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LEAST COST AVOIDANCE

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Least Cost Avoidance*

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Abstract

This paper shows that the least cost avoider approach is not necessarily the optimal way to attain least cost avoidance. When parties do not observe each other's costs of precautions at the time of the accident they are unable to determine which party is the least cost avoider and hence fail to anticipate the outcome of the adjudication. Under these circumstances, accident avoidance becomes a commons problem because the precaution of each individual party reduces the prospect of liability for both parties. As a result parties suboptimally invest in precaution. We show that regulation removes this problem and is superior both when parties act simultaneously and when they act sequentially. We further examine how different liability rules perform in this respect.

JEL: K13, K32
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1 Introduction

When accidents can be avoided by either of two parties, it seems obvious to place liability on the least cost avoider, that is, the party who could have prevented the accident at the lowest cost. This approach is unanimously recognized as desirable, because not only does it induce parties to prevent accidents but is also forestalls wasteful care-taking by the party with the highest costs of precaution or, even worse, care-taking by both parties.[1]

However, this outcome necessarily presupposes that each party can observe the cost of the other party's precautions before deciding his or her move, because, when parties do not do so, they may not know who the least cost avoider is and consequently fail to anticipate the outcome of the adjudication. As a result, the incentives generated by liability are distorted.[2] In most accident contexts, this is likely to be the case, as parties act rapidly, do

[1]We study accidents of the alternative-care type. Accidents of the joint-care type, in which it is socially optimal for both parties to take positive levels of precaution, and accidents of the unilateral-care type, in which only one party can take precautions fall outside the scope of our analysis. On this point see Shavell (1987, pp. 17-18).

[2]See Harel and Jacob (2002, p. 14) noting this point. They argue that salience is the solution that should be and, in fact, is sought through tort law: one party is somehow (even arbitrarily) singled out among the group of potential injurers, in order to counteract the dilution of incentives that arises if liability is placed on all of them or if, as in our case, it is not possible to foresee *ex ante* which party will bear liability. Our analysis is different both with respect to the methodology we use, as we analyze this problem through the lens of a formal model, and with respect to the results we derive. Namely, we will show that corner solutions – when one party only takes precautions – are not necessarily optimal and that it is generally desirable that both parties take some positive levels of precaution in order to minimize the adverse effects of two distinct types of occurrences: 1) two parties take precautions when one party's precautions would have been enough and 2) no party takes precautions when one party's precautions would have been necessary. On the contrary, Harel and Jacob (2002) argue in favor of corner solutions by advocating salience. This is due to the fact that they focus on the need to avoid the accident and not on the need to balance, on the one hand, the occurrence of accidents and, on the other, the costs of duplicative precaution or of precaution by the highest cost avoider. Moreover, contrary to their broad perspective, we distinguish in our analysis the specific problem of parties being unable to observe *ex ante* each other's costs of precaution from the non-verifiability of the parties' costs of precaution *ex post* before the court and the non-identifiability of parties. In principle, our analysis can be equally applied to acts and to omissions.

not know each other, or else do not have time to communicate.[3]

To illustrate, when party A decides to take precautions, he or she might not know whether ex post party A will turn out to be the least cost avoider – in which case A's precautions reduces A's ex post liability – or party B will turn out to be the least cost avoider – in which case the precautions taken by A have a positive external effect on B, as they also reduces B's expected liability payment. Since these two outcomes cannot be disentangled from each other when parties do not observe each other's costs ex ante, precaution always comes at a private cost for each individual party, but it produces benefits that are not perfectly internalized. Therefore, parties are induced to take suboptimal levels of precaution.

Accident prevention under the least cost avoider approach can be easily analogized to a traditional commons problem in which parties' precautions are private inputs to the production of a common good (accident prevention), which, as economic theory predicts, will be undersupplied. Elaborating upon this simple observation, we will contend that the least cost avoider approach is not the best way to attain least cost avoidance and show that fines are a more desirable solution. In fact, fines, which separately target each party irrespective of the occurrence of accidents, eliminate the positive externality of individual precautions and are thus immune from the commons problem and superior to the least cost avoider approach.

As we will show, what could be called the *tragedy of common safety*[4] does not only arise in connection with the least cost avoider doctrine, but it may derive from any liability rule and, more in general, from any output-based incentive device, under which a party is sanctioned only if an accident occurs. In this case, whether or not a sanction (damages, for example) will be levied upon failure to take precautions does not only depend on whether or not an individual party has taken precautions but also on whether or not the other party has done so, in which case there is no accident and hence no

[3] In the literature on the economic analysis of tort liability, it is standard to assume that accidents occur between strangers and that transaction costs are high enough to prevent bargaining among the parties. See on this point Calabresi and Melamed (1972) and Kaplow and Shavell (1996).

[4] The term *tragedy of the commons* was made popular by Hardin (1968), first emphasizing the adverse effects of common property over scarce resources.

sanction. The commons problem arises from the fact that the occurrence of accidents, and thus the levy of sanctions, depends on both parties' behavior, as either of them can avoid the accident. Under fines, on the contrary, and in general under any input-based incentive device, sanctions are levied upon individual behavior and hence the commons problem disappears.[5]

We therefore make the point that regulation may be superior to liability since, targeting parties separately, regulation is free from the adverse effects due to the commons problem. To our knowledge, this issue is novel in the literature on regulation versus liability, which has mainly focused on the advantages of regulation in dealing with judgment proof injurers or disappearing defendants and in reducing the uncertainty accompanying negligence standards.[6] Our analysis emphasizes instead an advantage of regulation in an environment in which parties are timely sued, able to pay the judgment, and accurately informed on the negligence standard. Our points are independent of the relative advantages of regulators and courts in gathering information about the accident context and the parties' types; nevertheless, we will discuss in some detail the information requirements of the various

[5]By fines we mean a form of ex ante input control. Ex post fines conditional to the occurrence of accidents would have the same shortcoming we identify for liability. By the same token, ex ante liability for risk could be designed in such a way that reaches the same outcome as fines. In this case, both fines and damages would consist of a form of ex ante input control, the only difference between the two being that the former is activated by a public body while the latter relies on private initiative.

