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The design of liability rules for highly risky activities—Is strict liability superior when risk allocation matters?

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Abstract

Strict liability is widely seen as the most suitable way to govern highly risky activities, such as environmentally dangerous production or genetic engineering. The reason which is usually given for applying strict liability to these areas, is that not only efficient care is supposed to be induced but also an efficient level of the risky activity itself. It is argued that, in case of no market relationship between injurers and victims, this could only be achieved through strict liability but not via the negligence rule. In this paper, we show that the superiority of strict liability does no longer persist in a world of risk averse parties. Our results suggest that in terms of risk allocation the negligence rule should be preferred for abnormally risky activities, if insurance markets are imperfect. The reason is that highly risky activities typically affect a large number of individuals, such that strict liability implies a quite unfavorable allocation of risk. Therefore, the negligence rule turns out to be superior, if a market relationship between the parties exists, since it incurs less cost of risk. If there is no market relationship between injurer and victims, no clear result can be derived. The paper concludes with some remarks on the usefulness of upper bounds to an injurer's liability as well as regulations that exclude liability for "unforeseeable" losses. We argue that this kind of supplement to a strict liability rule can improve efficiency.

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1. Introduction

Negligence is the fundamental liability principle in many countries, for example, in the United States and Germany. Apart from this, typically strict liability is applied to certain highly risky activities. In Germany, some areas like environmental liability, product liability or the liability for risks related to genetic engineering are ruled by special laws, according to which these risks are subject to strict liability. In the United States, the courts decide upon whether in a specific case the activity is deemed as being “abnormally dangerous”² such that strict liability should be applied.

The application of the strict liability rule to very risky activities is justified by means of different lines of reasoning, depending on whether a market relationship between defendant and victim does exist, as would be typical for product liability, or whether there is no such relationship. In the latter case, which can be assumed to be true for most environmental damages, a liability rule should not only set incentives for efficient loss prevention (care) but should also be able to induce efficient activity levels. Since, when the negligence rule is applied, a defendant is not held liable if she exercises a level of care that equals or exceeds due care, she will not take into account the remaining risk and will therefore exceed the welfare maximizing activity level. In contrast to this, strict liability would lead to optimal care *and* control activity in an efficient way, since a defendant would in any case internalize the entire liability risk. Thus, as the usual argument goes, the negligence rule and strict liability are equivalent with regard to loss prevention incentives, but strict liability seems to be a better solution in terms of controlling risky activities.

If a market relationship between defendant and victim does exist, it is usually argued that in a world with homogeneous and completely informed victims strict liability and the negligence rule would be equivalent in terms of setting incentives for loss prevention as well as controlling the activity level. The reason is that the remaining risk at the level of efficient loss prevention is borne entirely by the victims, either directly in the case of the negligence rule or indirectly via the product price in the case of strict liability, implying there would be no externalities.³ Reasons given for the supposed superiority of strict liability under these circumstances are the considerable problems of determining efficient care, in comparison to other areas of liability law,⁴ and the fact that only strict liability creates incentives to research and develop new security technologies.⁵

The statement, that the two liability regimes are equivalent with regard to control of loss prevention and activity level if there is a market relationship between the parties, or that strict liability is superior if there is none, is correct only if the parties are risk neutral. The standard assumption of risk neutrality is especially crucial within the context of this paper, considering that areas subject to strict liability usually bear extreme risks. In addition to this, damages will very often cause losses to many victims, such that strict liability leads to a risk accumulation while negligence spreads the risk. If the parties are

² See Restatement (Second) §§ 519, 520 of Torts.

³ See e.g. Landes and Posner (1985, p. 535).

⁴ See Rose-Ackerman (1991).

⁵ See e.g. Shavell (1980, p. 2).

risk averse in reality, the results from an analysis based on risk neutrality, might lead to substantial misjudgments and therefore incorrect policy recommendations. This is due to the following reasons: at first, as an additional criterion for the economic evaluation of liability rules, risk allocation effects come into play as soon as risk aversion is considered. Additionally, under these circumstances, liability rules are not necessarily equivalent in terms of inducing care. Furthermore, if there is a market relationship between injurers and victims, negligence leads to a better outcome, as it incurs lower risk-bearing costs than strict liability. Finally, in the case of no market relationship, the superiority of strict liability with regard to controlling the extent of risky activities might not persist, since strict liability probably leads to an activity level too low in comparison to the welfare maximizing level.

Considering the impact the risk attitude has on the analysis of liability rules for highly risky activities, the question of an adequate assumption has to be discussed in more detail: while it is widely accepted that individuals are risk averters, firms are normally considered as risk neutral. Since in our context the injurers typically are firms, the problem of adequately modeling risk preferences for this case has to be examined more closely. A typical rationale offered for the risk neutrality assumption is that the shareholders hold well-diversified portfolios and will thus aim to maximize the expected profit of the firm.⁶ It follows immediately that this explanation is only valid for joint stock companies, but not for partnerships. Furthermore, as is well known, even in perfect capital markets, a security's risk can only be completely diversified if there is no systematic component. Apart from this plenty of evidence for imperfectness can be found in real capital markets. Particularly, as a consequence of the transaction costs incurred by a transfer of shares, real investment portfolios are usually insufficiently diversified.

