specify the liability rule when both vehicles are "cars," or when both are "SUV's." Presumably this kind of rule would result in an inefficient Nash equilibrium in our model, where both X and Y are choosing vehicles at the cut-off size; that is the maximum size vehicle still considered a "car."

4. Conclusion

American Law Institute's *Restatement of the law third, torts: Apportionment of liability* focuses on the comparative responsibility system, reflecting the fact that all but four states (Alabama, Maryland, North Carolina, and Virginia) plus the District of Columbia, have adopted comparative negligence in place of the older contributory negligence rule. Spurred by this major doctrinal switch in tort law, scholars of law and economics have actively looked for an efficiency gain from the switch. The existing literature favoring the comparative negligence rule on efficiency grounds generally focuses on the characteristic of comparative negligence as a "sharing rule," and contrasts it with the "all-or-nothing" feature of contributory negligence.

In Section 2 of this paper, we focused on another aspect of comparative negligence that makes it superior to simple negligence, contributory negligence, or fixed-division negligence (other than equal division), namely the behavior of the rule under role-type uncertainty.[17] We showed that when each party enters the game with a subjective belief regarding the probability that she will be the victim (or the injurer), and the victimization probabilities do not sum to 1, only pure comparative negligence and the equal division rule guarantee social efficiency, while the rules of simple negligence, negligence with contributory negligence, and comparative negligence with fixed division other than 50:50, all allow the possibility of inefficient equilibria. Since the pure comparative negligence rule splits liability between negligent parties according to each party's degree of fault, it makes the accident loss division independent of one's role-type—victim or injurer. We showed that this often-overlooked characteristic implies that comparative negligence has a significant advantage over other rules in terms of social efficiency.

In Section 3 of this paper we extended our model to reflect the "arms race" in vehicle size, since vehicle size is an important factor in the determination of victimization probabilities in motor vehicle accidents. We found in this extension of the model that if we make information assumptions that guarantee that $\alpha + \beta = 1$ holds, all of the standard negligence-based liability rules we analyzed produce efficient care levels, but all result in another kind of inefficiency, because vehicles are too large. We found that if the notion of negligence could be broadened to encompass vehicle size, the vehicle size "arms race" inefficiency could be eliminated, and we also found that, without broadening the notion of

[17] Wittman et al. (1997) claim that the prevalence of comparative negligence is directly associated with the fact that automobile accidents have come to dominate the tort system. The superiority of comparative negligence under role-type uncertainty may be interpreted as supporting evidence for this claim.

negligence, a vehicle size tax could be used to mitigate the inefficiency. We ended by looking at two strict liability-based rules, both of which might be used to eliminate the vehicle size arms race. One of these rules, strict liability with a defense of comparative negligence, results in efficient levels of care and efficient vehicle sizes even when $\alpha + \beta = 1$ does not hold.

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