[6]Wittman (1977) first analyzed this issue, noting that the choice between input (fines) and output (liability) control depends on information, insurance and transaction costs. Shavell (1984a) compared liability and regulation according to four determinants: the level of information available to the parties and to the regulatory body, the possibility of insolvency, the possibility of escaping suit, the administrative costs of the system. Rose-Akerman (1991) and Innes (2004) also analyzed this problem. Only few contributions deal with the problem of combining liability and regulation. In this case, the focus is on insolvency or uncertainty concerning the legal standard. Shavell (1984b) analyzed the use of regulation when parties are insolvent and regulators are poorly informed and showed that a mix of the two systems may be superior to their separate use. Schmitz (2000) studies the combined use of regulation and liability when wealth varies among individuals. The effects of uncertainty have been formalized by Craswell and Calfee (1986); Kolstad, Ulen and Johnson (1990) discuss the combined use of regulation and tort liability in a context in which regulation is used to repair the shortcoming of tort liability in the face of uncertainty; Burrows (1999) focuses his analysis on situations in which the injurer lacks information on either or both the negligence rule and the regulatory standard.

policy solutions we analyze.

Looking more closely at tort liability, it is important to notice that not only does the least cost avoider approach relate to the least cost avoider doctrine, but it can be embedded into any negligence rule by reducing to zero the due level of care for the non-least cost avoider party, and hence it is a rather far-reaching and general concept. Consider for example a rule of simple negligence under which the injurer pays damages to the victim if and only if the injurer is found negligent. If, after examining the accident context it appears that the victim is the least cost avoider, then the optimal due care level for the injurer must be zero. Therefore, the injurer will never be found negligent and thus the victim will bear the cost.

Likewise, the same logic holds for comparative negligence, under which a negligent injurer pays compensatory damages to the victim only if the victim is found non-negligent and only a share of them if also the victim is found negligent. If the injurer is the least cost avoider, the optimal precaution level for the victim is zero and hence the victim is never found negligent. As a result the injurer is held liable for the entire harm whenever he does not take the required level of precaution. Similar considerations may be made for any other liability rule that makes use of the negligence inquiry.[7]

A second liability arrangement that we will consider is the sharing of the loss irrespective of fault.[8] This approach is different from comparative negligence, under which liability is allocated upon fault and, hence, in accordance to the least cost avoider approach. Under sharing irrespective of fault, instead, liability is shared between the parties according to some predetermined proportions which do not change depending on who is the least cost avoider. As we will show, also sharing irrespective of fault and, in general,

[7]See Chang (1993) noting this point.

[8]Sharing in tort law is mainly taken into account amoung faulty parties (see Bar-Gill and Ben-Shahar, 2003, for a recent review). Calabresi and Cooper (1996) argued that sharing irrespective of fault is in fact an increasingly common rule and that it may have an advantage over all-or-nothing arrangements. Parisi and Fon (*forthcoming*) take into account the sharing of the loss among non-negligent parties, in a framework labeled as *comparative causation*. To our knowledge, however, the application of a sharing rule to least cost avoidance in alternative-care cases is novel in the literature. See nevertheless the related discussion in Calabresi (1970, pp. 259-261).

any liability approach may generate a tragedy of common safety.

As a third solution, we study the doctrine of last clear chance,[9] which allocates responsibility to the party who could have last taken precautions in order to avoid the accident, and, hence, only applies to accidents in which parties act sequentially. A tragedy of common safety also arises in this case and parties take suboptimal levels of precaution.

There exists, however, a way to make liability generate optimal incentives for both parties to take precautions. The tragedy of common safety arises, as we have stipulated, from the fact that precautions have a private cost but produce common benefits. Fines solve this problem by transforming the parties' objective from avoiding the accident loss (a common bad) to avoiding a fine (a private bad). Precaution cost liability does the opposite, since the benefit of precaution is accrued by both parties, and so should be the cost. Under precaution cost liability, a rule similar to that proposed by Wittman (1981) in a different context from ours,[10] a party is entitled to recover his or her precaution costs from the other party. This way, the costs of precaution are borne by the least cost avoider irrespective of which party initially made those expenditures. Since the benefit of reduced liability ac-

[9] See Davis v. Mann (1842) 10 M&W 546, 152 Eng. Rep. 588.

[10] Wittman (1981) focuses his analysis on a the problems posed by accidents in which parties act sequentially. Namely, there might be two contrasting social goals. One to provide efficient incentives for both parties to take optimal precautions; another to provide the second mover with incentives to make up for the first mover's lack of precautions when, for some reason, the first mover failed to take the efficient level of precaution. It is shown that under ordinary liability rules, these two goals conflict. In fact, if the first mover can rely on the second mover compensating precaution, he or she will act strategically and always reduce his or her level of precaution. Wittman notices that marginal cost liability (a form of liability for precaution costs), unlike other rules, is complatible with both of these two goals. See also Rose-Ackerman (1989) on this point. In our framework precaution cost liability is shown to dominate other liability rules also when parties act simultaneously and our results are only related to the main goal of providing optimal incentives. In this respect, the superiority of precaution cost liability gains momentum irrespective of the virtues originally emphasized by its proponent. A discussion on the problems of allocating responsibility in sequential accidents may also be found in Shavell (1983) and Grady (1988). Harel and Jacob (2002, pp. 36-37) argue that precaution cost liability could be a possible solution to the dilution of incentives in alternative care cases when multiple parties are involved; however, they do not provide a formal proof of their claim.

crues ex post to the least cost avoider, when he or she also pays the cost of it, liability produces the same optimal incentives as fines. In sequential moves accidents, the optimal precaution cost liability rule requires instead the first mover to refund the costs of precaution of the second mover, irrespective of who was the least cost avoider. Since it is always socially optimal that the second mover makes up for the first mover's lack of precaution, this liability rule makes the first mover perfectly internalize the costs of precaution by the other party and hence yields an efficient outcome. Precaution cost liability may, however, as we will show, be difficult to apply.

The next several sections contain a formal analysis of this problem both when parties simultaneously take precautions and when they move sequentially; in each case, first we show that fines achieve the social optimum, then we analyze the performance of liability rules. Section 2 presents the model of parties who take precautions simultaneously; section 3 contains the model of parties who take precautions sequentially; section 4 discusses the information requirements of fines and of the different liability rules; section 5 concludes.

2 The model with simultaneous moves

We consider a simple model with two risk-neutral, utility-maximizing parties who are strangers to each other. Both of them can take precautions, but one party's precautions are enough in order to prevent an accident involving a passive victim.[11] They may be of different types, depending on their costs of precaution, and their types are distributed according to a certain probability density function, not necessarily the same for each party. Each party knows his or her type and the probability distributions, but he or she does not know the other party's type. The harm is assumed to be constant and positive. The law determines each party's sanction for failure to take precautions in terms of a fine or of a share in the harm.

[11] In our model, precaution is an "either/or" choice, that is, parties do not set the *levels* of their precautions, but only decide *whether or not* to take precautions and, if so, they incur costs exogenously dependent on their types. Nevertheless, we discuss optimal *levels* of precautions, meaning some maximal costs that it is socially optimal for the parties to bear in order to prevent an accident.