Even if there is no systematic risk and the risk arising from an individual investment can be eliminated entirely by means of diversification, it must still be stated that entrepreneurial decisions are made by the management, and that it is normally impossible for the owners to control every single decision.⁷ The management thus has a certain discretion in activity on the firm's behalf. It is a standard result of agency theory that management's income should depend on the firm's profit in order to give appropriate incentives.⁸ The individual manager cannot perfectly diversify her profit-dependent income. Therefore, some of the most influential decision makers will exhibit risk aversion, in particular if they are confronted with the possibility of large losses.⁹

Thus, even for joint stock companies, under realistic assumptions concerning the imperfect management–shareholder relationship and the resulting incentive problems, risk aversion in firm behavior is a very plausible assumption. This premise has empirical support as joint stock companies buy insurance coverage at a substantial rate, which is most easily explained by risk aversion.¹⁰

⁶ See e.g. Doherty (1985, p. 465), Shavell (1987, p. 189), or Milgrom and Roberts (1992, p. 187).

⁷ This will usually at least be true for those stockholders who, for diversification reasons, invest only a small part of their investment budget in the single firm.

⁸ See among others Tirole (1990, p. 29).

⁹ See Shavell (1987, p. 207).

¹⁰ Naturally, there is a multitude of possible additional motives for corporate insurance demand. For example, Mayers and Smith (1982) mention the reduction of expected transaction cost of bankruptcy, advantages due to

Another argument commonly used to justify the assumption of risk neutral decision making says the involved parties had the opportunity to buy insurance. In perfect markets, the insurance premium equals the expected losses from the contract, and insurance customers buy complete coverage. Therefore, an insured party would act like a risk neutral decision maker. But again, this indirect rationale for the risk neutrality assumption via insurance supply turns out to be of very limited value, as real markets demonstrate that insurance does not work in such a perfect fashion. Insurance coverage would not usually be available at an actuarially “fair” rate, a fact that may be attributed to many different reasons, such as transaction costs and in particular insurers’ risk aversion. This implies that, according to well known results from insurance demand theory, rational decision makers would not cover their entire risk by insurance.¹¹

Additional cost of risk allocation arises if, for example, insurability problems lead to limitations in the supplied coverage. Liability insurance usually covers losses up to a certain amount specified in the contract. In some areas of liability insurance, these upper bounds for indemnity payments leave the insured party with a significant share of the risk. In particular, the very cautious setting of sums insured in environmental liability insurance means that a considerable risk remains with the insured.

As we have seen, in essence all explanations for assuming risk neutrality are based on the assumption of perfect capital or insurance markets. However, the presence of transaction costs alone is sufficient to show that these markets are generally imperfect. Therefore, the premise of risk aversion, as the empirically dominant risk attitude, seems to be more suitable.

This leads us to question why, in light of these reflections, the law and economics literature almost always assumes risk neutral decision makers. Only very few authors, as for example, [Shavell \(1982, 1987\)](#), [Endres and Schwarze \(1991\)](#) and [Privileggi, Marchese, and Cassone \(2001\)](#), explicitly consider the implications of risk aversion. Two reasons might be decisive for this: first, optimal solutions tend to be significantly more complex when risk allocation is taken into account: rules that assign the entire risk to one party, as, for example, strict liability or the negligence rule, cannot be efficient anymore. Second, and this seems to be even more crucial, to be able to enforce optimal liability under these circumstances, courts would have to determine individual utility functions. Presumably, this is a task that could hardly be managed, as the parties would not be interested in disclosing their preferences properly but would try to indicate higher risk aversion. Therefore, to achieve useful results regarding the evaluation of different liability regimes, it usually seems to make sense to ignore risk allocation issues and to assume that decision makers are risk neutral.

For a very important part of liability law, however, this conclusion turns out not to be adequate: as will be shown in this paper for the case of highly risky activities in which one damage affects a large number of victims, rules are largely independent of the parties’

specialization the insurance companies might have in the area of loss handling—particularly the handling of liability claims—as well as tax incentives. [Grace and Rebelló \(1993\)](#) explain corporate insurance demand alternatively as a signaling behavior.

¹¹ For a detailed discussion of optimal insurance decisions see among many others [Borch \(1960\)](#), [Arrow \(1963\)](#), [Borch \(1976\)](#), and [Raviv \(1979\)](#).

actual utility functions. Taking risk aversion into account is possible in the context of highly risky activities, and, moreover, the results significantly differ from those derived under the less convincing risk neutrality premise.

We will analyze liability rules for highly risky activities under the assumption that both parties, injurers and victims, are risk averse. An analysis of this kind must at first address the question of why the activities which are subject to strict liability are considered highly risky. The main reason for this might be that damages caused by these activities typically affect a large number of victims. For example, a defective pharmaceutical product can give rise to health problems for many people. Similar consequences might be triggered if the production of a commodity is commonly influenced by certain stochastic factors. A scenario for the latter example could be that one defect, which was not disclosed at the time of production, later affects an entire line of production. As proven in particular by recalls quite often observed in the automotive industry, this problem is of considerable importance. Distinct positive correlation is rather obvious also in the environmental liability area, as environmentally harmful emissions usually inflict damages for many individuals. Finally, an extreme case of positive correlation arises if liability claims are combined to go to trial as a class action lawsuit.

The high risk in the above-mentioned examples does not primarily result from a high loss potential from the single claim, but from the possibility of a multitude of claimants. It is this kind of risk accumulation that is typically subject to strict liability.

