Relative Performance of Liability Rules: Experimental Evidence*

Vera Angelova,** Giuseppe Attanasi,† Yolande Hiriart‡

April 23, 2012

Abstract

We compare the performance of liability rules for managing environmental disasters when third parties are harmed and cannot always be compensated. A firm can invest in safety to reduce the likelihood of accidents. The firm's investment is unobservable to authorities. Externality and asymmetric information call for public intervention to define rules aimed at increasing prevention. We determine the investment in safety under *No Liability*, *Strict Liability* and *Negligence*, and compare it to the first best. Additionally, we investigate how the (dis)ability of the firm to fully cover potential damages affects the firm's behavior. An experiment tests the theoretical predictions. In line with theory, *Strict Liability* and *Negligence* are equally effective; both perform better than *No Liability*; investment in safety is not sensitive to the ability of the firm to compensate potential victims. In contrast with theory, prevention rates absent liability are much higher and liability is much less effective than predicted.

JEL classification: D82, K13, K32, Q58.

Keywords: Risk Regulation, Liability Rules, Incentives, Insolvency, Experiment.

*We thank David Alary, Marie Obidzinski and participants in the International Workshop on Economic and Financial Risks in Niort, the 20th SRA-Europe Meeting in Stuttgart, the ESREL Annual Conference in Troyes, the CES-ifo Conference on Law and Economics in Munich. The research leading to these results has received funding from the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013) Grant Agreement no. 230589. Financial support from the French *Agence Nationale pour la Recherche* (ANR) with the project *Environmental Regulation and Market Imperfections* is also acknowledged, together with CESifo sponsorship.

**Max Planck Institute of Economics, Jena, Germany. E-mail: angelova@econ.mpg.de. Phone: +49-3641-686637, fax:+49-3641-686667.

†Toulouse School of Economics, Toulouse, France. E-mail: giuseppe.attanasi@tse-fr.eu. Phone: +33-561-635-776.

‡Université de Franche-Comté (CRESE), 45D avenue de l'observatoire, 25030 Besançon cedex, France. E-mail: yolande.hiriart@univ-fcomte.fr. Phone: +33-381-666-826.

1 Introduction

We study the design of a suitable public policy for managing environmental disasters. Beginning in the 1970s, there has been a major wave of health, safety and environmental regulation. With the pioneering role of the United States, this led to the establishment of new regulatory agencies with broad responsibilities for risk and environmental policy, but also to Courts gaining importance (see Viscusi, 2007). The rationale for this tendency is twofold. First, liability is often viewed as a successful legal response to finance the remediation of hazardous sites or to indemnify the victims (compensation role). Second, it may also foster incentives for prevention by inducing private actors to internalize environmental damage (incentive role). Both dimensions are valuable, in particular if one does not want to use public funds for sites' restoration, a common practice until now in Europe.

There exist various ways of attributing liability.[1] The field of environmental risk does not depart from more general contexts of accident law in its use of *Strict Liability* and *Negligence* as the two main ways of holding (or not holding) the responsible party liable for damages. A quick look at the main northern American or European laws reveals that these two liability rules are the most common regimes. For instance, the *Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)*, that was enacted in 1980 in the U.S.A., is a *Strict Liability* rule forcing any responsible party to pay for the cleanup of contaminated sites. As for the European Community, the 2004 Directive for contaminated sites is a *Negligence* rule.[2] Despite the international tendency toward the introduction of liability regimes for environmental damage, a general agreement on the rationale for relying on them is still missing (see Faure and Skogh, 2003). In particular, it is widely accepted that the insolvency of potential injurers is a serious impediment to the effectiveness of

[1] See Posner (1992) or Shavell (2004) for a textbook description of these liability rules.

[2] *Directive 2004/35/CE on environmental liability regarding the prevention and compensation of environmental damages*, adopted by the European Parliament and Board of Ministers on April 21, 2004.

any liability rule.[3] It is thus essential to understand the behavior of judgment-proof firms (i.e. firms whose assets cannot fully cover potential damages) when subjected to these policies.

In this paper we investigate which liability rule is most effective in reducing the probability of an accident. Furthermore, we study the role of insolvency, i.e. whether the firm's willingness to invest in safety depends on the ability of the firm to compensate third parties.[4] More specifically, we compare the performance of *No Liability*, *Strict Liability*, and *Negligence* rules enforced against firms that can potentially harm third parties (i.e. the environment or human beings in their health or property). In our analysis, we assume that the firm does not directly suffer damage when an accident occurs. Only third parties who do not have any contractual or market relations with the firm suffer harm. Employees of the firm and consumers of the firm's products are thus excluded from our analysis. Notice that we restrict attention to unilateral accidents: while firms (potential injurers) have influence on the probability of occurrence of the harm, third parties (potential victims) play a passive role (i.e. they have no means to affect the probability and the size of the damage).[5]

The focus of our decision model is a potential disaster due to the firm's moral hazard when investing in prevention. With a small probability, the firm can cause a huge damage to third parties. However, the firm can reduce the likelihood of accidents by investing in safety measures. The firm's safety care involves, e.g., buying new

[3] Other limits are the low probability of a suit, the difficulty of proving causality between the decisions of injurers and harm and/or the long time it takes, the uncertainty about judgments by Courts due to mistakes and the subjectiveness of judges (Shavell, 1984b). Furthermore, liability may change the contractual or market relationships in risky sectors which may lead to underinvestment there (Hiriart and Martimort, 2006b). On the other hand, liability is a very natural way to align private with public interests. Therefore there is a strong tendency to introduce liability as a part of traditional regulation all over the world.

[4] Since we are talking about the firm and third parties, the reader may ask who the second party is. The second party is public authorities.

[5] See Shavell (2004) for *unilateral* accidents in the Law and Economics literature.

equipment, educating and training employees, increasing watchfulness. In addition, safety measures taken by the firm are not directly observable by the authorities. Since prevention is both costly to the firm and unobservable by the rest of the world, we model safety care as a moral hazard variable. The potential externality caused by a disaster together with asymmetric information require authorities to provide incentives for the firm to reduce risk. Public intervention takes the form of liability rules. They induce the firm to reduce risk and/or to compensate the victim in case of damage. We assume that if an accident occurs, victims lose their entire wealth. The injurer's assets, however, may not suffice to fully compensate victims. Since the firm is protected by limited liability, the firm can only be held liable for damages up to the value of her[6] wealth, but not beyond.

In our theoretical model, we determine the amount invested in prevention by the firm under *No Liability*, *Strict Liability* and *Negligence* and compare it to the first-best level of care. An experiment allows to test the main theoretical insights. Our experimental results show that in line with theory, both *Strict Liability* and *Negligence* perform better than *No Liability*: the firm increases her level of safety care under these rules. Further, there is no significant difference in the effectiveness of *Strict Liability* and *Negligence*, confirming another theoretical result. Last, investment in safety does not change when the firm is unable to cover losses of third parties. In contrast with theory, prevention rates absent liability are much higher and liability is much less effective than predicted.

This paper belongs to the Law and Economics literature devoted to tort law, more precisely to the public control of agents that can potentially and unintentionally harm third parties. We investigate the incentives provided by public authorities to foster prevention when safety care is unobservable. In this sense, this paper can be

[6] Although grammatically incorrect, when talking about the firm we will use the pronouns "her" and "she" in order to be consistent with the literature.

related to the Principal-Agent literature.[7] At the same time, our paper differs from this literature because the set of instruments available to public authorities (the Principal here) to control agents is restricted to the definition of liability rules. More in line with the Law and Economics literature, there is no direct and personalized regulation here (taking the form of a regulatory contract, for instance). Liability rules are common knowledge and apply equally to all agents. The theoretical model of this paper is related both to Shavell (1980), and Shavell (1986). Shavell (1980) analyzes thoroughly *Strict Liability* versus *Negligence* rules, while Shavell (1986) provides insights on the judgment-proof problem.

The original part of our work remains the empirical one. The empirical literature on liability rules is considered small. The few econometric studies that exist are, e.g., on the adoption of *Strict Liability* within the U.S.A. (Alberini and Austin, 1997), the effectiveness of *Strict Liability* when handling toxic spills (Alberini and Austin, 1998), on how firms escape *Strict Liability* (Alberini and Austin, 1999, 2001), etc. To the best of our knowledge, there is no study that compares the relative performance of liability rules. We aim to fill this gap. Since the variable of interest, i.e. investment in safety, is not observable in the field, we had to make use of the experimental method.