Let h be the harm, with $h > 0$, and c the costs of precaution of a certain party (that party's type), with $0 \leq c \leq h$.[12] For both parties, c is distributed according to a probability density function $f_i(c)$, for $i = 1, 2$, and a cumulative distribution $F_i(c)$; $f_i(c)$ is a continuously differentiable function over $0 \leq c \leq h$, positive over the same interval, and zero elsewhere; with $F_i(0) = 0$ and $F_i(h) = 1$.

The social cost is defined as the sum of the parties' precaution costs and the expected harm.[13] The first-best social optimum is a state of the world in which the least cost avoider takes precautions in each specific case. This article precisely deals with situations in which this is not the case, because, even if the costs of precaution may be verifiable *ex post*, at the time of the accident each party ignores the other party's costs of precaution, and hence they cannot coordinate their actions. Thus, we are looking for a second-best policy to minimize the social cost. This problem is equivalent to the problem of determining two levels of care c_1 and c_2 such that party 1 and party 2, respectively, take precautions if their costs are lower than or equal to them.

We begin by assuming that parties can be identified as party 1 and as party 2 *ex ante*;[14] thus, the standard of care can be conditioned on the identification of a certain party (that is, c_1 and c_2 may differ). In addition, we assume that the parties' precaution costs are verifiable *ex post* before the court or by the regulator (although they are *ex ante* unobservable for

[12]Notice that we have assumed that the costs of precaution are always less than the harm. Allowing the possibility that $c > h$ would generate situations where at least one individual should not take precautions in addition to cases in which the accident should efficiently occur as both individuals have costs of precaution higher than harm. Strictly speaking, these cases are of unilateral-care type, as at most only one party can prevent the accident at a cost lower than the harm; thus, they fall outside the scope of the current paper. By imposing $c < h$, the focus of our study is confined to the problem of making the least cost avoider take precautions. If the wrong party is picked, no accident occurs, but prevention is more expensive than optimal. If we allow for $c > h$ the focus slightly changes and encompasses situations in which the problem is indeed one of not avoiding the accident altogether.

[13]On this interpretation of the social function of tort liability see Calabresi (1970) and Brown (1973), who were somewhat anticipated by Holmes (1881). For a more general perspective see Shavell (1987).

[14]For example, they might be a motorist and pedestrian in an accident context or a doctor and a simple bystander in a rescue case.

the parties). Later we relax these assumptions and look at situations where parties cannot be identified *ex ante* (thus, c_1 and c_2 must be equal), and at situations where the costs of precaution are not verifiable *ex post*. Legal rules will be evaluated on the basis of the levels of precautions c_1 and c_2 they induce the parties to take, which determine the resulting social cost.

The social cost may therefore be written as follows:

$$S(c_1, c_2) = \int_0^{c_1} cf_1(c)dc + \int_0^{c_2} cf_2(c)dc + (1 - F_1(c_1))(1 - F_2(c_2))h \qquad (1)$$

The two first terms in (1) are the expected costs of precaution when parties take precautions up to costs equal to c_1 and c_2, respectively. The last term is the expected accident cost and is calculated as the magnitude of the accidental loss, h, times the probability of an accident actually occurring, given by the product of the probabilities of each party not taking precautions, that is, the probability mass associated to costs of precaution above c_1 and c_2, respectively.

If parties move simultaneously, the socially optimal levels of precautions minimize (1). The first-order conditions of (1) with respect to c_1 and c_2 yield that the socially optimal levels of c_1 and c_2 depend on the shape of the distribution and satisfy:[15]

$$\begin{aligned} c_1^* &= (1 - F_2(c_2^*))h \\ c_2^* &= (1 - F_1(c_1^*))h \end{aligned} \qquad (2)$$

The economic interpretation of the interior solution described by (2) is straightforward. The marginal increase in expected prevention cost from setting a higher level should equal the marginal value from reducing the probability of accidents. At least one solution to (2) exists by direct application of Brouwer's fixed point theorem. However, there is no guarantee that such

[15] The first order conditions of (1) are $\frac{\partial S}{\partial c_1} = f_1(c_1)[c_1 - (1 - F_2(c_2))h] = 0$ and $\frac{\partial S}{\partial c_2} = f_2(c_2)[c_2 - (1 - F_1(c_1))h] = 0$, from which (2) follows. The second order sufficient conditions should be verified to make sure that the interior solution to (2) is a minimum and not a maximum or a saddle point. They are satisfied as long as $f_1(c_1)f_2(c_2)h^2 < 1$. An interior solution satisfying (2) will be optimal and preferred to corner solutions as long as $S(c_1^*, c_2^*) \leq \min\{\int_0^h cf_1(c)dc; \int_0^h cf_2(c)dc\}$.

a solution is unique. In fact, we can easily show that the set of solutions to (2) is not necessarily a singleton. Just consider corner solutions with $c_1^* = 0$ and $c_2^* = h$ or $c_1^* = h$and $c_2^* = 0$, both satisfying (2). Finally, a symmetric solution might be possible. The necessary condition for a symmetric solution is of course that $F_2[(1 - F_1[c_1^*])h] = F_1[(1 - F_2[c_1^*])h]$, which is trivially satisfied when the distribution of costs is symmetric.

To illustrate, consider the simplest case in which the parties' costs of precaution are uniformly distributed. In this case, $f_1(c) = f_2(c) = 1/h$, and $F_1(c) = F_2(c) = c/h$. The solution to the minimization problem is given by any c_1^* and c_2^* such that $c_1^* + c_2^* = h$, when the social cost in expression (1) becomes $S(c_1, c_2) = \frac{c_1^2}{2h} + \frac{c_2^2}{2h} + (1 - \frac{c_1}{h})(1 - \frac{c_2}{h})h = h/2$.

Suppose now the distribution of costs for party 2 is uniformly distributed between $[\beta h, (1-\beta)h]$, with $\beta \in [0, 1/2)$, with $f_2(c) = \frac{1}{(1-2\beta)h}$ and $F_2(c) = \frac{c-\beta h}{(1-2\beta)h}$. It is the case that party 1's distribution is a mean-preserving spread of party 2's distribution, that is, both have the same expected value, but the variance of the distribution is strictly greater for party 1 than for party 2. Simple computation shows that, besides the two corner solutions, there is only an interior solution given by $c_1^* = c_2^* = h/2$ for any $\beta \in (0, 1/2)$.[16] If the distribution is skewed to the left or to the right, the optimal levels of the parties' precautions will also change, and different local minima might yield different levels of the social cost. For example, if party 2's costs are uniformly distributed between 0 and $h/2$, it can be shown that the optimal solution is the corner solution $c_1^* = 0$ and $c_2^* = h$, since the costs for party 2 are expected to be lower.