Liability rules for areas characterized by the potential of loss accumulation have not been a subject of extensive research in economic literature so far. This is remarkable, as the importance of loss accumulation for the design of optimal liability rules when risk allocation matters, was mentioned in the famous textbook by Shavell (1987): "... even large firms may cause losses that are high relative to their assets yet that are the aggregation of only relatively modest losses for each victim. This possibility may arise, for example, where design errors affect a high percentage of the units of a firm's product. In such cases a firm's risk aversion could be a more important consideration than victims'."¹² However, the possibility of many individuals being affected by one event has not been considered in most of the law and economics research.¹³

Instead, the assumption usually employed is that damages would only harm one person. This seems to be surprising at first glance, since problems of environmental and product liability have in particular been discussed heavily, and they certainly are—as was mentioned above—good examples for the danger of loss accumulation. Nevertheless, there is a simple explanation for the neglect of the number of victims as an important factor: taking it into account would not change the structure of the results, as long as the parties are assumed to be risk neutral. This can be shown as follows.

¹² Shavell (1987, p. 208).

¹³ To the best of our knowledge, the only paper that explicitly takes into account the implications the number of victims has on the efficient design of liability rules, is Nell and Richter (1996). There, however, the authors employ a completely different model. In essence, they use a mean variance approach by approximating the parties' risk premiums via the variance of the loss distribution. The approximation, though, tends to be less accurate the greater the potential losses. Furthermore, the paper does not entail an explicit comparison of strict liability versus negligence, and it also does not take into account the case where the activity level is a decision variable.

Let us assume that a certain liability risk threatens $n \geq 1$ identical potential victims. For each of them the expected losses are $E[\tilde{L}|x]$, depending on the injurer's level of loss prevention (x). Regarding the effects of loss prevention measures we introduce the usual assumptions:

$$\frac{dE[\tilde{L}|x]}{dx} < 0, \quad \frac{d^2E[\tilde{L}|x]}{dx^2} > 0 \quad (1)$$

If the parties are risk neutral, the optimal level of care minimizes the function $c(x) + nE[\tilde{L}|x]$ (where $c(x)$ with $c'(x) > 0$, $c''(x) \geq 0$ denotes the cost of loss prevention). If the (unambiguous) global minimum is an interior solution, the minimum locus x^* is the solution of

$$c'(x) = -n \frac{dE[\tilde{L}|x]}{dx} \quad (2)$$

As can be seen from Eq. (2), the optimal level of care increases with the number of victims. This result, however, is not specific for the many victims problem, as any increase in risk that can be modeled as a linear transformation of the expected losses affects x^* in the same way. The only effect of an increasing n , under these circumstances, is that for determining the optimal loss prevention level a larger extent of risk has to be considered. No other consequences have to be taken into account. For example, it does not matter whether many individuals are in danger of suffering comparably small losses or whether there is only one potential victim facing the sum of these risks. Therefore, reducing the model to the analysis of one “representative” victim does not have any significant influence on the results.

If, on the other hand, risk averse decision makers are considered, the number of victims becomes relevant. This is because, for evaluating a liability rule, it is not the incentive function alone anymore which is important. As was stated earlier, one also has to take into account the risk allocation effects, and thus, particularly, the impact of the number of involved parties on optimal risk sharing. An interesting question is how the fact that the number of risk bearers increases with the risk affects the optimal liability rule. Crucial with respect to this is the interaction between the number of victims and the injurer's risk premium. This interaction, again, depends on the correlation between the single risks. As we are going to analyze the consequences of risk accumulation, we concentrate on the case of complete correlation.

Liability insurance against this kind of risk is either mandatory or it is purchased voluntarily to a significant extent. Thus, we will incorporate insurance supply in our analysis. Reasonably, we assume imperfect insurance markets in this paper.

The remainder of the paper is organized as follows: in Section 2, we investigate the efficient liability rule for correlated risks when the parties are risk averse and the activity level is given exogenously. In Section 3, insurance is included in the analysis. The activity level under strict liability is the subject of Section 4. The paper concludes with a summary and discussion of the main aspects.

2. Optimal liability for correlated losses when no insurance is available

2.1. Basic assumptions

We consider the case of one (potential) injurer engaging in some activity that involves the risk of harming $n \geq 1$ victims, who are assumed to have identical preferences.¹⁴ The amount of losses, \tilde{L} would be the same for every single victim, where \tilde{L} has a two point distribution $(L_1, p, 0)$ with $L_1 > 0$ and $0 < p < 1$. Since in the situations which are to be investigated here the loss distribution usually can only be influenced by the potential injurer, but not by the victims, we do not consider victims' loss prevention measures. With regard to the impact the injurer's loss prevention (x) has on the distribution of losses, the model is kept more general than standard law and economics models. Those models usually concentrate on the case of loss prevention reducing the loss probability. In this paper, however, we allow for mitigation measures which either reduce the probability or the extent of losses.

The function of the cost of care, $c(x)$ is assumed to be convex, as was mentioned earlier. Furthermore, a premise is added here that will be relevant in the context of large n : among other things this paper will analyze how results change when the number of victims increases. If the set of possible loss prevention levels would be assumed to be unbounded, the result for many situations would be as follows: any arbitrarily high prevention level could be efficient if only n is large enough. In reality, however, usually there would be a *maximum* mitigation level. Additional mitigation might be possible but remain without any impact. Examples include installing the most up to date filter plant for avoidance of harmful emissions or carrying out all known tests before marketing a new pharmaceutical product. For this reason, we will use the assumption of a maximum level of care, x_{\max} such that the injurer can choose from the set $[0, x_{\max}]$.