Also, there are not many experiments on liability rules. King and Schwartz (1999, 2000) and Dopuch and King (1992) study the special case of liability rules for auditors. Dopuch, Ingberman and King (1997) explore liability rules applied to the multi-defendant case, namely *proportionate* versus *joint and several* liability rules. Wittman et al. (1997) investigate the learning of liability rules. The experimental study which is most similar to ours is by Kornhauser and Schotter (1990). The main difference between our framework and theirs is that we consider accidents of substantial size compared to the injurer's level of assets. Disasters pose a particular problem for

[7] See Pitchford (1995), Newman and Wright (1990), or Hiriart and Martimort (2006a), although all these papers study essentially the case of *extended liability*.

public authorities due to the frequent insolvency of the responsible parties. Our main contribution is to shed light on the level of prevention when potential injurers cannot fully compensate victims. This is a question that, to our knowledge, has not been the object of experiments yet. Further three important design issues contrast our study with Kornhauser and Schotter (1990). First, in our experiment there is a real third party, i.e. a subject who is sitting in the laboratory and can potentially suffer losses resulting from the behavior of the injurer. In Kornhauser and Schotter (1990), if an accident occurs, the injurer is called upon to pay for the damage but no one gets "hurt". Second, subjects in our experiment earn their endowment in a real effort task. This way they are induced to perceive the money at risk as their own, which makes the decision situation more realistic and may lead to a different behavior compared to the case where the money at risk is provided as a windfall by the experimenter. Third, Kornhauser and Schotter (1990) lack a *No liability* treatment, for which we find rather intriguing results. Given these differences in the experimental designs, it is not surprising that also the results differ. While we find evidence in favor of the equivalence between *Strict Liability* and *Negligence*, Kornhauser and Schotter (1990) do not find such equivalence, even when the standard of due care is set at the optimal level.

The paper is organized as follows. Section 2 presents the model. The experimental design, procedures, and behavioral predictions are described in Section 3. Results are given in Section 4. Section 5 briefly concludes by pointing out alleys for further work.

2 The Model

A firm can cause a damage of a given size h to third parties (human beings and/or the environment). The firm can exercise some safety care $e \in \{0, 1\}$, i.e. invest in safety, in order to reduce the probability of accident from p_0 to p_1 (both being in $[0,1]$), with $\Delta p = p_0 - p_1 > 0$. The firm has assets w_0 to start with. Let us denote by w_t the assets at time t. It costs an amount $c > 0$ to the firm to invest in safety ($e = 1$), whereas not investing in safety ($e = 0$) costs nothing. This level of investment in safety is privately known by the firm: it is neither observable by public authorities, nor by third parties.[8]

In each period t, the firm faces the same decision problem: to invest in safety or not. Each unit invested in safety decreases the firm's remaining wealth by the same amount. The intertemporal dimension is reduced to nothing because there is no binding constraint in the problem the firm solves in each period: the firm's wealth is by large greater than the total amount she may invest in safety, even if she would invest in safety in each period. The investment decision in each period is thus completely independent from the investment decision in the other periods. The framework boils down to a static decision model, which is repeated a finite number of times.

When an accident takes place, the firm is held liable or not to pay for the harm caused, depending on the liability rule.

In the absence of liability, i.e. *No Liability* (henceforth *NoL*) rule, the firm does not pay anything, and the third party bears the losses.

Under a *Strict Liability* (henceforth *SL*) rule, the firm responsible for the harm caused to a third party must compensate the third party, independently of the firm's behavior in the conduct of the operations that have led to the damage, i.e. even if the firm has been cautious and the damage could not have been avoided by the exercise of due care.[9]

Under a *Negligence* (henceforth *Ne*) rule, the firm is not held liable for the harm

[8]This model is an adaptation of Shavell (1984a).

[9]See Shavell (2004).

caused, unless she is found negligent, i.e. unless the firm has not satisfied a standard of due care in the conduct of the operations that have led to the damage.[10] Here the standard of due care is set at $e = 1$.

■ **Social optimum.** Investing in safety is socially optimal if the expected social cost of investing is smaller than the expected social cost of not investing:

$$p_1 * h + c \leq p_0 * h.$$

This condition can be rewritten as

$$c \leq \Delta p * h. \tag{1}$$

The high level of safety care is thus socially optimal when the prevention cost borne by the firm is smaller than the incremental expected harm affecting third parties. Let us assume that this inequality holds in what follows: the objective of public authorities is then to implement this high level of care. Since investment in safety is unobservable, the best authorities can do is to impose policies so as to induce the firm to exercise $e = 1$. This is the role assigned to liability rules. We will first assess their efficiency from a theoretical viewpoint before testing it with an experiment. To this end, we characterize the circumstances under which the firm invests in safety care: if a liability rule induces the firm to exercise $e = 1$ in any circumstances, then the rule is socially efficient.

We now have to characterize the firm's cost-minimizing choice under each liability rule. Whatever the rule, the firm invests in safety if the expected private cost of investing is smaller than the expected private cost of not investing.

■ Under *NoL* rule, the firm invests in safety care if

$$p_1 * 0 + (1 - p_1) * 0 + c \leq p_0 * 0 + (1 - p_0) * 0,$$

[10] An injurer firm is held liable for losses if her level of care is less than a level called *due care* that the Courts specify. See Posner (1992).

which never holds true since $c > 0$. Hence, the firm is never induced to exercise $e = 1$: *NoL* rule is always inefficient.

■ Under *SL* rule, a responsible firm with assets w_t at time *t* has to pay an amount equal to $\min\{h, w_t\}$ since the firm is protected by limited liability. The firm thus invests at time *t* if

$$p_1 * \min\{h, w_t\} + (1 - p_1) * 0 + c \leq p_0 * \min\{h, w_t\} + (1 - p_0) * 0,$$

which can be rewritten as

$$c \leq \Delta p * \min\{h, w_t\}. \tag{2}$$

Comparing (2) to (1), it is clear that a *SL* regime will induce the proper investment in safety (or choice of care) when the firm is rich enough. The firm will always invest in safety when her assets are sufficient to cover the external harm, i.e. when $w_t \geq h$. In this favorable case, the firm exercises $e = 1$ and, if an accident occurs, the firm is able to (and will) fully compensate the third party for losses. The firm will also invest when her assets fall in a medium range, i.e. when $w_t \in \left[\frac{c}{\Delta p}, h\right)$: *SL* creates enough incentives to take care, although the firm will compensate the third party only partially. Conversely, when the firm's assets fall below the threshold $\frac{c}{\Delta p}$, the firm will not take care. In this case the compensation provided by the firm to the harmed third party will be lower than in the medium range case.

■ Under *Ne* rule, the firm is held liable only if she did not exercise $e = 1$. Hence, the firm invests in safety if

$$p_1 * 0 + (1 - p_1) * 0 + c \leq p_0 * \min\{h, w_t\} + (1 - p_0) * 0,$$

which can be rewritten as

$$c \leq p_0 * \min\{h, w_t\}. \tag{3}$$

Comparing (3) to (2), it is clear that *Ne* rule will induce the firm to take care more often than *SL* rule: (3) is less demanding than (2), since $p_0 \geq \Delta p$.[11] Again, three

[11] This means that the firm's choice $e = 1$ will be induced by *Ne* rule for a larger set of parameters,

intervals of the firm's wealth can be defined according to the efficiency of the rule and to the extent of the compensation. When $w_t \geq h$, the firm takes care and pays h if damage occurs. In a medium range of wealth where $w_t \in \left[\frac{c}{p_0}, h\right)$, the firm takes care but compensates only partially the third party if an accident occurs. Last, when the firm's wealth is below the threshold $\frac{c}{p_0}$, the firm does not take care and can compensate the third party even less for the harm caused.

The results above hold for risk neutral firms. The analysis for risk averse firms using a CARA utility function is provided in Appendix A. Under risk aversion, the conditions for which the firm chooses to invest in safety under each liability regime are slightly different but the qualitative results obtained under risk neutrality remain the same. Namely, the firm should not invest in safety under *NoL* but should do so under *SL* or *Ne*, provided that, both the prevention cost, and the degree of risk aversion are not too large. *Ne* induces prevention for a larger set of parameters than *SL*.

3 Experiment

3.1 Design

We implemented six distinct treatments (see Table 1). They differed in the type of liability rule (*NoL*, *SL*, or *Ne*) and in whether the harm potentially caused could be fully compensated by the injurer. In the *low* (*high*) damage treatments, the potential injurer would always (never) be able to fully compensate the potential victim.

The experiment consisted of two phases with 5 periods each. Phase 2 was merely a repetition of phase 1. One of the phases was randomly selected for payment at the end of the experiment. We opted for a repeated set-up with a restart (i.e. phase 2)

i.e. also for $w_t \in \left[\frac{c}{p_0}, \frac{c}{\Delta p}\right)$.

	low damage	*high* damage
No Liability (*NoL*)	*NoL-low*	*NoL-high*
Strict Liability (*SL*)	*SL-low*	*SL-high*
Negligence (*Ne*)	*Ne-low*	*Ne-high*

Table 1: Treatments

to check whether decisions of experienced subjects differed from those of inexperienced ones. This offers a control for learning. At the same time phases were chosen not too long in order to avoid noise in the decisions caused by boredom and fatigue.

