Self-Insurance And Liability Insurance Under Ambiguity

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Abstract

This paper provides an experimental test of the effects of tort rules on the demand for both insurance and self-insurance. More precisely, we examine the effects of risk and ambiguity under two different liability regimes: negligence rule and strict liability. The experiment relies on an original model of unilateral accident with civil liability. A potential injurer has an economic activity that can generate an accident. She can invest in self-insurance to decrease the magnitude of harm and to buy an insurance coverage for the potential claims for damages of any kind. To differentiate between risk and ambiguity, we successively assume that the probability of accident can be known perfectly or with imprecision; in the latter, we have recourse to the KMM approach (Klibanoff et al. (2005)). Our experimental results confirm that both ambiguity-loving and ambiguity-averse individuals provide the socially optimal level of self-insurance under the negligence rule, while the strict liability regime does not yield efficient incentives under ambiguity. Moreover, the experiment shows that under risk, strict liability and negligence rule are not equivalent in their deterrence effect, contrary to the predictions of the standard model.

Keywords: self-insurance, liability insurance, ambiguity, tort law

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1 Introduction

Liability is a legal rule that obligates a party who causes harm to make a repayment to the victim of the harm (Shavell, 1980, 2007). As liability rules set monetary constraints on those who harm others, they induce the potential injurers to provide care, to avoid accidents. In Europe, the Environmental Liability Directive (ELD) establishes a framework for environmental liability based on the "polluter pays" principle,intended to prevent and remedy damage to animals, plants, natural habitats, water resources, and damage affecting the land. With the ELD pure ecological damage is acknowledged and treated distinguishably from damage to property, economic loss and personal injury in the European Union.[1] Environmental damage is tackled with two different liability regimes, depending on the nature of the corporate activity. Strict liability can be held against operators whose occupational activities are listed in Annex III of the ELD. Other operators face negligence rule. This paper questions the efficiency of these liability regimes under the assumption that environmental damage can be described with ambiguity. Ambiguity is a concept introduced by Ellsberg's seminal article (1961). It relates to situations in which probability distribution of possible events is vague, dubious, uncertain (Cabantous and Smith, 2006; Camerer and Weber, 1992; Frisch and Baron, 1988). This imprecision of probabilities can come from an imperfect knowledge of the phenomenon at stake, or even a lack of statistical data. [2] Ambiguity characterizes partly environmental risk. For instance, Chakravarty and Kelsey (2012) highlight that in environmental accidents such as the British Petroleum Deepwater Horizon oil spill, corporations may not be able to form correct beliefs about the probability of an accident or to estimate the potential damages because of the insufficient information or time to assign precise probability to accident. [3] This feature of environmental damages drives to an in-depth discussion of the implications of an ambiguous context for the efficiency of liability regimes, particularly given the expansion of environmental liability in Europe.

Moreover, in recent years a market for corporate insurance coverage for environmental damages has been developed in Europe, given the implementation of the ELD. [4] Nevertheless, the development

[1] See Directive 2004/35/EC

[2] For a complete review of the descriptive models of ambiguity, see Camerer and Weber (1992) and Abdellaoui et al. (2011).

[3] For insights on the predictability of environmental risk, see also Michael Faure (2000).

[4] Report From The Commission To The Council, The European Parliament, The European Economic And Social Committee And The Committee Of The Regions Under Article 14(2) of Directive 2004/35/CE on the environmental

of the market for environmental liability coverage is heterogenous in Europe. [5] Hence, one can wonder what are the effect of different degrees of availability of liability insurance on the demand for prevention in this setting.

Focusing mainly on self-insurance in the sense of Ehrlich and Becker (1972) - prevention investments dedicated to loss reduction - this paper investigates two connected questions. From a positive perspective, we wonder what would be the specific effects of ambiguity and the availability of liability insurance on the demand for self-insurance for each liability regimes implemented by the ELD. From a normative perspective, we investigate which liability regime gives the better incentives to provide the socially optimal level of self-insurance under the assumptions of our model. In this paper, the socially optimal level of self-insurance is operationalized as the one that minimizes the expected social cost of an accident. Hence, this paper is primarily interested in the deterrence effect of the liability regimes, intended to minimizing the cost of preventing and remedying environmental damages.