As was explained before, this paper deals with risk averse decision makers. When risk aversion is taken into account, in general the parties' levels of wealth become relevant, as for most utility functions the degree of risk aversion depends on wealth. The degree of risk aversion influences the optimal liability rule. Thus, the use of utility functions which do not show constant absolute risk aversion implies a wealth-dependent design of the optimal liability rule. This again is criticized with convincing arguments in literature.¹⁵ To avoid these problems we assume utility functions with constant absolute risk aversion (CARA). The risk aversion coefficients are denoted by α for the injurer and β for the victims ($\alpha, \beta > 0$), the utility functions are denoted by U and V . Furthermore, q ($0 \leq q \leq 1$) is the share of a loss that has to be borne by the injurer. This means that we allow for a strict division of losses ($0 < q < 1$) as a solution as well as for boundary solutions, such as the negligence rule or strict liability.

All relevant parameters are assumed to be known by the involved parties, in particular by the courts. Furthermore, we assume that the necessary differentiability requirements are fulfilled in any case, which means especially that the order in which one takes the

¹⁴ In this paper, we do not consider the possibility of more than one injurer influencing the risk, although this is an important problem, in particular if one is concerned with certain environmental liability problems.

¹⁵ See e.g. Abraham and Jeffries (1989). See also Miceli and Segerson (1995) who criticize Arlen (1992), as the latter paper argues in favor of wealth-dependent liability rules in a not very consistent way.

expected value and the derivative can be exchanged. First, we consider the case of an exogenously-given level of activity.

2.2. The social cost function

The expected utility of an injurer with a liability share q conducting mitigation at level x is

$$E[U(W_I - c(x) - qn\tilde{L})|x] = -\frac{1}{\alpha} E[e^{-\alpha(W_I - c(x) - qn\tilde{L})}|x] \tag{3}$$

where W_I is the injurer’s initial wealth.

The single victim’s expected utility is

$$E[V(W_V - (1 - q)\tilde{L})|x] = -\frac{1}{\beta} E[e^{-\beta(W_V - (1 - q)\tilde{L})}|x] \tag{4}$$

(W_V denotes the victim’s initial wealth).

The certainty equivalent of the injurer’s final wealth is given by

$$CE(\tilde{W}_I^f) = -\frac{1}{\alpha} \ln\{E[e^{-\alpha(W_I - c(x) - qn\tilde{L})}|x]\} = W_I - c(x) - \frac{1}{\alpha} \ln\{E[e^{\alpha qn\tilde{L}}|x]\} \tag{5}$$

For a single victim, we get

$$CE(\tilde{W}_V^f) = W_V - \frac{1}{\beta} \ln\{E[e^{\beta(1 - q)\tilde{L}}|x]\} \tag{6}$$

We consider mitigation measures that affect either the probability or the size of loss. This is modeled such that either the probability of loss, $p(x)$ is a strictly decreasing and convex function and the size of loss, L_1 is a constant, or that otherwise $L_1 = L_1(x)$ ($L'_1 < 0$ and $L''_1 > 0$) with constant loss probability p . To keep things simple, however, we will restrict the derivations to the general formulation in the following. The problems that require explicitly distinguishing between the two models are tackled in the appendix.

Welfare will be measured by the sum of the parties’ certainty equivalents:

$$W_I - c(x) - \frac{1}{\alpha} \ln\{E[e^{\alpha qn\tilde{L}}|x]\} + n \left[W_V - \frac{1}{\beta} \ln\{E[e^{\beta(1 - q)\tilde{L}}|x]\} \right] \tag{7}$$

Since W_V and W_I are not affected by the liability rule, we will concentrate on the function of social cost:

$$C_T(x, q) := c(x) + \underbrace{\frac{1}{\alpha} \ln\{E[e^{\alpha qn\tilde{L}}|x]\}}_{=:R_I^n(x, q)} + n \underbrace{\frac{1}{\beta} \ln\{E[e^{\beta(1 - q)\tilde{L}}|x]\}}_{=:R_V(x, q)} \tag{8}$$

The social cost is the sum of the loss prevention cost, the monetary equivalent of the injurer’s stochastic liability payments ($R_I^n(x, q)$), and the corresponding value for the victims ($nR_V(x, q)$). The latter expressions will be called the parties’ *individual cost of risk* in this paper. We assume these cost functions to be strictly decreasing and strictly convex in x for any (positive) liability share:

$$\frac{\partial R_I^n(x, q)}{\partial x} < 0, \quad \frac{\partial^2 R_I^n(x, q)}{\partial x^2} > 0, \quad x \geq 0, 0 < q \leq 1 \tag{9}$$

and

$$\frac{\partial R_V(x, q)}{\partial x} < 0, \quad \frac{\partial^2 R_V(x, q)}{\partial x^2} > 0, \quad x \geq 0, \quad 0 \leq q < 1 \quad (10)$$

This means the marginal benefit from loss prevention is positive and strictly decreasing in x .¹⁶

2.3. The optimal liability rule

The optimal liability rule is a solution to the optimization problem:

$$\min_{0 \leq x \leq x_{\max}, 0 \leq q \leq 1} C_T(x, q) = c(x) + R_I^n(x, q) + nR_V(x, q) \quad (11)$$