The 30 participants were randomly assigned to roles (*A* and *B*) and *A*-*B*-pairs at the beginning of each phase.[12] One can think of subject *A* as the firm or potential injurer and of subject *B* as the third party, or potential victim.[13] Just like in the model, the third party was passive in all treatments of the experiment: *B* was going to be affected by the decisions of *A*, but could not do anything to influence them. Since there was no interaction between *A* and *B*, subjects in the experiment faced an individual decision making situation in a non-strategic set-up. In addition, the investment decision remained private information to *A*: no other participants could observe it.

Subjects were not informed until the end of the phase about their role, so that first everyone was asked to decide as if they had been assigned the role of *A*. This way we collected 30 individual decision paths as *A* for each phase and each treatment.[14] At the end of each phase, subjects were informed about their actual role. The decision path of the subject who had been assigned the role of *A* became relevant for the

[12]Phase 1 was independent from phase 2 in both the random draw of roles, and the random assignment to pairs.

[13]To keep a neutral frame, we never used the terms "injurer" and "victim" in the instructions.

[14]This procedure is known as *random dictatorship*. It allowed us to collect data on twice as many subjects because this way also subjects, who were assigned the role of *B* and would otherwise have been passive, were asked to make decisions.

payoff outcome of the *A*-*B* pair. In contrast, the decision path of *B* became irrelevant for the payoff outcome of the same *A*-*B* pair.

In each of the five periods, with a probability of 5%, an accident[15] would occur and lead to a loss of endowment to *A*, *B*, or both, depending on the treatment. In each period, subject *A* was asked to decide whether she wanted to reduce this probability to 1% by investing 1 ECU (Experimental Currency Units). An endowment of 40 ECU was given to subject *A* at the beginning of each phase. Subject *B*'s endowment depended on the treatment: it was 30 ECU in the *low* damage treatments and 50 ECU in the *high* damage treatments. When an accident occurred, the victim lost her entire wealth. In the *low* damage treatments, *A* was able to fully compensate *B* in every period t of the phase independently of *A*'s investment in prevention. Conversely, in the *high* damage treatments, *A* was never able to fully compensate *B*.

In each period, each subject first made her decision and then learned whether she was hit by an accident. Subjects also learned how many other subjects were hit. This information was restricted to the "the subject's feedback group", i.e. to 14 other subjects with whom the subject in question had not been paired for sure.[16] We opted for general feedback about accidents in order to add more realism to the experiment. In reality information about major environmental disasters is usually provided in the form of statistics in the news and may lead to a change in the behavior of potential injurers.

Whenever a subject was hit by an accident, that subject was not allowed to make decisions in the remaining periods of the current phase.[17]

[15]Instead of an "accident" we spoke of an "event" in the instructions to keep a neutral frame.

[16]Recall that until the end of the phase subjects did not know their role in the pair. Therefore, receiving information about an accident occurring to a subject potentially paired with oneself would unnaturally influence one's decision path.

[17]An accident introduces an asymmetry in the decision situation. Before the accident, *A* holds her endowment less the cost for investment in safety. After the accident, depending on the liability rule, *A* may not have any more resources to invest in safety, even if she wants to.

At the end of the phase, subjects were informed about their actual role, whether their pair was hit by an accident and the resulting payoffs. If the pair was not hit by an accident, *A*'s payoff was her initial endowment less her total prevention cost (the ECUs paid for investment in safety in the five periods of the phase). *B* simply kept her initial endowment. In the case of accident, payoffs depended on the treatment. First, *B* lost her initial endowment (30 ECU in the *low* damage treatments and 50 ECU in the *high* damage treatments). Then,

- in the ***NoL* treatments**, *A* was not required to compensate *B*. Therefore, *A*'s payoff amounted to her initial endowment less her total prevention cost, independently of *B*'s initial endowment. *B* was left with nothing.
- in the ***SL* treatments**, *A* was required to compensate *B* up to the level of *A*'s remaining wealth, independently of whether *A* had invested in safety in that period or not.[18] In treatment *SL-low*, *B* received 30 ECU from *A*. *A* was left with a positive amount of money: 40 ECU less the 30 ECU compensation less the total prevention cost (at most 5 ECU). In the *SL-high* treatment, *B* received from *A* 40 ECU less *A*'s total prevention cost (i.e., at most 40, which is 10 less than *B* initially possessed). *A* was left with nothing since her entire wealth was transferred to *B*.
- in the ***Ne* treatments**, payoffs were conditional on *A*'s decision in the period of the accident. If *A* had invested in safety in the period of the accident, *A* was not required to compensate *B*: by investing 1 ECU, *A* had complied with the standard of due care and was not liable for the harm caused. Hence, payoffs were exactly as in the *NoL* treatments. If *A* had not invested in safety in the period of the accident, *A* was required to compensate *B* up to the level of *A*'s wealth. The resulting payoffs were, therefore, the same as in the *SL* treatments.

[18]Since *A* was protected by *limited liability*, *A* was not supposed to give to *B* more than *A* owned.

The last task was a post-experimental questionnaire consisting of three questions. Questions aimed at collecting information about the risk attitudes[19] of subjects and their perceptions of others' and own selfishness. The translation from German read: 1. "How do you judge yourself: are you generally a risk loving person, or do you try to avoid risks?"; 2. Would you say that most of the time people try to help others or only follow their own interests? 3. Would you say that most of the time you try to help others or only follow your own interests?. The answer to 1. was on a scale from zero (not risk loving at all) to ten (very risk loving). Answers to 2. and 3. were on a scale from 0 (help others) to 6 (follow own interests).

At the end of the experiment, payoffs were converted from ECU into euros at the exchange rate of 6 ECU = 1 euro. A show-up fee of 2.5 euros was added to that amount and paid to subjects in cash.

3.2 Procedures

We performed one session per treatment, i.e. six sessions altogether. A total number of 192 undergraduate students from the University of Jena (32 per session) participated in this experiment. They were recruited with the online recruitment system for economic experiments ORSEE (Greiner, 2004). Additional 64 subjects took part in the two pilot sessions. On average, participants earned 8.65 euros and spent 60 minutes (15 minutes of which on the instructive part) in the laboratory of the Max Planck Institute of Economics in Jena (Germany).

Upon arrival in the laboratory, subjects were randomly assigned to a cubicle with a computer. First, subjects received only instructions for Part I of the experiment, explaining a real effort task they had to perform in order to earn their initial endowment for Part II. Earning the initial endowment was equivalent to earning the right

[19] Asking this question is a simple procedure to estimate risk attitudes of subjects. It is shown to be as effective as other common and much more complicated procedures (see Dohmen et al., 2005).

to participate in Part II or the main experiment. Subjects were given five minutes time to solve as many as possible mathematical tasks of summing up five two-digit numbers (as in Niederle and Vesterlund, 2007). At the end of the real effort task subjects were ranked according to the number of math tasks they had solved correctly. The 30 best performers received their initial endowment and the second part of the instructions.[20] The two worst performers did not earn an endowment and had to leave the laboratory. They were compensated with 3 euros each. The purpose of the real effort task was to make subjects earn their endowment and hence perceive the money at risk as their own or as that of the potential victim.

For both parts of the experiment, after subjects read the instructions individually, instructions were also read aloud by the experimenter. The experimenter clarified the instructions in private, when necessary. Additionally, before Part II of the experiment began, subjects answered a list of questions checking their understanding of the instructions. Part II did not start before everyone had answered all questions correctly. The experiment was programmed in z-Tree (Fischbacher, 2007).

In Part II of the experiment, the realization sequences for accident/no accident for each of the two probabilities 1% and 5%, and for each subject were drawn in advance. Each subject within a treatment faced an independent sequence of realizations. In order to ensure the comparability of treatments, subjects with the same identification number in different treatments (e.g. subjects with number 1 in all treatments) were confronted with the same sequence of realizations. To help subjects calculate the probability to be hit by an accident in one of the remaining periods of the current phase, we supplied them with an on-screen calculator.[21] In this calculator subjects could enter their planned decisions until the end of the phase. The calculator would then compute the probability for an accident to occur and the complementary probability for an accident not to occur until the end of the phase.

[20]See Appendix B for an English translation of the instructions.

[21]See Instructions in Appendix B for a picture of it.

By showing both probabilities we made sure that we did not influence subjects in an optimistic or pessimistic way. The calculator was accessible to subjects at all times.

During the experiment, eye contact was not possible. Although participants saw each other at the entrance of the lab, there was no way for them to guess with which person(s) from the crowd of 30 students they would be matched in the two phases of Part II of the experiment. Most subjects were experienced – only 10 out of 256 had never participated in an experiment before.

3.3 Behavioral predictions

In this section, we derive hypotheses based on the theoretical model from Section 2, its extension for risk aversion (in Appendix A), and the following parameter values: $c = 1$, $p_0 = 0.05$, $p_1 = 0.01$, (hence $\Delta p = 0.04$), $h = \{30, 50\}$, and $w_t \in [35, 40]$.