It is easy to see that, under any distribution, the second-best socially optimal levels of precautions can always be implemented by regulation, even if the parties' levels of precautions cannot be verified *ex post* by the police or by a regulatory body. In fact, a fine set equal to these levels induces parties to take precautions if precaution costs less than the fine and to bear the fine otherwise, and does not require the enforcer to verify the costs of precaution for individual parties. Formally, a fine of magnitude ϕ_i will induce party i to take precautions for any $c_i \leq \phi_i$. Hence, fines $\phi_i = c_i^*$ for $i = 1, 2$ will induce

[16] In the limit case such that $\beta = 0$, we are back to the first example where costs of precaution are symmetrically distributed.

the second-best levels of precautions for both parties.[17]

A similar approach is often referred to as strict-liability type of enforcement, as fines are levied irrespective of the cost of the parties' compliance. The same result may be reached by setting a fine that parties pay only if they fail to take due care (when the cost is lower than or equal to the legal standard), and pay nothing otherwise. The latter form is of the fault-based type, as fines are levied only if a party is found at fault, that is, if compliance costs less than the fine.[18]

2.1 The least cost avoider approach with simultaneous moves

Let us now turn to liability rules based on the least cost avoider approach. We assume that the costs of precaution, although not observable *ex ante*, are verifiable *ex post*. Therefore, a liability rule can be designed such that the courts verify *ex post* which party is the least cost avoider and allocate liability entirely to that party. Nevertheless, since parties do not know each other's costs of precaution at the time of the accident, they will decide whether to take precautions according to their expectations to pay damages, as in a traditional Cournot setting.

When parties move simultaneously without observing each other's decisions, a party will take precautions if his or her precaution costs are lower than or equal to the expected liability costs. Thus, the parties will take precautions up to:

$$\begin{aligned} \hat{c}_1 &= (1 - F_2(\hat{c}_2))(1 - F_2(\hat{c}_1))h \\ \hat{c}_2 &= (1 - F_1(\hat{c}_1))(1 - F_1(\hat{c}_2))h \end{aligned} \tag{3}$$

The right-hand sides of (3) describe the expected liability of a party,

[17] As usual, we assume that fines are costless to enforce. If not, the second-best levels of precautions would have to be determined taking into account enforcement costs.

[18] See Polinsky and Shavell (2000) for a distinction and a comparison between these two types of enforcement. Shavell (1980) first formalized the difference between the two approaches in tort law.

given that party's level of precaution and the precautions taken by the other party. Given a cost c_1, the probability that c_2 is greater than or equal to c_1 is given by $1 - F_2(c_1)$, in which case party 1 pays the harm (we can disregard the instance of the two costs being equal as it does not affect the result). In addition, party 1 will be liable only if party 2 does not take precautions, otherwise there would be no harm to pay for; this possibility is accounted for by the factor $1 - F_2(c_2)$. The same applies to party 2.

By comparing (2) and (3), we can notice that $\hat{c}_i$ will differ from c_i^*, for both $i = 1, 2$, and will be typically lower as $1 - F_i(c) < 1$, hence the liability approach does not attain the second-best optimum. Also it contradicts the possibility of corner solutions as discussed previously.[19] Therefore, we can unambiguously say that the liability approach cannot yield the second-best outcome.

Consider the example with a symmetric uniform distribution introduced before. Easy calculation will show that $\hat{c}_1 = \hat{c}_2 = h(3-\sqrt{5})/2$ which is clearly less than the second-best solution.

2.2 Sharing irrespective of fault with simultaneous moves

Another possibility under liability is to share the loss between the parties according to shares σ and $1 - \sigma$ for party 1 and party 2, respectively. The shares do not depend on whether parties were at fault nor on who is the least cost avoider. As we explained in the introduction, sharing the loss among the parties upon fault according to a comparative negligence rule necessarily embeds a least cost avoider approach.

On the contrary, here we examine the effect of sharing that does not take into account the costs of the parties' precautions and, thus, the shares are determined *ex ante* and applied *ex post* irrespective of the parties' behavior. Similarly to the previous section, parties will take precautions as long as its cost is lower than or equal to the expected liability cost. In a sense, this

[19] Moreover, we can also see that the liability approach will ensure $\hat{c}_1 = \hat{c}_2$ when costs are symmetrically distributed which was shown not to be always optimal in the previous section.

approach resembles fines but it is more constrained, because the sum of the parties' shares always amounts to 1 and thus the sum of the costs up to which parties are willing to take precautions cannot be greater than h.[20] This restriction is not present in a regulatory approach. Therefore, as our results will show, sharing irrespective of fault is inferior to fines.

When parties move simultaneously, their reaction functions are:

$$\begin{aligned} \hat{c}_1 &= (1 - F_2(\hat{c}_2))\sigma h \\ \hat{c}_2 &= (1 - F_1(\hat{c}_1))(1 - \sigma)h \end{aligned} \tag{4}$$

The right-hand sides to (4) describe the expected cost of liability. Each party is liable for only a fraction of the harm and in only those cases in which the other party does not take precautions (otherwise there is no accident). It is easy to see that $\hat{c}_i$ will generally be lower than c_i^*, for both $i = 1, 2$, because we cannot have $\sigma = 1$ and $1 - \sigma = 1$ simultaneously. The exception would be for the corner solutions. By setting $\sigma = 1$, we would have $\hat{c}_1 = h$ and $\hat{c}_2 = 0$. The other possible corner solution will result when $\sigma = 0$.

In fact, we are concluding that sharing irrespective of fault only works if courts do not have to make comparisons and make one of the parties fully liable for the accident.[21] Putting aside this situation that is contrary to the notion of sharing, we can say that the second-best solution is not achieved.

[20] This is clearly not true if liability is decoupled, that is, if the damages paid by the injurer and the compensation received by the victim diverge. Decoupling liability consists of adding fines or subsidies to damages and in fact amounts to a (partially) regulatory solution. In our model, perfectly set decoupled liability would yield the same outcome as a regulatory approach. Polinsky and Che (1991) advocate decoupling in relation to the incentives to take care and to litigate; Kahan and Tuckman (1995) discuss the decoupling of punitive damages under "special levy" statutes and extend the conclusions reached by Polinsky and Che (1991) for the case in which litigation effort varies with litigation stakes; Choi and Sanchirico (2004) reach an opposite result and revise the desirability of decoupling liability; Lewis and Sappington (1999) relate decoupling to the judgment proof problem.