As necessary conditions for an interior solution, we derive

$$c'(x) = -\frac{\partial R_I^n(x, q)}{\partial x} - n\frac{\partial R_V(x, q)}{\partial x} \quad (12)$$

and

$$\frac{\partial R_I^n(x, q)}{\partial q} = -n\frac{\partial R_V(x, q)}{\partial q} \quad (13)$$

implying that the efficient sharing of liability is defined by

$$q^* = \frac{\beta}{n\alpha + \beta} \quad (14)$$

The injurer's optimal liability share decreases in n , because $R_I^n(x, q)$ increases in n faster than at a linear rate, and therefore, stronger than the sum of the victims' costs. For $n \rightarrow \infty$, q^* tends to zero. Furthermore, the following results can be derived:

Proposition 1. *Under the assumptions of this section the optimal mitigation level increases in n . For a sufficiently large number of victims the maximum level of care becomes optimal.*

Proof. See [Appendix A](#). □

Thus, for a given activity level, the negligence rule with due care x_{\max} is approximately efficient. The injurer fulfills the standard of due care, and risk allocation would at least be approximately optimal. In contrast to this, strict liability yields the more unsatisfactory economic results the larger the number of victims. The injurer would choose x_{\max} for sufficiently large n , but her liability share would be one, while the optimal value tends to zero.

¹⁶ This assumption is due to purely technical reasons. It guarantees that certain problems with respect to the uniqueness of solutions are avoided. For the case of loss prevention affecting the extent of loss, this assumption is not needed. If, however, mitigation reduces the probability of loss, the convexity of $R_I^n(x, q)$ (and $R_V(x, q)$, respectively) would not be ensured without additional assumptions.

3. The impact of insurance supply

So far, results have been derived under the assumption that the parties bear the entire risk assigned to them by a liability rule. In reality, however, potential injurers as well as potential victims usually have the opportunity to buy insurance. In this section, we analyze the way in which the supply of insurance coverage influences the design of an optimal liability rule. To avoid unnecessary complications, we concentrate on insurance being available for the injurers.

If insurance markets were perfect, economic actors could get rid of their entire risk at a premium that equals expected losses. In contrast to this, liability insurance contracts in real markets limit the provided coverage, and premiums normally exceed the expected losses. For both of these reasons, a share of the risk is typically kept by the insured. Therefore, in the following, we will analyze how insurance supply affects the optimal liability rule if markets are imperfect. At first, we will concentrate on the effects of premiums exceeding the expected value of claims.

Insurance premiums are assumed to be calculated as the sum of the expected losses and a proportional loading. The price of liability insurance is

$$\Pi[d, \tilde{L}|x] = n(1 + m)dqE[\tilde{L}|x] \tag{15}$$

where m is the loading factor and d ($0 \leq d \leq 1$) denotes the level of coverage.¹⁷

We start by considering insurance demand decisions for a given level of loss prevention and a given risk sharing. The optimal coverage then is determined as a solution to

$$\min_{0 \leq d \leq 1} c(x) + \underbrace{\frac{1}{\alpha} \ln\{E[e^{n\alpha q(1-d)\tilde{L}}|x]\}}_{=: R_1^n(d, x, q)} + n(1 + m)dqE[\tilde{L}|x] \tag{16}$$

yielding the first-order condition:

$$(1 + m)E[\tilde{L}|x] = \frac{E[\tilde{L} e^{n\alpha q(1-d)\tilde{L}}|x]}{E[e^{n\alpha q(1-d)\tilde{L}}|x]} \tag{17}$$

From Eq. (17), we get—for our model framework—the well known fundamental result, that was briefly mentioned before: if the loading factor m is positive, rational insurance customers choose a level of coverage $d < 1$. The optimal coverage increases if ceteris paribus the number of victims increases or the loading factor decreases. Complete insurance coverage ($d = 1$) can only be optimal if $m = 0$.

Let us assume from now on that insurance is always worthwhile ($d > 0$).¹⁸ We consider the following minimization problem:

$$\min_{0 \leq x \leq x_{\max}, 0 \leq q \leq 1, 0 \leq d \leq 1} C_T(d, x, q) = c(x) + R_1^n(d, x, q) + nR_V(x, q) + n(1 + m)dqE[\tilde{L}|x] \tag{18}$$

¹⁷ As well as the other parties, insurers are assumed to have complete information. This means that, in particular, problems of moral hazard are not discussed in this paper. In our model, the insurer is able to observe the insureds' actions, and thus, to directly tie the premium to the level of care.

¹⁸ Formally, we ensure through an additional premise (see Proposition 2) that, for sufficiently large n , the level of coverage is positive in the optimal solution.

As first-order conditions for an interior solution, we get

$$c'(x) + \frac{\partial R_I^n(d, x, q)}{\partial x} + n \frac{\partial R_V(x, q)}{\partial x} + n(1+m)dq \frac{dE[\tilde{L}|x]}{dx} = 0 \tag{19}$$

$$\frac{\partial R_I^n(d, x, q)}{\partial q} + n \frac{\partial R_V(x, q)}{\partial q} + n(1+m)dE[\tilde{L}|x] = 0 \tag{20}$$

and also Eq. (17). Substituting the explicit expressions for the partial derivatives in Eq. (20) and using Eq. (17), we get

$$q^* = \frac{\beta}{n\alpha(1-d^*) + \beta} \tag{21}$$

This means q^* is increasing in the insurance coverage. In particular, the optimal injurer’s liability share is larger if liability insurance is available, compared to the case without insurance. In this sense, the opportunity to buy insurance expands the injurer’s “capacity,” as long as the premium is not prohibitively high. The more efficient the risk allocation device insurance works, the more risk would be borne by the injurer. But only if insurance is costless ($m = 0$), we derive $q^* = 1$.