It is straightforward to see that (1) is satisfied for both harm sizes. Hence, investment in safety (i.e. $e = 1$) is socially optimal.

What should the decision of a subject be under each liability rule? Subjects should not invest in safety under the *NoL* rule,[22] but should do so both under the *SL* rule[23] and the *Ne* rule.[24]

[22]In both treatments *NoL-high* and *NoL-low*, the subject pays 1 ECU if she invests in safety and nothing if she does not invest. The occurrence of an accident does not lead to any cost for this subject. Hence, the subject should not invest whatever her attitude towards risk.

[23]In treatment *SL-low*, $\min\{h, w_t\} = h = 30$; $c = 1$ is smaller than $0.04 * 30 = 1.2$. In treatment *SL-high*, $\min\{h, w_t\} = w_t$; $c = 1$ is smaller than $(0.04 * w_t) \in [1.4; 1.6]$. Condition (2) is thus satisfied in all *SL* treatments, meaning that a risk neutral subject should invest in safety in each period. From Appendix A, it is easy to see that the same result holds for risk averse subjects, when their degree of risk aversion is not so extreme.

[24]In treatment *Ne-low*, $\min\{h, w_t\} = h = 30$; $c = 1$ is smaller than $p_0 * 30 = 1.5$. In treatment *Ne-high*, $\min\{h, w_t\} = w_t$; $c = 1$ is smaller than $(p_0 * w_t) \in [1.75; 2]$. Condition (3) is thus satisfied in all *Ne* treatments, meaning that a risk neutral subject should invest in safety in each period. From Appendix A, it is easy to see that the same result holds for risk averse subjects, for any degree of risk

In accordance with the model and the chosen parameter values, the potential injurer should invest in safety in the presence of liability rules; the corollary is that the potential injurer should not invest in safety in the absence of any liability rule. If this result holds at the individual level, it should also hold when considering a group of individuals faced with the same decision task, without any strategic interaction among them. This leads us to the following hypotheses:

H1. On average, investment in safety under SL and Ne will be above investment in safety under NoL.

H2. On average, investment in safety under Ne should not differ from investment in safety under SL.

In her desire to reduce the probability of an accident, the potential injurer should be driven by her own loss (the amount the injurer will be asked to pay as a compensation for the harm caused to third parties), but not directly by the loss borne by third parties. In particular, in the model the potential injurer is protected by limited liability. Hence, in her investment decision, she should never take into account the losses that exceed her own liabilities, i.e. the losses that she is unable to compensate:

H3. For a given liability regime, whether the potential damage can be fully compensated or not will not influence investment in safety.

4 Results

In analyzing the results we will proceed as follows. In the subsection "Main results" we will (i) compare investment in safety under the three liability rules, and (ii) check whether the ability to fully compensate the victim influences investment in safety. In the subsection "Controls", we will look at how additional factors – like individual perception of risk, of own and general selfishness, and learning from own and

aversion.

others' experience – influence the decision to invest in safety.

4.1 Main results

Table 2 shows the distribution of the variable *investment in safety* (INVEST). Remember that for each liability rule we ran two sessions (60 subjects in total) – one, in which the victim could be fully compensated for a potential damage and one for which she could not. In this table we pooled the data within each liability rule. Thus, for the time being we neglect the influence of the ability to compensate the victim. This is done to assess only the influence of the liability rule on investment behavior.

Treatment	*NoL*	*SL*	*Ne*
Number of INVEST decisions	296	391	416
Total number of decisions	570	584	588
% of INVEST decisions	0.52	0.67	0.71

Table 2: Investment in safety decisions by treatment, pooled.

Note: The number of missing decisions due to accidents was 30 in *NoL*, 16 in *SL*, 12 in *Ne*.

Investment in safety is highest under *Ne*, followed by *SL*, and *NoL*. To assess whether these differences are significant, we compared pairwise the three distributions using a χ^2–test. Investment in safety is significantly lower under *NoL* than under *Ne* ($p = 0.000$) and *SL* ($p = 0.000$). The small difference between investment in safety under *SL* and *Ne* is not statistically significant ($p = 0.279$).

Figure 1 shows the proportion of investment in safety decisions over time. Notice that learning (within a phase and between the two phases) neither causes an increase in investment in safety, nor a decrease. Further below we confirm this visual observation with several regressions.

We summarize our results so far as follows:

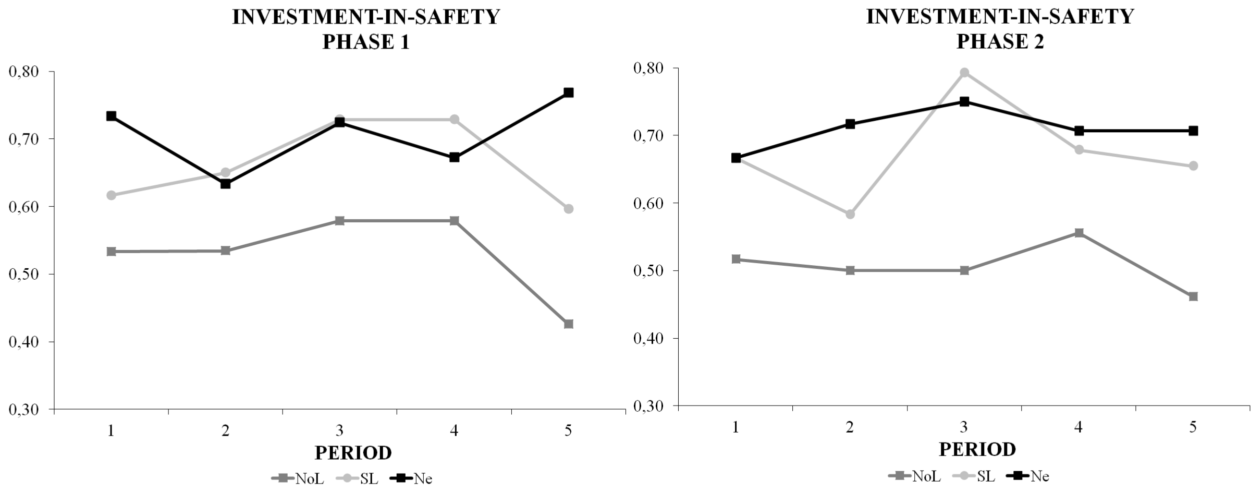

Figure 1: Investment in safety decisions over time (in %), by liability rule (pooled for ability to compensate the victim)

Result 1 : *Investment in safety in the presence of liability rules is always above investment in safety in the absence of liability rules.*

Result 2 : *Investment in safety under the Ne rule does not significantly differ from investment in safety under the SL rule.*

Our findings differ from Kornhauser and Schotter (1990) who observe that *SL* and *Ne* are not equivalent, even when the standard of due care is set at the socially optimal level.[25] Under *Ne*, they find compliance to the standard of due care (when set at its optimal level or not too far above), with remarkably stable investment in safety behavior over 35 periods. Under *SL* however, behavior in their experiment is quite volatile, showing over-investment in the first periods and under-investment in the final periods. We observe rule equivalence and stable investment in safety under both rules.

[25]The standard of due care is also set at its optimal level $e = 1$ in our experiment, so the difference in results cannot come from this specification. It should be noticed that we have adopted a binary level of care whereas Kornhauser and Schotter (1990) modeled care as a continuous variable.

Next, we shed light on how being able to compensate victims' losses affects investment in safety. Table 3 presents investment by treatment.

Treatment	*NoL-low*	*NoL-high*	*SL-low*	*SL-high*	*Ne-low*	*Ne-high*
Number of INVEST decisions	140	156	202	189	205	211
Total number of decisions	287	283	292	292	293	295
% of INVEST decisions	0.49	0.55	0.69	0.65	0.70	0.72

Table 3: Investment in safety by treatment

Note: The number of missing decisions due to accidents was 13 in *NoL-low*, 17 in *NoL-high*, 8 in each of the two *SL* treatments, 7 in *Ne-low*, and 5 in *Ne-high*.

To assess whether being able to fully compensate the victim influences investment in safety, we compare treatments where the victim can be compensated with treatments where she cannot be compensated, keeping the liability rule the same. So, using a χ^2–test, we check whether the distribution of the *investment in safety* variable is the same for *SL-low* and *SL-high*, and for *Ne-low* and *Ne-high*. These pairwise comparisons of treatments do not yield any significant differences. This is also confirmed by our regressions further below.

Result 3 : *Investment in safety in the presence of liability rules is not sensitive to the size of the potential damage.*

Keeping the size of the damage the same while pairwise comparing liability rules, confirms Results 1 and 2: liability significantly increases prevention, and *SL* and *Ne* are equally effective.[26]

Fig. 2 depicts proportions of investment decisions by treatment over time.