[21] Bar-Gill and Ben-Shahar (2003, p. 438) seem to make a similar point but they refer to the ordinary use of the comparative negligence doctrine, under which the parties' shares are functions of their levels of precaution. As we have already noted, in this case the optimal share of the least cost avoider is always equal to one (thus, the other party's share is equal to zero) and in fact sharing does not take place. We have examined this approach in the previous section. In this section, we refer instead to a different use of the principle

Take the example with uniform distribution discussed previously. The solution is given by $\hat{c}_1 = \frac{\sigma^2}{1-\sigma(1-\sigma)}h$, and $\hat{c}_2 = \frac{(1-\sigma)^2}{1-\sigma(1-\sigma)}h$. Clearly their sum is less than h for $0 < \sigma < 1$. The magnitude of the under-prevention will be more significant when $\sigma = 1/2$.

2.3 Precaution cost liability with simultaneous moves

Under precaution cost liability, the least cost avoider is not only liable for the harm he fails to prevent (if an accident occurs), but also for the precaution costs incurred by the other party (if no accident occurs).

When parties move simultaneously, their decisions whether or not to take precautions may be formalized as follows. Let us first consider the cost of not taking precautions. The expected cost party 1 and party 2 bear if they do not take precautions is respectively given by:

$$(1 - F_2(c_1))\,(1 - F_2(\hat{c}_2))h + (1 - F_2(c_1))\,F_2(\hat{c}_2)\frac{\int_{c_1}^{h} c dF_2(c)}{1 - F_2(c_1)}$$

$$(1 - F_1(c_2))\,(1 - F_1(\hat{c}_1))h + (1 - F_1(c_2))\,F_1(\hat{c}_1)\frac{\int_{c_2}^{h} c dF_1(c)}{1 - F_1(c_2)}$$

The first term is the same as under the least cost avoider approach: party 1 (who does not take precautions) pays the harm if and only if he or she turns out to be the least cost avoider and if party 2 did not take precautions either. In addition, as indicated by the second term, party 1 may be held liable for the precaution costs borne by party 2 if party 1 is the least cost avoider – with probability $1 - F_2(c_1)$ – and if party 2 has taken precautions – with probability $F_2(\hat{c}_2)$; the expected precaution costs borne by party 2 are calculated as the average costs of precaution for party 2 conditional to the fact that such costs must be higher than the costs of precaution for party 1 (as party 1 is the least cost avoider). The same symmetrically applies to party 2.

of sharing and note that it only replicates the outcome assured by regulation in the case of optimal corner solutions, a point not made in the literature.

Consider now the situation where a party takes precautions. The expected cost party 1 and party 2 bear if they take precautions is respectively given by:

$$(1-F_2(c_1))\,c_1+(1-F_2(c_1))\,F_2(\hat{c}_2)\frac{\int_{c_1}^{h}cdF_2(c)}{1-F_2(c_1)}$$
$$(1-F_1(c_2))\,c_2+(1-F_1(c_2))\,F_1(\hat{c}_1)\frac{\int_{c_2}^{h}cdF_1(c)}{1-F_1(c_2)}$$

Contrary to the previous cases party 1, on the one hand, does not always bear his or her cost – this cost is refunded by party 2, if party 2 is the least cost avoider, and hence is borne by party 1 only with probability $1-F_2(c_1)$ – and, on the other hand, he or she might also bear the precaution costs of party 2, if party 1 is the least cost avoider – with the same probability seen before – and if party 2 has taken precautions – with probability $F_2(\hat{c}_2)$. Again, the same applies to party 2.

The decision whether or not to take precautions is taken by comparing the two previous expressions. It is instructive to notice that liability for the other party's precaution costs appears in both expressions. This is because, say, party 1 is held liable for party 2's precaution costs only on the basis of whether party 1 is the least cost avoider and party 2 took precautions. Thus, precaution cost liability occurs irrespective of whether party 1 took precautions and thus appears on both sides of the expression (and, consequently, cancels out). Simplifying, we have:

$$\begin{aligned}\hat{c}_1 &= (1-F_2(\hat{c}_2))h\\ \hat{c}_2 &= (1-F_1(\hat{c}_1))h \qquad (5)\end{aligned}$$

By comparing (2) and (5) it is easy to see that parties under precaution cost liability take precautions up to the socially (second best) optimal levels. The intuition behind this result is straightforward. The shortcoming of the least cost avoider approach was that a party's precaution has positive external effects on the other party's liability, which are not internalized and thus reduce the parties' willingness to take precautions. Precaution cost liability perfectly internalizes these externalities, by obliging the least cost avoider to pay either the accident cost or the other party's precaution costs. This way, the parties' private incentives to take precautions are aligned with the social goal of minimizing the total accident cost.

[INSERT TABLE ONE HERE]

Table one presents a comparative analysis for symmetric uniform distributions of costs. Precaution cost liability is the only rule that is able to mimic the second-best solution (apart from the regulatory approach). The least cost avoidance rule is not efficient, but performs better than the sharing rule (for $\sigma = 1/2$).

3 The model with sequential moves

If parties move sequentially, the second mover observes whether or not the first mover has taken precautions.[22] Therefore, social policy can be improved by exploiting this information in order to avoid that an accident occurs or that both parties take precautions. In the course of this analysis we will constantly assume that party 1 moves first and party 2 second, it being evident that the roles can be reversed without prejudice to our results. Using backward induction, we begin by analyzing the socially optimal decision of party 2, given the move of party 1.

It is immediately evident that the socially optimal strategy for party 2 is to take precautions if party 1 did not take precautions (in fact, by assumption the cost for party 2 is lower than the harm) and not to take precautions if party 1 has already taken precautions (in fact, the accident will not occur and additional precautions would only increase the social cost). In other words, party 2's precaution is a function of party 1's previous decision.

We can now define the socially optimal precaution decision of party 1, given the above reaction for party 2. Since party 2 always takes precautions

[22]If parties move sequentially but the second mover does not observe the first mover's move, we are back to the simultaneous move model.

whenever party 1 fails to do so, there will never be an accident. Thus, the social cost is as follows:

$$S(c_1) = \int_0^{c_1} c f_1(c)dc + \int_{c_1}^{h} \left[\int_0^h c dF_2(c)\right] f_1(c)dc \tag{6}$$

The social cost minimization problem is one of deciding whether the precaution costs should be borne by party 1 or by party 2, subject to the condition that party 2 will always do the opposite of party 1 and therefore there will be no accident. In turn, party 1's optimal decision consists of taking precautions if his or her cost is less or equal to the *expected* cost for party 2. From the first-order condition of (6) with respect to c_1, we find that the socially optimal levels of c_1 and c_2 depend again on the shape of the distribution function and satisfy:[23]

$$\begin{aligned} c_1^{*s} &= \int_0^h c dF_2(c) \\ c_2^{*s} &= \{ \begin{matrix} 0 & if c_1 \leq c_1^{*s} \\ h & if c_1 > c_1^{*s} \end{matrix} \end{aligned} \tag{7}$$

It is evident that a solution exists and is unique for any distribution function. Furthermore, a corner solution is never efficient for party 1, but could be efficient for party 2. Take the example developed in the previous subsection with symmetric uniform distribution of precaution costs, we have $c_1^{*s} = h/2$ and c_2^{*s} is h if $c_1 > h/2$ and zero otherwise, when (6) becomes $S(c_1) = \frac{c_1^2}{2h} + \frac{h}{2} - \frac{c_1}{2}$.