An interesting question is whether or not, in the case with insurance, the optimal risk sharing still tends to the risk allocation situation of the negligence rule or whether this tendency is possibly compensated by increases in insurance coverage. In fact, it can be shown that d^* tends to one so fast that the optimal injurer’s liability share does not converge to zero, but remains above a certain level.

Proposition 2. *Under the assumptions of this section and if*

$$(1+m)E[\tilde{L}|x] < \frac{E[\tilde{L} e^{\beta\tilde{L}}|x]}{E[e^{\beta\tilde{L}}|x]} \quad \forall x \tag{22}$$

a positive q_{\min} exists with the property that for any number of victims

$$q^* \geq q_{\min} \tag{23}$$

Proof. See Appendix B. □

Thus, if the injurer has the opportunity to pass risk to an insurance company at a constant rate, the strong increase of its individual cost of risk and the impact on efficient risk sharing are slowed down. The efficient liability rule under these circumstances does not converge to the negligence rule.

We now consider the level of loss prevention for very large n : From Eq. (19) follows:

$$c'(x^*) > -n(1+m)q^*d^* \frac{dE[\tilde{L}|x^*]}{dx} \tag{24}$$

if x^* is an interior solution. Therefore,

$$c'(x^*) > -n(1+m)q_{\min}d^* \frac{dE[\tilde{L}|x_{\max}]}{dx} \tag{25}$$

As n increases, the right hand side of Eq. (25) grows without bound, such that for a sufficiently high number of victims the maximum level of care will be optimal.

If insurance premiums consist of the expected value of losses and a proportional loading, neither strict liability nor the negligence rule approximate the optimal solution. Instead, a liability rule that assigns a share q_{\min} of every victim's claim to the injurer turns out to be approximately efficient, given the latter fulfills the due care standard x_{\max} .

The comparison of strict liability and the negligence rule depends heavily on the loading factor m . As the transaction cost of insurance declines, strict liability gets more attractive in comparison to the negligence rule and vice versa.

However, the latter results on the approximately efficient liability rule only hold if there are no limitations to the demand of liability insurance and if the insurers are risk neutral, and therefore base calculated premiums on the expected losses only. If, on the other hand, insurers are risk averse, the price of insurance respectively in case of limited coverage, the injurer's risk premium grows faster than at a linear rate. In this case again, the negligence rule, with a standard of due care x_{\max} , would be approximately optimal for large numbers of victims. Since upper bounds for the coverage are very common in real liability insurance markets, there seems to be considerable evidence that the results of Section 2 still hold even if liability insurance is available.

4. Variable level of activity

One argument that is quite often stated in favor of strict liability in the context of highly dangerous activities is the fact that this rule would lead to an efficient activity level. On the other hand, negligence would, if there were no market relationship between the parties, induce the activity to be carried out at an excessive level. The reason for this is that an injurer would not be held liable for damages as long as the standard of due care is fulfilled.¹⁹ But, as was mentioned above, strict liability only leads to an optimal activity level if we assume risk neutral parties and/or perfect insurance markets. If, however, injurers are risk averse and insurance markets are imperfect, the induced activity level is too low and the extent of the under-investment in the risky activity increases in the number of victims.

We want to explain this interaction in more detail. For that purpose we consider a society that consists of n identical individuals. We assume that a risky activity can be carried out at a level a which can be varied continuously. As the focus here is on the problem of controlling the activity, it is assumed for the moment that the liability risk can only be influenced through the activity level, but not by means of loss prevention. Furthermore, we assume that the amount of potential damages, but not the loss probability, depends on the level of a ($L_1 = L_1(a)$ with $L'_1(a) > 0$, $a \geq 0$). The activity does not incur any other costs, and for φn ($0 < \varphi \leq 1$) individuals it yields utility $Z(a)$ with $Z'(a) > 0$, $Z''(a) < 0$. To keep the model simple, we allow for φn to assume non-integer values. The social optimum then is a

¹⁹ See e.g. Shavell (1980, p. 11, 1987, p. 42).

solution to

$$\max_a n \left[\varphi Z(a) - \frac{1}{\gamma} \ln \{ p e^{\gamma L_1(a)} + 1 - p \} \right] \quad (26)$$

where γ is the individuals' risk aversion coefficient. This gives the first-order condition:

$$Z'(a) = \frac{1}{\varphi} \frac{p L_1'(a) e^{\gamma L_1(a)}}{p e^{\gamma L_1(a)} + 1 - p} \quad (27)$$

It is assumed that the activity can only be carried out by one individual. If the activity is ruled by strict liability, the individual's objective function is the following:

$$G_n(a) := n \varphi Z(a) - \frac{1}{\gamma} \ln \{ p e^{\gamma n L_1(a)} + 1 - p \} \quad (28)$$

A first-order condition for an interior solution is

$$n \varphi Z'(a) = n \frac{p L_1'(a) e^{\gamma n L_1(a)}}{p e^{\gamma n L_1(a)} + 1 - p} \quad (29)$$