[26] Investment in safety under *NoL-low* is significantly below investment in safety under both *SL-low* and *Ne-low*, with both $p = 0.000$. The same is true when comparing *NoL-high* to *SL-high*, and *NoL-high* to *Ne-high* with $p = 0.012$ and $p = 0.000$, respectively.

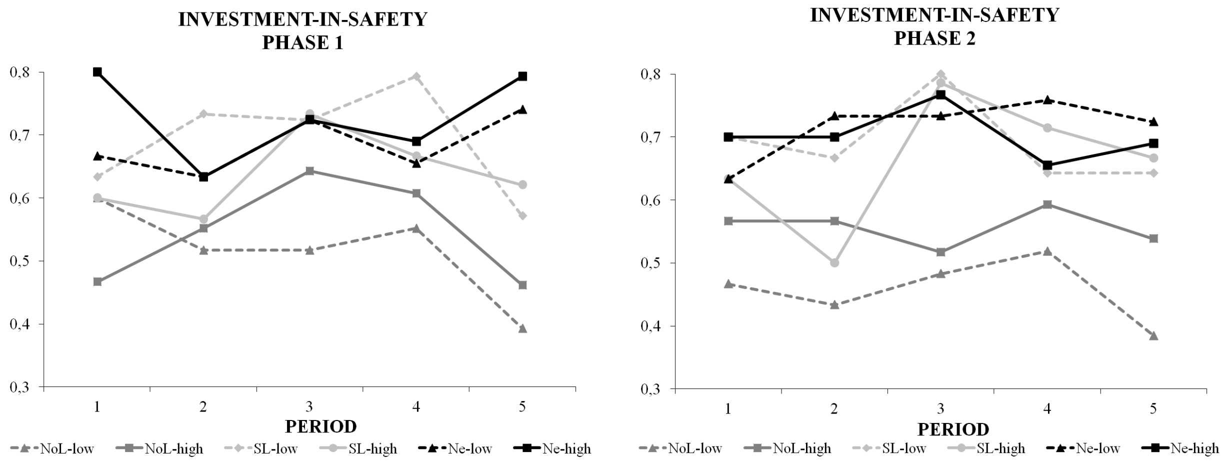

Figure 2: Investment in safety decisions over time (in %), by treatment

Keeping the liability rule the same and comparing the size of the damage phase by phase yields significant results only for the *NoL* treatments. In phase 2 of the experiment, investment in safety under *NoL-high* is significantly above investment in safety under *NoL-low* (χ^2–test, $p = 0.044$). Thus, only subjects experienced with phase 1 are sensitive to the potential damage caused to third parties and only in the *absence* of liability rules. It seems that this (second-phase) sensitivity to damage is crowded out by liability.

Generally, it is quite striking that investment in safety under *NoL* (around 50%) is larger than the increase in prevention achieved with the introduction of liability rules (around 20%). Moreover, although liability increases prevention significantly, prevention never reaches 100%. One reason for the last observation may be that our theoretical prediction of 100% prevention under liability relies on the assumption that agents are risk neutral or risk averse.[27] Therefore, this result may be due to

[27] In Appendix A we show that under *Strict Liability* a risk-averse subject should invest in safety only for $r \in \{0, 9.65\}$, i.e. if she is not extremely risk averse. However, subjects with a constant absolute risk aversion r greater than 9.65 are very rare in the real world. For them, predictions for risky choices with higher payoffs would be absurd (see, e.g., Binswanger, 1980, 1981). For instance, such subjects would prefer a sure amount of 1 EURO to a lottery giving them 1000 EURO with probability 0.99 and 0 EURO otherwise.

the presence of a significant percentage of risk loving subjects in our pool. To check this conjecture, we separated risk averse and risk neutral subjects from risk loving subjects. Table 4 shows that the average investment in safety grows when we take out the risk loving subjects (compare the last row of Table 3 to the second column of Table 4). However, also for the group of risk averse and risk neutral subjects only, investment in safety remains considerably below 100% (for a detailed version of Table 4, see Table 6 in Appendix C).

Treatment	Risk averse & neutral subjects	Risk loving subjects
NoL-low	0.70	0.30
NoL-high	0.62	0.43
SL-low	0.77	0.46
SL-high	0.70	0.50
Ne-low	0.86	0.48
Ne-high	0.80	0.43

Table 4: Investment in safety by risk attitude

Note: risk averse and risk neutral subject are those, who reported a score lower or equal to 5 in the post experimental questionnaire; risk-loving subjects are those who reported a score greater than 5.

Result 4 : *The rate of prevention without liability is unexpectedly high. The rate of prevention with liability is unexpectedly low. The rate of prevention in the absence of liability rules is higher than the increase in prevention achieved with the introduction of liability rules.*

4.2 Controls for individual characteristics and learning

In this section we present evidence on whether and how additional factors, like individual characteristics and learning affect investment in safety.

Although our theoretical model assumes risk neutrality, decision makers may not be risk neutral.[28] The majority of our subjects exhibit risk aversion when asked about their attitude towards risk at the end of the experiment. In fact, the median reported risk attitude in our experiment is 4 – on a scale from 0 (risk averse) to 10 (risk loving) – which is significantly less than the risk neutral value of 5 (one sample median test). Also, subjects may have a preference for helping others that can interfere with liability rules. Further, subjects may learn. Learning may be due to subjects getting used to the decision situation and also to own experience (e.g. having been hit by an accident in phase 1) and feedback about the experience of others (accidents in the 'feedback group'). In the regressions in Table 5 we control for these additional factors to show that the increase in investment in safety with respect to treatments *NoL* is indeed due to liability rules.

The variables that enter the regressions in Table 5 can be grouped into treatment variables (the first four), individual characteristics (the next four), and learning (the last five). Now, we will describe them in detail. The data from *NoL-low* and *NoL-high* are pooled under the *NoL* dummy. The same applies to the *SL* dummy and the *Ne* dummy. This is done to measure the effect of the type of liability rule only. By construction, these dummies ignore the size of the damage. Therefore, we introduced the *High damage dummy* to measure the effect of the size of the damage, independently of the liability rule. It takes the value of 1 for *NoL-high*, *SL-high*, and *Ne-high*,

[28]We acknowledge that the risk attitude of an individual cannot directly be translated as the risk attitude of a company. It is debatable whether firms are risk averse, like individuals, or not. The attitude towards risk of companies is certainly related to their size and to their financial constraints. The framework of our experiment is by far too simple to take into account such parameters. To sustain the argument that firms are not necessarily risk neutral and that the resulting decisions can look like the ones of individuals, we refer to Leland and Pyle (1977). These authors show that the assumption of risk aversion has some meaning for small companies that suffer from restricted access to financial markets. However, in order to convince investors that their project is worthwhile, these risk averse small firms accept to bear some risk and, finally, seem to behave like risk neutral big companies.

Dep.var.: INVEST	Ia	Ib	Ic	IIa	IIb
NoL dummy	.69***(.13)	.69***(.14)	.84***(.15)	.74***(.14)	.74***(.15)
SL dummy	.86***(.12)	.86***(.13)	.75***(.13)	.88***(.14)	.88***(.14)
Ne dummy	.93***(.12)	.93***(.13)	.80***(.14)	.98***(.14)	.98***(.14)
High damage dummy	–	–.00(.07)	.01(.06)	–	–.01(.07)
Risk attitude	–.08***(.01)	–.08***(.01)	–.08***(.01)	–.09***(.01)	–.09***(.01)
Others–selfish	–.06**(.03)	–.06**(.03)	–.06**(.03)	–.07**(.03)	–.07**(.03)
Me–selfish	–.02(.03)	–.02(.03)	.02(.03)	–.01(.03)	–.01(.03)
Me–selfish * *NoL* dummy	–	–	-.12**(.05)	–	–
Phase 2 dummy	–.03(.10)	–.03(.10)	–.03(.10)	–	–
Phase 1 dummy * Period	–.00(.01)	–.00(.01)	–.00(.01)	–	–
Phase 2 dummy * Period	.00(.01)	.00(.01)	.00(.01)	–.00(.01)	–.00(.01)
N. of accidents in $t-1$	–.03(.02)	–.03(.02)	–.03(.02)	.00(.03)	.00(.03)
Accident in phase 1 dummy	–	–	–	-.12(.14)	-.12(.14)
N of observations	1549	1549	1549	856	856

Table 5: Marginal effects from logit regressions explaining investment in safety. Random effects at the individual level control for the fact that individuals decide repeatedly. Standard errors (computed with the delta method) in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Regressions Ia, Ib, Ic use the whole data set. Regressions IIa, IIb use data from phase 2 only.

and 0 otherwise. While regressions **a** only measure the effect of liability rules, regressions **b** also measure the effect of insolvency (i.e. the size of the damage caused to third parties). The next three variables were elicited in the post-experimental questionnaire: *Risk attitude* on a scale from 0 (very risk averse) to 10 (very risk loving), *Others-selfish*[29] and *Me-selfish*[30] on a scale from 0 (help others) to 6 (follow own in-

[29] Recall that the question was "Would you say that most of the time people try to help others or only follow their own interests?".