As we have shown for the simultaneous move model, also in this case fines $\phi_i = c_i^{*s}$ for $i = 1, 2$ will induce the second-best levels of precaution for both parties. The other considerations already made also apply.

[23]The first order condition for (6) with respect to c_1 yields $\frac{\partial S}{\partial c_1} = f_1(c_1)\left[c_1 - \int_0^h c dF_2(c)\right] = 0$, from which the first line in (7) is derived. The second order condition is clearly satisfied at the optimum.

3.1 The least cost avoider approach with sequential moves

Under the least cost avoider approach it is evident that if party 2 observes that party 1 has taken precautions, party 2 will not take any precaution, and this is optimal. Nevertheless, if party 2 has observed that party 1 has not taken precautions, party 2 will not always take precautions, but will do so only if the costs of precaution are lower than or equal to the expected liability, which depends on the probability to be the least cost avoider. Unlike under simultaneous moves, the fact that party 1 has not taken precautions, is a signal of his or her true costs of precaution. Thus, party 2 takes this fact into consideration when calculating his or her expected liability.

Party 1, in turn, will anticipate party 2' reaction while deciding on his or her precautions. In a sense, party 1 is a Stackelberg leader taking into account the follower's reaction function (party 2). Party 1, thus, will compare the costs of precaution with the expected liability as already in (3), while party 2 will react to that choice, after observing party 1's behavior. Thus:

$$\begin{aligned} \hat{c}_1^s &= (1 - F_2(\hat{c}_2^s))(1 - F_2(\hat{c}_1^s))h \\ \hat{c}_2^s &= \{ \begin{array}{ll} 0 & if c_1 \leq \hat{c}_1^s \\ \frac{1-F_1(\hat{c}_2^s)}{1-F_1(\hat{c}_1^s)}h & if c_1 > \hat{c}_1^s \end{array} \end{aligned} \tag{8}$$

Party 2 never takes precautions if party 1 has already done so. Instead, if party 2 observes that party 1 has not taken precautions, he or she knows that the actual costs of precaution borne by party 1 are necessarily higher than $\hat{c}_1^s$. Otherwise, party 1 would have taken precautions. By incorporating the signal sent by party 1, party 2 recognizes that his or her probability of being liable is higher than otherwise, since it is the conditional probability of $c_1 > \hat{c}_2^s$ given that $c_1 > \hat{c}_1^s$.

From (8), it is quite clear that $\hat{c}_1^s < \hat{c}_2^s$.[24] The economic rationale is that player 2 knows that if player 1 did not take precautions it is because his or

[24] Note that if $\hat{c}_1^s \geq \hat{c}_2^s$ were true, then we would have $\frac{1-F_1(\hat{c}_2^s)}{1-F_1(\hat{c}_1^s)} \geq 1$ and thus, from (8), $\hat{c}_2^s \geq h$; $\hat{c}_2^s > h$ is evidently impossible; $\hat{c}_2^s = h$ would imply $\hat{c}_1^s = 0$ which is in turn incompatible with the premise that $\hat{c}_1^s \geq \hat{c}_2^s$. Therefore $\hat{c}_1^s \geq \hat{c}_2^s$ is impossible and thus the opposite must always hold true.

her precaution costs are reasonably high, thus player 2 is more willing to take precautions since there is a higher-than-otherwise probability of being liable for the accident. The same logic explains why also $\hat{c}_2 < \hat{c}_2^s$ must be true, that is, party 2 is more willing to take precautions if he or she has observed party 1's move than if parties move simultaneously. Conversely we have $\hat{c}_1 > \hat{c}_1^s$; that is, party 1 is less willing to take precautions when parties move sequentially than when they move simultaneously, since in the former case he or she can rely to some extent on the fact that party 2 will take precautions in his or her place and hence there will be no accident to pay for.

Consider again the example with uniform distribution introduced before. Easy computation will show that $\hat{c}_1^s = (1 - \sqrt{1/2})h$ and $\hat{c}_2^s = 2(1 - \sqrt{1/2})h$ if $c_1 > (1 - \sqrt{1/2})h$ and zero otherwise. The private precaution decision by party 1 is less than the second-best solution, however the private choice by party 2 could actually be above the second-best solution. In fact, expressions (8) and (7) are generally different. Also, notice that with the least cost avoider approach there is the possibility that an accident actually takes place.

3.2 Sharing irrespective of fault with sequential moves

If liability is allocated according to fixed shares, the parties' precaution decisions are as follows:

$$
\begin{aligned}
\hat{c}_1^s &= (1 - F_2(\hat{c}_2^s))\sigma h \\
\hat{c}_2^s &= \{ \begin{array}{ll} 0 & if c_1 \leq \hat{c}_1^s \\ (1-\sigma)h & if c_1 > \hat{c}_1^s \end{array}
\end{aligned} \tag{9}
$$

If party 2 has observed that party 1 has not taken precautions, he or she will take precautions only if its costs are below his or her share in the harm. Party 1 will therefore take this reaction into account *ex ante* and discount the probability of party 2's precaution from his expected liability. As under simultaneous moves, sharing fails to achieve the second best outcome. Notice that an accident can actually take place.

By making use of our example with uniform distribution, we can see that the solution is given by $\hat{c}_1 = \sigma^2 h$ and $\hat{c}_2 = (1-\sigma)h$ if $c_1 > \sigma^2 h$ and zero otherwise. We cannot achieve the second-best solution under sharing; we can fix $\sigma = \sqrt{1/2}$, thus achieving an efficient solution for party 1 or we can fix $\sigma = 0$ and achieve an efficient solution for party 2.

3.3 Last clear chance

Under this doctrine the party who has the last chance to avoid the accident bears the accident loss. Therefore the doctrine only refers to accident contexts in which parties move sequentially. In this case, the second mover bears the whole cost if an accident takes place.