If *ceteris paribus*, the number of victims increases, the relevant decision maker's marginal cost (right hand side of Eq. (29)) increases at a higher rate than the marginal return of the activity, and we derive

$$\frac{da}{dn} = \frac{n}{G_n''(a)} \frac{\gamma L_1(a) p L_1'(a) e^{\gamma n L_1(a)} (1 - p)}{\{ p e^{\gamma n L_1(a)} + 1 - p \}^2} < 0 \quad (30)$$

The optimal level of activity strictly decreases in the number of potential victims, such that the difference between the activity level induced by strict liability and the socially optimal level increases as the number of victims increases. Under realistic premises concerning the marginal cost and marginal benefit functions we can proceed from the assumption that for large n the risky activity is entirely prevented, even if it is socially desirable according to Eq. (27).²⁰

Let us now turn to the case where a potential injurer decides upon the level of activity as well as upon risk mitigation. From our results, we can derive the following conclusions: if there is a market relationship between injurer and victims, the negligence rule with a standard of due care $x^* = x_{\max}$ is superior to strict liability for highly risky activities. It yields optimal care *and* activity levels, if the number of victims is sufficiently large. The injurer would comply with the standard, and the potential victims would take into account the cost of risk for their demand decisions, such that an efficient activity level is achieved.²¹ On the other hand, under a rule of strict liability, the injurer would still choose efficient care, as long as there is positive activity, but the activity level would be too low. This is due to the fact that the injurer's cost of risk increases at a faster than

²⁰ This result is not decisively affected by taking insurance markets into account, if these markets are imperfect. Under these circumstances strict liability would still induce an insufficient activity level. However, if a proportional loading on top of the expected value of losses is charged as the insurance premium and if insurance coverage is unlimited, the marginal cost does not increase without bound in n , and thus, the activity level does not tend to zero.

²¹ Note, however, that the optimal activity level under the negligence rule is lower in comparison with the case of risk neutrality.

linear rate, and thus, the total cost of risk increases faster than it does under the negligence rule. If the number of victims is sufficiently large the injurer chooses not to carry out the activity.

In the case of no market relationship, the negligence rule would also lead to efficient loss prevention. The activity level, however, would be chosen too high, since the injurer would not take into account the victims' risk premiums. Strict liability, on the contrary, would yield, again because of the strongly (in n) increasing injurer's risk premium, an activity level lower than in the social optimum. And it would entirely prevent the activity for sufficiently large n . Without additional assumptions, one cannot make a general statement about the comparison of the two regimes under these conditions.

5. Concluding remarks

Many countries employ the negligence rule as their main liability regime. Highly risky activities, however, are often governed by strict liability. The reason usually given for applying strict liability to these areas is that not only efficient care is supposed to be induced, but also an efficient level of the risky activity itself. It is argued that, in the case of no market relationship between injurers and victims, this could only be achieved through strict liability but not via negligence.

Most activities which are considered very risky are characterized by the fact that they endanger a large number of potential victims. Therefore, strict liability implies a quite unfavorable allocation of risk, as the risk is not spread but completely assigned to the injurer. The hereby incurred secondary cost of risk allocation in the sense of Calabresi has been largely ignored in the law and economics literature, by means of assuming risk neutral individuals or perfect insurance markets.

The premise of risk neutral decision making as well as the assumption of perfect insurance markets are empirically not very well established. Therefore, the topic of this paper is the question of whether strict liability remains the superior regime for highly risky activities even if the parties are risk averse and the insurance markets are imperfect. We have shown that for a given level of activity and a sufficiently large number of victims, negligence is the better solution, if no insurance is supplied. Strict liability, on the contrary, turns out to be clearly suboptimal because of its risk allocation effects. Taking insurance markets into account does not affect these results substantially, if the available insurance coverage is limited. The same statement holds if insurance premiums include a risk dependent loading due to risk aversion of the insurer. However, if the loading does not depend on the structure of the risk, but is calculated as a percentage of expected losses, neither strict liability nor the negligence rule is optimal. In this situation, a liability rule is efficient that makes the injurer participate with a certain positive fraction (smaller than one) in every damage.

We can therefore conclude that strict liability cannot be seen as the superior liability rule for highly dangerous activities, if risk allocation aspects are taken into account. In terms of risk allocation, the negligence rule should be preferred for activities with the potential of loss accumulation, if insurance markets show a substantial degree of imperfectness. With respect to controlling the level of the risky activity negligence turns out to be su-

perior, if a market relationship between the parties exists. This is because the negligence rule incurs less cost of risk. If there is no market relationship between injurer and victims, no clear result can be derived. We can only state that negligence induces excessive use of the risky activity while strict liability leads to an activity level below the social optimum.

For risks subject to strict liability the extent of an injurer's share in the risk is very often limited by an upper bound.²² Furthermore, rules are common which exclude losses from an injurer's liability, if there would have been no way to prevent them according to most recent science findings or by applying latest technology.²³ At first glance, these regulations seem to be economically questionable and incompatible with the principle of strict liability. In particular, the existence of upper bounds has been criticized.^{24,25} Our considerations, however, show that this kind of limitation of strict liability is actually a way to improve efficiency. The exclusion of unforeseeable losses, for example, can be interpreted as a negligence rule with a very restrictive standard of due care: an injurer is held liable if the loss was foreseeable. Therefore, to avoid having to compensate the victims all known loss prevention measures must be carried out, or in other words, the maximum level of care must be carried out. But this is, as we have shown, the optimal standard of a negligence rule if the number of potential victims is large. Furthermore, in the case of an upper bound of liability, the actual injurer's share in the risk decreases with an increasing number of victims. This, again, is exactly a feature we derived for the optimal regime to govern abnormally dangerous activities. Thus, both kinds of supplements for a rule of strict liability seem to be useful tools to reduce inefficiencies this rule would have when applied to areas characterized by the potential of loss accumulation.