[30] Recall that the question was "Would you say that most of the time you try to help others or only follow your own interests?".

terests). The interaction *Me–selfish * NoL dummy* shows how the opinion of subjects about being selfish or pro-social influences their behavior in treatment *NoL* only. Regression Ic differs from Ib only in this variable. *Phase 2 dummy* takes the value of 1 for phase 1 and 0 for phase 2. It accounts for learning from phase 1 to phase 2. The interaction between the *Phase* dummies and *Period* (going from 1 to 5) accounts for learning within each phase.[31] *N. of accidents in* $t-1$ is the number of accidents that occurred in the subject's feedback group in the previous period. Here we assume that accidents from at most the previous period may affect decisions in the current period. *Accident in phase 1 dummy* takes the value 1 if a subjects was hit by an accident in phase 1.[32]

We run logit regressions (since the dependent variable *investment in safety* or INVEST is binary) and report marginal effects. Because individuals make decisions repeatedly, decisions made by the same individual are correlated. Individual-specific random effects correct for this. The significant coefficients are marked with stars. We use a Wald post-estimation test to pairwise compare significant coefficients. If coefficients are different given this post-estimation test, we can conclude that the variable with the larger coefficient has a larger effect.

While regressions "I" make use of the whole data set, regressions "II" use only data from phase 2. The purpose of regressions IIa, and IIb is to check whether having

[31]E.g. *Phase 1 dummy * period* takes the value of 1 if we are in phase 1, period 1. The same variable takes the value of 2 if we are in phase 1, period 2, and so on until phase 1, period 5. *Phase 1 dummy * period* takes the value 0 if we are in phase 2.

[32]Both the number of accidents that occurred to others in the previous period and whether a subject was hit by an accident in the previous phase should not influence investment behavior since accidents occur independently. However, it is well-known that people fall prey to fallacies when faced with a random sequence of events. The two fallacies that may apply here are the *gambler's fallacy* and the *hot hand fallacy*. Given a fair coin, after a sequence of heads, people suffering from the former would expect tails while people suffering from the latter would expect heads (see, e.g., Slovic, 2000). For our experiment this would mean respectively that a person who was hit by an accident in phase 1, would not expect to be hit in phase 2 or indeed expect to be hit again in phase 2.

experienced an accident in phase 1 affects behavior in phase 2. Table 5 shows this is not the case.

The following results hold for all regressions. All variables related to learning are insignificant. Among the variables that deal with individual characteristics, *risk attitude* is always negatively correlated with investment behavior, meaning that independently from the treatment, the more risk loving an individual is, the less likely she is to invest in safety. Furthermore, the probability to invest in safety decreases with the individual's perception of others being selfish. Whether an individual considers herself selfish or not does not influence behavior. Among the treatment variables, subjects are not sensitive to the size of the harm caused to third parties (*High* damage dummy is not significant). In regressions Ia, Ib and IIa, IIb, investment in safety is more likely under both *SL* and *Ne* than under *NoL*.[33]

Regression Ic differs from Ia and Ib in only one variable: *Me–selfish * NoL dummy*, which is significant, meaning that the more selfish an individual rated herself, the less likely she was to invest in safety in treatments *NoL*. The difference in the coefficients between the *NoL dummy* and the liability dummies vanishes in regression Ic. I.e., when there is a control for selfishness in treatment *NoL*, behavior in the absence of liability rules does not differ from behavior in the presence of liability rules. This means that liability rules induce the selfish subjects to invest in prevention, such that in the end, prosocial subjects under no liability invest in safety as much as the pool of prosocial and selfish subjects under liability.

To sum up, risk aversion increases investment in safety, learning (from own and others' experience) does not change investment behavior, and the opinion about others being selfish decreases investment in safety. Furthermore, controlling for risk aversion, learning, and social preferences does not change our previous conclusions: *SL* and *Ne* rules induce more investment in safety than *NoL* and insolvency does not

[33] *SL* vs. *NoL*: $p = 0.03$, *Ne* vs. *NoL*: $p = 0.00$, Wald test.

change investment behavior of subjects. Regression Ic shows that the difference between treatments without liability and with liability is driven by the increased investment in safety of the selfish subjects in the liability treatments.

5 Conclusions

In this paper, we compare the performance of three liability rules (*No Liability*, *Strict Liability* and *Negligence*) enforced against a firm that can potentially cause a disaster and thereby harm third parties. We model the firm's investment in safety as a moral hazard variable. The predictions of our theoretical model are tested in an experiment. In line with theory, *Strict Liability* and *Negligence* perform better than *No Liability*: agents increase their level of care when they can be held liable for the harm caused. Furthermore, there is *no* significant difference in the effectiveness of *Strict Liability* and *Negligence* rule. Last, for a given size of own wealth, agents do not invest more when losses to third parties increase (i.e. when the insolvency problem is more stringent). In contrast with theory that predicts zero prevention under *No Liability* and 100% prevention under liability (for risk neutral and risk averse subjects), prevention rates are as high as 50% in the former and significantly below 100% in the latter case. Investment in safety remains below 100% even when excluding risk loving subjects from the analysis.

Our work can be extended in the following directions.

Most of the theoretical predictions were confirmed by a subject pool of German undergraduates. However, the substantial level of investment that appeared under *No liability* will have to be further explored. Other-regarding preferences, as subjects caring for the well-being of third parties may be responsible for this outcome. This conjecture would be in line with Brennan et al. (2007), who show that once the own outcome is not at risk, subjects care for the risk borne by others. More research will also be needed to provide explanations for the relatively low investment in prevention in the presence of liability rules.

In our setting, the size of the harm is given, and the only way of reducing expected losses is to reduce the probability of an accident. However, one could consider a more general model where both the probability of an accident, and the size of the harm can be influenced by prevention. Then, the size of the harm can be linked to the firm's scale of activity, and the probability of an accident can be linked to the intensity of safety effort. From the Law and Economics literature[34] we know that *Strict Liability* is effective in providing incentives both for activity and probability reduction, since the responsible firm is held liable for the entire loss whatever her behavior was in the conduct of the operations that had led to damages. The firm has thus incentives to use all the available means to reduce expected losses. On the contrary, *Negligence* rule is only effective for probability reduction: since the injurer is not held liable if she complied with a standard of due care, only her level of prevention matters. Her level of activity has no influence on the Court's decision to hold her liable or not. Thus, it would be worth developing an experiment to test such differences in firm's incentives in managing potential damages to third parties.

An adequate adaptation of the present experiment could also provide empirical arguments for a number of long lasting theoretical debates in the Law and Economics and Incentive Regulation literature. For instance, one could test the effectiveness of extended liability,[35] and also whether the risk of an accident is better controlled with *ex-ante* instruments (standard regulation implemented by agencies) or with *ex-post* instruments (liability rules, enforced by Courts of Law).[36]

[34]See Segerson (2002) for informal arguments and Shavell (1980) for formal ones.

[35]See Pitchford (1995) or Hiriart and Martimort (2006a) and the references therein.

[36]See Shavell (1984a), Kolstad, Ulen and Johnson (1990), or Hiriart, Martimort and Pouyet (2008, 2010).

References

Alberini, A., and Austin, D. H. (1997). "On and off the Liability Bandwagon: Explaining State Adoptions of Strict Liability in Hazardous Waste Programs", *Resources for the Future, Discussion paper 98–08.*

Alberini, A., and Austin, D. H. (1998). "Strict Liability as a Deterrent in Toxic Waste Management: Empirical Evidence from Accident and Spill Data", *Resources for the Future, Discussion paper 98–16.*

Alberini, A., and Austin, D. H. (1999). "Accidents Waiting to Happen: Liability Policy and Toxic Pollution Releases", *Resources for the Future, Discussion Paper 99–29.*

Alberini, A., and Austin, D. H. (2001). "An Analysis of the Preventive Effect of Environmental Liability." Study commissioned by DG ENV of the European Commission.

Binswanger, H. (1980). "Attitudes toward risk: Experimental measurement in rural India", *American Journal of Agricultural Economics* 62: 395–407.

Binswanger, H. (1981). "Attitudes toward risk: Theoretical implications of an experiment in rural India", *Economic Journal* 91: 867–890.

Brennan, G., Gonzales, L. G., Güth, W., and Levati, M. V. (2008). "Attitudes toward private and collective risk in individual and strategic choice situations", *Journal of Economic Behavior and Organization* 67: 253–262.

Dohmen, T., Falk, A., Huffman, D., Sunde, U., Schupp, J., and G., W.G. (2005). "Individual risk attitudes: New evidence from a large, representative, experimentally-validated survey." *Discussion paper 511, DIW Berlin.*

Dopuch, N., and King, R. R. (1992). "Negligence versus strict liability regimes in auditing: an experimental investigation", *The Accounting Review*, 67: 97–120.