Party 1 anticipates party 2's decision and will compare the costs of precaution with the expected liability given the probability that party 2 does not take precautions times zero compensation (since party 2 is fully liable). As to party 2, the observation that party 1 has not taken precautions is irrelevant, since he or she knows that, if there is an accident, he or she will be fully liable. Therefore, trivially, we have:

$$\begin{aligned} \hat{c}_1^s &= 0 \\ \hat{c}_2^s &= h \end{aligned} \tag{10}$$

This rule is not efficient since (10) is clearly different from (7). In fact, the last-clear chance doctrine will simply implement a highly inefficient solution due to the moral hazard behavior by party 1. However, it should be recognized that no accident takes place.

3.4 Precaution cost liability with sequential moves

In this section we study a different version of the precaution cost liability that we analyzed in the case of simultaneous moves. In this case, we need to take into account the fact that the move of party 1 is observed by party 2. The optimal precaution cost liability rule requires that if party 1 does not take precaution, he or she refunds the costs of precaution eventually borne by party 2. Party 2, in turn, is liable for the accident cost.

Under this rule, when party 2 observes party 1's move it is easy to see that the optimal reaction for party 2 is to take precautions if party 1 has not taken precautions and not to take precautions otherwise. In fact, precaution costs will be refunded by party 1, while the harm would be borne by party 2; therefore, if party 1 has not taken precautions, it is optimal for party 2 to take precautions. On the contrary, if party 1 has already taken precautions, precaution by party 2 comes at a private cost to party 2 but yields no benefit, since the accident will not occur due to party 1's precaution; thus, if party 1 has already taken precautions, it is not convenient for party 2 to do the same.

Party 1, in turn, anticipates party 2's decision and hence knows that if he or she does not take precautions, he or she will have to reimburse party 2's costs. Therefore, we have that the parties' decisions of whether to take precautions are as follows:

$$\begin{aligned} \hat{c}_1^s &= \int_0^h c dF_2(c) \\ \hat{c}_2^s &= \left\{ \begin{array}{ll} 0 & if c_1 \leq \hat{c}_1^s \\ h & if c_1 > \hat{c}_1^s \end{array} \right. \end{aligned} \tag{11}$$

It is easy to see that (11) is as in the social optimum (7). Therefore, as in the simultaneous moves case, precaution cost liability reaches the second best socially optimal outcome, by making both parties internalize costs and benefits of their precautions.

[INSERT TABLE TWO]

Table two presents a comparative analysis for symmetric uniform distributions of costs. Precaution cost liability is the only rule that is able to reproduce the second-best solution (apart from the regulatory approach). The least cost avoidance rule is not efficient. It performs better than the sharing rule (for $\sigma = 1/2$), but not as well as the last clear chance doctrine.

4 On the feasibility of optimal least cost avoidance

In the previous sections we analyzed the incentive properties of fines and of different liability rules in a theoretical settings. In this section we will ask the question of whether the rules proposed are actually implementable in practice and of what kind of information the regulator or the courts need to acquire. In particular, we will first discuss two different information requirements: knowledge of the parties' cost distributions *ex ante* and verifiability of the parties' actual costs of precaution *ex post*.

Under fines, the regulator needs to know the distributions of the parties' costs in order to be able to set the fines optimally and he or she also needs to verify whether or not parties took precautions. It is evident that the strict-liability approach – under which a fine is levied whenever a party fails to take precautions – does not require the enforcer to verify *ex post* the costs of precaution for individual parties. Parties will individually choose whether or not to comply with the rule depending on whether their precaution costs are greater or less than the expected fines – also considering the probability of apprehension. Fault-based fines – which are levied only if a party's costs are less than the expected fine – instead require regulators to also verify the parties' costs, and hence might not always be feasible, or, at least, will involve a higher cost. Also under sharing irrespective of fault, as under fines, the regulator needs to know the distribution of the parties' types in order to set the shares optimally, but can ignore the actual costs of precaution of each party.

On the other hand, under the least cost avoider approach, the courts do not need to know the distribution of the parties' types. However, it is crucial that the parties' precaution costs be verifiable *ex post*, a task not strictly necessary under fines.

Whether it is easier or less expensive for regulators to acquire information of the parties' cost distributions *ex ante* or for courts on the parties' actual precaution costs *ex post* is difficult to say and it may depend on the accident context.

Precaution cost liability combines the informational requirements of the least cost avoider approach (the parties' costs of precaution must be verifiable *ex post*) and a requirement similar but not identical to the regulatory approach; in fact, the distributions of the parties' costs of precaution must be known *ex ante* to the parties, and not to the courts or to the regulator. However, this rule features a characteristic absent in any other. Under fines, parties' precautions are controlled when precaution decisions are taken before the accident occurs and irrespective of it. Under liability, courts normally intervene only if an accident occurs and do nothing if either party takes precautions. Under precaution cost liability, when an accident occurs courts allocate the costs of the accident, but if no accident occurs courts also need to allocate the costs of precaution.

This task may be feasible in certain industrial or environmental accidents, or in rescue cases, but seems at first sight to be utterly difficult to implement in ordinary accident prevention. How are courts going to verify whether the fact that a motorist slowed down before a crossing point really avoided an accident that would have otherwise occurred? How can they possibly quantify the costs of precaution? For this reason, precaution cost liability, might not be always a practical solution.[25]

The doctrine of last clear chance seems to be *sui generis* in this respect, as it only requires courts to establish the order of the parties' sequential moves and whether or not the second mover could have done anything to prevent the accident, and it may be implemented irrespective of knowledge of the parties' *ex ante* costs distributions and of their actual *ex post* costs of precaution.

A second problem to be distinguished may concern the possibility to identify the parties as party 1 and party 2 *ex ante*. Our analysis has so far been confined to instances in which the parties can be so identified – for instance, they are a motorist and a pedestrian. Suppose instead that this is not possible – they are both motorists or both pedestrians. The third-best policy should then be to minimize expression (1) subject to $c_1 = c_2 = c_u$ since

[25] On the applicability of marginal cost liability to contracts and property see Wittman (1981).

the standard cannot be conditioned on the party's unknown identification.[26] When parties are not identifiable *ex ante*, the optimal standard is:

$$c_u^* = (1 - \frac{f_2(c_u^*)F_1(c_u^*) + f_1(c_u^*)F_2(c_u^*)}{f_1(c_u^*) + f_2(c_u^*)})h$$

The first remark should be that a corner solution can never be optimal. The second remark is that $c_u^* = h/2$ when $F_i(h/2) = 1/2$ for both $i = 1, 2$. As an illustration, take the example of costs symmetrically uniformly distributed. The social cost in expression (1) becomes $S(c_u) = \frac{c_u^2}{h} + (1 - \frac{c_u}{h})^2 h$. The solution to the minimization problem is $c_u^* = h/2$. Due to the fact that parties cannot be identified *ex ante* and are alike, the standard should be the same for any party and equal to $h/2$.