In this work, we do not address the insolvency problem, although it may characterize environmental damage, and leave this particular issue for further research. We are particularly interested in the specific effect of ambiguity on self-insurance and insurance, since there are few theoretical papers on the effects of ambiguity on the deterrence function of liability regimes. Notable examples are Chakravarty and Kelsey (2012), Teitelbaum (2007) and Franzoni (2013). Regarding the substitution property between insurance and self-insurance, revealed in the seminal article by Ehrlich and Becker (1972), the literature developed relatively few extensions. Courbage (2001) show the robustness of the substitutability property under the dual theory of choice while Konrad and Skaperdas (1993) prove that most of the properties of self-insurance demand remain true with a rank-dependent expected utility. Meanwhile to our knowledge, none has theoretically studied these interactions under ambiguity. Consequently, this paper contributes to the literature on the economics of accident law and insurance.

From an empirical point of view, few articles study the substitutability property, always under risk. Carson et al. (2013) find empirical evidence for this substitution in the case of homeowner insurance and catastrophic risks. Pannequin et al. (2014), in an experimental setting, also cor-

liability with regard to the prevention and remedying of environmental damage /* COM/2010/0581 final */

[5] Survey Of Environmental Liability Insurance Developments, Insurance Europe, June 2014.

roborate this property but obtain an imperfect matching to the theory. This paper contributes to the experimental economics literature by proposing an original experimental design to test self-insurance and insurance behavior for different liability regimes under both ambiguity and risk. Few experiments can be found on liability rules. [6] Our experimental approach particularly builds upon the previous experiment by Angelova et al. (2014). Our experiment differs somewhat, as their study focuses on self-protection - an investment in prevention intended for reducing the accident probability, while we consider self-insurance, an investment that can reduce the magnitude of damages. Moreover, precautionary measures in their setting is modeled by a binary decision: either the agent invests a lump sum cost $c > 0$, either she does not invest. In our experiment, we allow for a wider range of investment possibilities in self-insurance. Contrary to Angelova et al., we do not deal with insolvency, but we introduce ambiguity and availability of liability insurance. The experiment relies on an original theoretical analysis, built upon the standard model of civil liability (Brown, 1989). A potential injurer has an economic activity that can generate an accident. He has the opportunity to invest in self-insurance in order to decrease the magnitude of harm and to buy an insurance coverage for the potential claims for damages of any kind. We introduce ambiguity in this framework, considering the probability of accident can be vague under some circumstances. The modeling of ambiguity relies upon Klibanoff, Marinacci and Mukerji (hereafter "KMM", 2005) and Snow (2010). We derive the demand for self-insurance under two different liability regimes, namely the strict liability and the negligence rule, and compare it to the social optimum.

The main finding derived from the experimental results is that strict liability and negligence rule are not equivalent in their deterrence effect. If one retains the criterium that a majority of individuals chooses the socially optimal level of prevention, negligence rule always meets this requirement, whereas the strict liability regime never does. This result holds for the four different characteristics of the decision context, which are the presence of risk or ambiguity on the one hand, the availability or not of liability insurance coverage on the other hand. This experimental result is particularly important regarding the literature on accident law.

Surprisingly, contrary to the traditional theoretical analysis of liability rules, in the simplest setting

[6] See King and Schwartz (1999,2000); Dopuch and King (1992); Dopuch et al. (1997); Wittman et al. (1997); Korhnauser and Schotter (1990).

with risk and unavailability of insurance, strict liability and negligence rule are not equivalent at the sample level. A majority of investments result in an over-provision under the strict liability regime, whereas a majority of investments are socially optimal under the negligence rule. Moreover, the introduction of liability insurance in the risk context does not affect the deterrence effect of the negligence rule, while the introduction of liability insurance drops the level of investment in prevention under strict liability, with a majority of decisions relating to an under-provision in self-insurance. Hence, from a normative perspective, the experiment shows that the negligence rule is preferred to the strict liability regime under risk, for different degrees of availability of liability insurance. From a positive perspective, this result provides evidence for the substitutability of insurance and self-insurance under strict liability.

Regarding the effect of ambiguity on the deterrence effect of these two liability regimes, the experimental results indicate that ambiguity does not affect the deterrence effect of the negligence rule. This result holds for different degrees of availability of insurance. Meanwhile, under strict liability, the behavior of the agents is more erratic and depends on attitudes towards ambiguity and availability of insurance.