Dopuch, N., Ingberman, D., and King, R. R. (1997). "An experimental investigation of multi-defendant bargaining in 'joint and several' and proportionate liability regimes", *Journal of Accounting and Economics*, 23: 189–221.

Faure, M., and Skogh, G. (2003). "The Economic analysis of Environmental Policy and Law", Edward Elgar Publishing.

Fischbacher, U. (2007). "Z-Tree: Zurich toolbox for ready-made economic experiments", *Experimental Economics*, 10: 171–178.

Greiner, B. (2004). "An Online Recruitment System for Economic Experiments", *Forschung und wissenschaftliches Rechnen 2003*, Kurt Kremer, Volker Macho (eds), GWDG Bericht 63, Goettingen: Ges. fuer Wiss. Datenverarbeitung, 79–93.

Hiriart, Y., and Martimort, D. (2006a). "The Benefits of Extended Liability", *Rand Journal of Economics* 37: 562–582.

Hiriart, Y., and Martimort, D. (2006b). "Liability Rules and Regulation for Environmentally Risky Ventures", in *Frontiers in the Economics of Environmental Regulation and Liability*, Boyer, Hiriart, Martimort (eds), Ashgate.

Hiriart, Y., Martimort, D., and Pouyet, J. (2008). "The Regulator and the Judge: The Optimal Mix in the Control of Environmental Risk", *Revue d'économie Politique*, 119: 941–967.

Hiriart, Y., Martimort, D., and Pouyet, J. (2010). "The Public Management of Environmental Risk: Separating Ex-Ante and Ex-Post Monitors", *Journal of Public Economics*, 94: 1008–1019.

King, R., and Schwartz, R. (1999). "Legal penalties and audit quality: an experimental investigation", *Contemporary Accounting Research* 16(4).

King, R., and Schwartz, R. (2000). "An experimental investigation of auditors' liability: implications for social welfare and exploration of deviations from theoretical predictions", *The Accounting Review*, 75: 429–451.

Kolstad, C., Ulen, T., and Johnson, G. (1990). "Ex-post Liability for Harm vs. Ex-Ante Safety Regulation: Substitutes or Complements", *American Economic Review*, 80: 888–901.

Kornhauser, L., and Schotter, A. (1990). "An experimental study of single-actor accidents", *Journal of Legal Studies*, 19(1): 203–233.

Leland, H., and Pyle, D. J. (1977). "Informational Asymmetries, Financial Structure and Financial Intermediation", *The Journal of Finance*, 32: 381–387.

Newman, H., and Wright, D. (1990). "Strict Liability in a Principal-Agent Model", *International Review of Law and Economics*, 10: 219–231.

Niederle, M., and Vesterlund, L. (2007). "Do women shy away from competition? Do men compete too much?", *The Quaterly Journal of Economics*, 122: 1067–1101.

Pitchford, R. (1995). "How Liable Should a Lender Be? The Case of Judgment-Proof Firms and Environmental Risks", *American Economic Review*, 85: 1171–1186.

Posner, R. A. (1992). "Economic Analysis of Law", Little, Brown and Company, Fourth edition.

Segerson, K. (2002). "Economics and Liability for Environmental Problems", Ashgate.

Shavell, S. (1980). "Strict Liability versus Negligence", *Journal of Legal Studies*, 9: 1–25.

Shavell, S. (1984a). "A Model of the Optimal Use of Liability and Safety Regulation", *RAND Journal of Economics*, 15: 271–280.

Shavell, S. (1984b). "Liability for Harm versus Regulation of Safety", *Journal of Legal Studies*, 13, 357–374.

Shavell, S. (1986). "The Judgment Proof Problem", *International Review of Law and Economics*, June, 6: 45–58.

Shavell, S. (2004). "Foundations of Economic Analysis of Law". Cambridge, Mass.: Harvard University Press.

Slovic, P. (2000). "The perception of risk". Earthscan Publications.

Viscusi, K. (2007). "Regulation of health, safety, and environmental risks", *Handbook of Law and Economics*, volume I, edited by A. Mitchell Polinsky and Steven Shavell, Elsevier.

Wittman, D., Friedman, D., Crevier, S., and Braskin, A. (1997). "Learning liability rules", *Journal of Legal Studies*, 26: 145–164.

Appendix A

Risk-aversion. Let us now assume that the firm is risk-averse and her preferences are reflected by a CARA utility function: $u(x) = \frac{1-e^{-rx}}{r}$, where the parameter $r > 0$ measures the absolute risk aversion and x is a monetary payoff.

Social optimum. Prevention is socially optimal as long as:

$$p_1 u(w_t - h - c) + (1 - p_1)u(w_t - c) \geq p_0 u(w_t - h) + (1 - p_0)u(w_t),$$

a condition that can be rewritten as:

$$c \leq \frac{1}{r} * \ln\left(\frac{1 - p_0 + p_0 e^{rh}}{1 - p_1 + p_1 e^{rh}}\right). \tag{4}$$

No Liability. The firm chooses to invest in prevention as long as:

$$p_1 u(w_t - c) + (1 - p_1)u(w_t - c) \geq p_0 u(w_t) + (1 - p_0)u(w_t),$$

a condition that boils down to $u(w_t - c) \geq u(w_t)$ and that, obviously, never holds true. Hence, the firm never invests in safety in the absence of liability.

Strict Liability. The firm chooses to invest in prevention as long as:

$$p_1 u(w_t - \min\{h, w_t\} - c) + (1 - p_1)u(w_t - c) \geq p_0 u(w_t - \min\{h, w_t\}) + (1 - p_0)u(w_t),$$

a condition that can be rewritten as:

$$c \leq \frac{1}{r} * \ln\left(\frac{1 - p_0 + p_0 e^{r \min\{h,w_t\}}}{1 - p_1 + p_1 e^{r \min\{h,w_t\}}}\right). \tag{5}$$

Comparing (4) and (5), it is straight to see that the firm will take the socially optimal decision if she is wealthy enough, i.e. if her wealth w_t is sufficient to cover harm h.

Negligence. The firm chooses to invest in prevention as long as:

$$p_1 u(w_t - c) + (1 - p_1)u(w_t - c) \geq p_0 u(w_t - h) + (1 - p_0)u(w_t),$$

a condition that can be rewritten as:

$$c \leq \frac{1}{r} * \ln\left(1 - p_0 + p_0 e^{r \min\{h,w_t\}}\right). \tag{6}$$

Comparing (5) and (6), we can show easily that the former is more demanding than the latter: the firm is induced to exercise care for a larger set of parameters when submitted to Negligence rather than Strict Liability.

Hence, the qualitative theoretical results obtained with a risk-neutral firm do not change when moving to the risk-aversion case. In particular, for the set of parameters (w_t, h, p_0, p_1) that characterize our experimental setting, a risk-averse firm should behave as a risk-neutral one both under *No Liability* and under *Negligence*: for every $r > 0$, she should *not invest* in safety in the former regime and *invest* in the latter. Under *Strict Liability*, a risk-averse firm should *invest* in safety for each $r \in \{0, 9.65\}$, i.e. when she is not extremely risk averse.

Appendix B

Instructions – for the convenience of the referee, not for publication

Instructions Part I[37]

These instructions are identical to all 32 participants in the experiment.

Welcome and thank you for participating in this experiment. Please turn off your cell phones and stop communicating with other participants. Please raise your hand if you have any question. We will come to your cubicle and answer your questions in private.

This is the first part of the instructions. The second part will be distributed to you after you finish the following task.

You can earn your endowment by adding up two-digit numbers for five minutes. When you are done with one mathematical task, please click the "Continue"-button and a new mathematic task will appear on your screen. Only paper and pencil are allowed during Part I of the experiment.

The thirty participants who solve correctly the highest number of mathematical tasks will earn an endowment and hence the right to participate in Part II of the experiment. The remaining two participants will have to leave the laboratory and will receive 3 euros each.

If you have any questions, you may now raise your hand. If everything is clear, please click the "Continue"-button.

[37] Part I is identical for all treatments.

Instructions Part II

These instructions are identical to all 30 participants in the experiment.

Decision situation

This part of the experiment consists of two phases. Each phase consists of five periods. You will have to make a decision in every period. The decision you are asked to make is the same in each period. Phase 2 is a repetition of phase 1.

At the beginning of each phase, half of the participants will be randomly assigned to role *A*. The other half will be assigned to role *B*. Each participant *B* will be randomly paired with a participant *A*.

During each phase, participant *A* will make the decisions for the pair *A*-*B*. Participant *B* will be affected by *A*'s decisions. *B* will not be able to influence *A*'s decisions. At the beginning of each phase, *A* will receive an endowment of 40 ECU. *B* will receive an endowment of x ECU.[38] Notice that **6 ECU = 1 EURO**.

Whether you are *A* or *B* in one phase, will become clear only at the end of that phase. During a phase, everyone will decide as if they were participant *A*.