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²² See, for example, the German Environmental Liability Law § 15 (85 million Euros for bodily injury and the same amount for material damage), the Product Liability Law § 10 (1) (85 million Euros for bodily injury), the Pharmaceutical Products Law § 88 (120 million Euros, respectively, 7.2 million Euros in pension payments), and the Genetic Engineering Law § 33 (85 million Euros).

²³ One example is again the German Product Liability Law (§ 1), according to which a defendant is not held liable if it was impossible, according to recent research findings, respectively, by use of latest technology, to detect the defect at the time the product was put on the market. See also § 84 of the German Pharmaceutical Products Law that assigns losses due to insufficient instructions to the injurer only if, roughly speaking, these instructions do not comply with the standards of medical science.

²⁴ See Faure and v. d. Bergh (1990).

²⁵ The exclusion of "unforeseeable" losses in the sense that state of the art loss prevention is applied, is seen less one-sided, since by definition liability for this kind of losses does not have an impact on behavior. In favor of strict liability even for these losses is argued, if in principle, the injurer would have been capable of finding out about unknown dangers through research. On the other hand, it has to be kept in mind that the danger of being held liable for unforeseeable losses keeps investors from investing in the development of useful but dangerous activities.

Appendix A.

Proof of Proposition 1. Consider the minimization problem:

$$\min_{0 \leq x \leq x_{\max}, 0 \leq q \leq 1} C_T(x, q) = c(x) + R_I^n(x, q) + nR_V(x, q) \tag{A.1}$$

where for the case that mitigation affects the loss probability,

$$R_I^n(x, q) = \frac{1}{\alpha} \ln\{p(x) e^{\alpha q n L_1} + 1 - p(x)\} \tag{A.2}$$

and, if mitigation affects the extent of losses,

$$R_I^n(x, q) = \frac{1}{\alpha} \ln\{p e^{\alpha q n L_1(x)} + 1 - p\} \tag{A.3}$$

($R_V(x, q)$ is determined in the same way).

Firstly, it has to be shown how the optimal level of mitigation reacts on a ceteris paribus variation of n . Therefore, we substitute for q^* in Eq. (12). We derive

$$c'(x) = -\frac{n\alpha + \beta}{\alpha\beta} \frac{p'(x)(e^{(n\alpha\beta/(n\alpha+\beta))L_1} - 1)}{p(x) e^{(n\alpha\beta/(n\alpha+\beta))L_1} + 1 - p(x)} \tag{A.4}$$

respectively

$$c'(x) = -n \frac{L_1'(x) e^{(n\alpha\beta/(n\alpha+\beta))L_1(x)}}{p e^{(n\alpha\beta/(n\alpha+\beta))L_1(x)} + 1 - p} \tag{A.5}$$

With $n\alpha\beta/(n\alpha + \beta)$ also the right hand side in Eqs. (A.4) and (A.5) strictly increases in n . Since furthermore the marginal benefit of loss reduction decreases in x , the optimal mitigation level increases as n grows.

For sufficiently large n , we get $x^* = x_{\max}$. If for all n x^* were smaller than x_{\max} , there would have to be an $\bar{x} \leq x_{\max}$ with $x^* \xrightarrow{n \rightarrow \infty} \bar{x}$. Then, however, the left hand side in Eqs. (A.4) and (A.5) would tend to $c'(\bar{x})$, while obviously the right hand side would grow without bound, implying that for sufficiently large n equality could not be fulfilled (in contradiction with the assumption that $x^* < x_{\max}$). □

Appendix B.

Proof of Proposition 2. With $q = \beta/(n\alpha(1 - d) + \beta)$ one gets

$$n\alpha q(1 - d) = \frac{\alpha\beta}{\alpha + (\beta/n(1 - d))} \tag{B.1}$$

Using Eq. (17) and $h := n(1 - d)$ yields

$$(1 + m)E[\tilde{L}|x] = \frac{E[\tilde{L} e^{(\alpha\beta/(\alpha+\beta/h))\tilde{L}}|x]}{E[e^{(\alpha\beta/(\alpha+\beta/h))\tilde{L}}|x]} \tag{B.2}$$

and we find

$$\frac{\alpha\beta}{\alpha + \beta/h} \xrightarrow{h \rightarrow \infty} \beta \quad \text{and} \quad \frac{\alpha\beta}{\alpha + \beta/h} \xrightarrow{h \rightarrow 0} 0 \tag{B.3}$$

Considering Eq. (22) it can be seen that for any given level of care there exists an $h(x)$, which solves Eq. (B.2). The hereby defined function $h(x)$ is continuous on the compact interval $[0, x_{\max}]$, and thus, assumes a maximum in this set. With $h_{\max} := \max\{h(x) : x \in [0, x_{\max}]\}$

$$q^* = \frac{\beta}{n\alpha(1-d^*) + \beta} \geq \frac{\beta}{\alpha h_{\max} + \beta} =: q_{\min} \quad (\text{B.4})$$

□

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