In a regulatory setting, this solution would be easily achieved by a policy of $\phi = c_u^*$ for both party 1 and party 2. As the model stands, all liability rules would be inefficient since none is able to replicate c_u^*. However, precaution cost liability, despite the difficulties in its implementation, could solve the problem and actually yield the second-best solution. In fact, under this rule parties need to be identified *ex ante* as under fines, but their different distributions must be known by the parties themselves rather than by the regulator. Therefore, the identification problem, although it has the same consequences, may occur under different conditions for the regulator (or the courts) and for the parties, leaving some room for the implementation of different rules.

5 Conclusions

The problem of providing incentives through tort liability to two parties who can alternatively prevent an accident is a commons problem. Each party will try to free-ride on the other party's precautions. When both parties try to do so accident prevention ends up being suboptimal. In this sense, accident

[26]The *ex ante* identification of the parties is likely to be a less serious problem in sequential settings, as in these cases the order in which the parties move can be used as a way to distinguish them.

prevention becomes a *tragedy of common safety.* Allocating responsibility on the party with the lower costs of precaution – the least cost avoider approach – may not help, since, as we have stipulated, parties may not know each other's costs at the time when they decide whether or not to take precautions.

We have shown that there are two solutions to this problem, both of them helping to disentangle the commons problem. Fines target each party individually and *ex ante*, irrespective of whether or not an accident occurs. This way, both the costs of precautions and their benefits – the possibility to avoid the fine – are entirely private and hence no free-riding arises. Contrary to fines, precaution cost liability makes the least cost avoider liable either for the accident loss, if an accident occurs, or for the other party's costs of precaution, if the accident has been avoided by the other party. This way, parties again bear both the costs of precaution and its benefit, and they are prevented from free-riding on each other's precautions. A modified version of this rule applies to sequential moves contexts.

We have also shown that both fines and precaution cost liability achieve the desirable outcome, where all other liability approaches fail. However, they differ with respect to their actual feasibility. While fines are a centralized incentive device, which requires informed regulators, precaution cost liability appears to be a more decentralized system, which requires informed parties. Moreover, precaution cost liability requires courts to adjudicate a case even when an accident did not occur, in order to allocate the costs of precaution. This task may be not so difficult to carry on in some cases, such as rescue, but it seems utterly complex and, in fact, severely curbs the applicability range of this rule to ordinary torts.

Our model analyzes a situation in which two injurers may prevent a loss incurred by passive victims. Thus, if fines instead of tort liability are implemented, the injurers only bear the expected fine and are completely free of liability costs. For this reason, we were able to analyze the working of fines in an *in vitro* environment. In the absence of liability, the accident loss is borne by the passive victims, whose incentives we did not take into account. Nevertheless, our analysis clearly applies also to accident contexts in which injurers and victims can alternatively prevent the accident loss. In this case, the victims are not passive and, more importantly, in the absence of tort liability, they bear the accident loss. Therefore, even when fines are implemented, the victims' incentives will depend both on fines and on the accident loss they bear.

As it is evident, when both injurers and victims' incentives are considered,

a rule of no liability simply means liability of the victims,[27] which may distort the incentive effects of fines. Thus, in order to clear the victims from the effects of liability and enable the functioning of fines, it may not be sufficient to remove liability in a *juridical* sense, by denying any liability claim, but it is necessary to remove liability in an *economic* sense, by actually removing the accident loss from all parties involved in the accident. This result may be attained through public or private insurance or any other means to prevent all parties from bearing the accident loss. For this reason, when the problem is to provide incentives to victims and injurers, rather than to injurers only, fines need to be complemented by an insurance coverage.[28]

We also analyzed several other liability rules and concluded that any liability rule other than precaution cost liability fails to solve the *tragedy of common safety*. This is because liability is normally exclusively triggered by the occurrence of the accident. Thus, each individual party's liability costs are inescapably dependent on the other party's precaution decision. Since one party's precaution, by concurring to avoid the accident, also reduces the prospect of liability for the other party, accident prevention is undersupplied under any standard liability rule.

[27]See on this point Landes and Posner (1987, p. 62) noting that no liability is a liability rule in an economic sense, since it only differs from strict liability in that it allocates the accident loss to the victim instead of to the injurer.

[28]This point and the function of insurance as a way to remove tort liability was originally developed by De Geest and Dari-Mattiacci (2003).

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TABLE 1

Numerical example

Symmetric uniform distribution of costs for simultaneous moves

	Standard party 1	Standard party 2	Social cost
Second best solution	$\frac{1}{2}h$ 0 h	$\frac{1}{2}h$ h 0	$\frac{1}{2}h$
Regulatory approach	fine = standard	fine = standard	$\frac{1}{2}h$
Least cost avoider	$0,382h$	$0,382h$	$0,527848h$
Sharing irrespective of fault	$0\ (\sigma = 0)$ $h\ (\sigma = 1)$ $\frac{1}{3}h\ (\sigma = 1/2)$	$h\ (\sigma = 0)$ $0\ (\sigma = 1)$ $\frac{1}{3}h\ (\sigma = 1/2)$	$\frac{1}{2}h\ (\sigma = 0)$ $\frac{1}{2}h\ (\sigma = 1)$ $0,55556h\ (\sigma = 1/2)$
Precaution cost liability	$\frac{1}{2}h$ 0 h	$\frac{1}{2}h$ h 0	$\frac{1}{2}h$

TABLE 2

Numerical example

Symmetric uniform distribution of costs for sequential moves

	Standard party 1	Standard party 2 (if party 1 does not take precaution)	Social cost
Second best solution	$\frac{1}{2}h$	h	$\frac{3}{8}h$
Regulatory approach	fine = standard	fine = standard	$\frac{3}{8}h$
Least cost avoider	$0,293h$	$0,586h$	$0,507359h$
Sharing irrespective of fault	$0\ (\sigma = 0)$ $h\ (\sigma = 1)$ $\frac{1}{4}h\ (\sigma = 1/2)$	$h\ (\sigma = 0)$ $0\ (\sigma = 1)$ $\frac{1}{2}h\ (\sigma = 1/2)$	$\frac{1}{2}h\ (\sigma = 0)$ $\frac{1}{2}h\ (\sigma = 1)$ $0,53125h\ (\sigma = 1/2)$
Last clear chance	0	h	$\frac{1}{2}h$
Precaution cost liability	$\frac{1}{2}h$	h	$\frac{3}{8}h$