Your task

In each of the five periods of every phase, the following can happen to you with a probability of 5%:

– the phase ends;
– the participant assigned to you loses money.

Henceforth, we will call this "event".

In every period you can pay 1 ECU to reduce the event probability from 5% to 1%. You can only reduce your "own" event probability and this probability cannot be

[38] $x = 30$ for *low* damage treatments *NoL-low*, *SL-low*, and *Ne-low*; $x = 50$ for *high* damage treatments *NoL-high*, *SL-high*, and *Ne-high*.

influenced by the decisions made by other participants.

The following explanation will help you understand better the probability that the event occurs. Imagine two urns. Urn "5-b" contains 95 white balls and 5 black balls. Urn "1-b" contains 99 white balls and 1 black ball. The event occurs when a black ball is drawn. When a ball is drawn it is always put back into the urn, so that the contents of each urn is the same in each period. In each period you can choose one of the urns. If you choose urn "5-b", you do not have to pay anything. If you choose urn "1-b", you have to pay 1 ECU.

In each of the five periods of every phase you will be asked the following question: "Would you like to reduce the probability of the event to 1%?" If you answer with "No", you pay nothing and you choose urn "5-b". If you answer with "Yes", you pay 1 ECU and you choose urn "1-b".

Payoffs

At the end of each phase each participant will learn what role was randomly assigned to her. Apart from chance, only decisions of participant *A* in this phase will affect the payoff of each pair *A*-*B*. Decisions of participant *B* will become irrelevant.

If during the phase **the event does not occur** for participant *A*, *B*'s payoff will be equal to her initial endowment of x ECU. *A*'s payoff will be equal to 40 ECU minus her cost for probability reduction.

If **the event occurs** for participant *A* **in period t**, *B* will lose her initial endowment of x ECU.

The NoL treatments read: Hence, *B*'s payoff will be 0 ECU. *A*'s payoff will be 40 ECU minus her cost for probability reduction until period t.

The SL treatments read: B will be compensated by *A* up to *A*'s wealth in **period t**.

SL-low reads: Hence, *B*'s payoff will be 30 ECU. *A*'s payoff will be 40 ECU minus her cost for probability reduction in this phase, minus the compensation payment made to *B*. **Example**: The event occurs in period t=5. *A* payed in all periods. Hence, *A* has 35 ECU left at the end of the phase. *B* loses 30 ECU, but is compensated by *A*. Payoffs: *A*: 40-5-30=5 ECU; *B*: 30 ECU.

SL-high reads: Hence, *B*'s payoff will be smaller or equal to 40 ECU. *A*'s payoff will be 0 ECU. **Example**: The event occurs in period t=5. *A* payed in all periods. Hence, *A* has 35 ECU left at the end of the phase. *B* loses 50 ECU, but is compensated by *A*. Payoffs: *A*: 0 ECU; *B*: 35 ECU.

The Ne treatments read: *A* and *B*'s payoffs will depend on whether *A* paid for probability reduction in period t. If ***A* paid in period t**, *B* will not be compensated. Hence, *B*'s payoff will be 0 ECU. *A*'s payoff will be 40 ECU minus the cost for probability reduction. **Example**: The event occurs in period t=5. *A* payed in all periods. Hence, *A* has 35 ECU left at the end of the phase. *B* loses x ECU. *B* does not get compensated by *A*. Payoffs: *A*: 35 ECU; *B*: 0 ECU.

Ne-low reads: If ***A* did not pay in period t**, *B* will be fully compensated by *A*. Therefore, *B*'s payoff will be 30 ECU. *A*'s payoff will be 40 ECU minus her cost for probability reduction, minus the compensation payment made to *B*. **Example**: The event occurs in period t=5. *A* payed in period t=1, but not in the other periods. Hence, *A* has 39 ECU left at the end of the phase. *B* loses 30 ECU. *A* has to compensate *B* since *A* did not pay in period t=5. Payoffs: *A*: 39-30=9 ECU, *B*: 30 ECU.

Ne-high reads: If ***A* did not pay in period t**, *B* will be compensated by *A* up to *A*'s wealth in period t. Therefore, *B*'s payoff will be smaller or equal to 40 ECU. *A*'s payoff will be 0. **Example**: The event occurred in period 5. *A* payed in period 1, but not in the other periods. Hence, *A* has 39 ECU left at the end of the phase. *B* loses 50 ECU. *A* has to compensate *B* since *A* did not pay in period t=5. Payoffs: *A*: 0 ECU , *B*: 39 ECU.

All treatments read: Phase 2 is a repetition of phase 1. At the beginning of phase

2, new random draws of roles and pairs will be made. Therefore, they will be independent from those made at the beginning of phase 1. The final payoff of each participant is **either** her payoff from phase 1 **or** from phase 2 converted in euros. At the end of the experiment, one of the two phases will be selected for payment at random (with equal probability). Additionally you will receive a show-up fee of **2,50** euros.

Feedback

At the end of each period you will learn whether the event occurred for you. If the event did not occur, the current phase will continue with the next period. If the event did occur, the current phase will end for you. Please stay at your place until the phase ends for all participants.

Additional feedback will be given on the number of events that occurred to other 14 participants in the experiment. Let us call this group "your feedback group". The other participant in your pair does not belong to your feedback group.

Overview of the sequence of events in each phase

- Each participant is assigned to either role *A* or role *B*.
- Each *B* is assigned to one *A*.
- *A* receives 40 ECU and *B* receives x ECU as their initial endowment.
- At first, participants do not know their roles.
- All participants always make decisions as if they were *A*.
- After each period, participants learn whether the event occurred for themselves and for participants in their feedback group.
- At the end of each phase, participants learn their roles.

- If in this phase the event did not occur for the participant who was randomly selected as *A*, then *A*'s payoff is 40 ECU minus her cost for probability reduction. Participant *B* in the same pair keeps her initial endowment of x ECU.

- If in this phase the event occurred for the participant who was randomly selected as *A*, then participant *B* in the same pair loses her initial endowment of x ECU. *The NoL treatments read*: *A*'s payoff is 40 ECU minus her cost for the event probability reduction. *B*'s payoff is 0. *The SL treatments read: B* is compensated by *A* up to *A*'s wealth in the period in which the event occurred. *The Ne treatments read:* Payoffs for *A* and *B* depend on whether *A* paid for probability reduction in the period when the event occurred.

- *All treatments read*: Whether an event occurred for the participant randomly selected as *B*, is irrelevant for her pair *A*-*B*.

Calculator

In each period you may help yourself with the "calculator" on your screen (see picture below). It can calculate the probability for the event to occur **between the period that you are in and the the last period of the phase**. This probability depends on the number of the remaining periods and on your decisions in each of the remaining periods. Imagine tossing a coin. If you toss the coin only once, you have a 50% chance of not getting heads. But if you toss the coin five times in a row, the chance of never getting heads is lower than 50%. **Example**: You are in period t=4 and want to know the probability that the event will occur before the end of the phase. For this purpose, you need to enter your planned decisions for periods t=4 and t=5 into the calculator. The calculator will tell you the probability for the event to occur and the complementary probability for the event not to occur in one of the periods t=4 or t=5.

Calculator for round 4

Round	Would you like to reduce the probability?
4	Yes o o No
5	Yes o o No

The probability that the event occurs is …%.
The probability that the event does not occur is…%.

Control questions and post-experimental questionnaire

Before Part II of the experiment starts, we will ask you to answer a few questions which will help you better understand the instructions. Questions that you answer wrongly will reappear on your screen until you answer them correctly.

At the end of the experiment, we will ask you to complete another short questionnaire.

If you have any questions, you may now raise your hand. If not so, please click the "Continue"-button.

Appendix C

Risk attitude	*NoL-low*		*NoL-high*		*SL-low*		*SL-high*		*Ne-low*		*Ne-high*	
	Investment	N	Investment	N	Investment	N	Investment	N	Investment	N	Investment	N
0	1	1							1	2	1	1
1	0.80	3							0.94	2	0.70	2
2	0.78	5	0.75	3	0.73	4	0.54	5	0.72	8	0.97	6
3	0.24	2	0.66	7	0.87	7	0.95	6	1	3	0.88	4
4	0.85	4	0.40	2	0.57	5	0.62	5	0.80	1	0.70	7
5	0.67	3	0.55	6	0.79	3	0.64	6	1	3	0.50	3
6	0.30	5	0.71	5	1	2	0.40	1	0.51	5	1	1
7	0.40	5	0.21	3	0.20	2	0.59	3	0.00	1	0.30	2
8	0.08	4	0.05	2	0.27	3	0.46	4	0.44	6	0.60	2
9									0.10	2	1	1
10									1	1	0.00	1

Table 6: Investment in safety by treatment and risk attitude

Note: Investment=Investment in safety; N=Number of subjects; Risk attitude: the higher the reported score, the lower the aversion to risk.