The remainder of this paper is as follows. Section 2 introduces the assumptions and the behavioral predictions derived from the model. Section 3 presents the design and procedures of the experiment. Results are displayed and discussed in section 4. Section 5 ends the paper with some concluding remarks.

2 The model

2.1 The standard model of civil liability

Assumptions and notations Before presenting our model with self-insurance and liability insurance under ambiguity, we introduce the standard model of civil liability under risk. We consider a standard unilateral accident model. Let be a producer whose activity is likely to generate an accident. In this setting, the potential victim is not able to invest in preventive measures to decrease the probability or the magnitude of the accident. Only the producer can affect those latter parameters. Moreover, the producer is supposed to be not harmed by the accident.

When an accident occurs, the magnitude of damages is a function of a, the investment in self-insurance. The level of damages is noted $x(a)$ with $x'(a) < 0$ and $x''(a) > 0$. These conditions on $x(a)$ induce that the more the agent invests in self-insurance, the lower are the potential damages on the one hand; the returns to scale of self-insurance being decreasing on the other hand. We also suppose $-x'(a) > 1$, which requires that the marginal cost of self-insurance (equal to 1) is inferior to the marginal decrease in damages $-x'(a)$.

The producer is supposed to operate on a market with imperfect competition. The technology of production on this market gives a gross return $W_0 > 0$, which one can interpret as the initial level of wealth of the producer. [7] We suppose that the producer is not exposed to an insolvency issue in the event of an accident. To rule out this possibility, we suppose $W_0 - x(0) \geqslant 0$, which means that the producer can cover the damages with her assets even if she has not previously invested in self-insurance.

When the probability of accident is known, this probability is noted q. When an accident occurs, the producer can be submitted to a liability rule that obligates a party who causes harm to make a repayment to the victim of the harm (Shavell, 1980, 2007). Therefore, the level of wealth of the producer is noted $W_N = W_0 - a - pI$ when no accident occurs, and $W_A = W_0 - a - pI + h(a, I)$ in case of accident, with $h(a, I)$ a function describing the result of the liability rule and the insurance policy. The decision-maker can purchase an amount of insurance I at price p. He receives an indemnity I in case he is held liable for an accident. We limit the insurance coverage I to a maximum amount equal to $x(a)$ to ensure that the producer has no incentive to encourage occurrences of accidents.

Liability regimes Under the strict liability rule, the injurer is liable under all circumstances, no matter if he is at fault or not. Therefore, $h(a, I) = -x(a) + I$. When an accident occurs, the producer has to compensate the victim for the harm $x(a)$, but the insurance can cover this extra cost with an indemnity I. The last liability scheme is the negligence rule where the victim bears the cost of accident unless the injurer is found negligent. Negligence lies in the insufficiency of investment a in prevention compared to a legal standard $\bar{a}$. Therefore, for $a < \bar{a}$, $h(a, I) = -x(a) + I$ and for $a \geqslant \bar{a}$, $h(a, I) = 0$. The legal standard $\bar{a}$ in this setting is equal to the socially optimal level of self-insurance, noted a^s. The level of self-insurance is such that it minimizes the total social

[7] In this paper we do not endogenize the output level of the producer and her decision to enter the market.

cost of accident $SC(a) = qx(a) + a$, which means that a^s is such that $\frac{1}{q} = -x'(a^s)$.

Expected utility Individual preferences are supposed to be characterized by a utility function $U(W)$ with $U'(W) > 0$ and $U''(W) < 0$ for risk-averse agents and $U''(W) = 0$ for risk-neutral agents.[8] Therefore the expected utility of the agent depends on self-insurance a and insurance I and can be written

$$EU(a, I; q) = (1 - q)U(W_0 - a - pI) + qU(W_0 - a - pI + h(a, I))$$

In this setting, the insurer is assumed to be risk neutral and to charge an actuarial price of insurance. Insurance market is assumed to be competitive, there is no profit, while transaction costs are neglected. As a consequence, the price of insurance p is actuarial and equal to the probability of accident q. The expected utility can then also be written

$$EU(a, I; q) = (1 - q)U(W_0 - a - qI) + qU(W_0 - a - qI + h(a, I)) \quad (1)$$

2.2 Modeling ambiguity in the standard model of civil liability

Evaluation function of the expected utility under ambiguity In presence of ambiguity, the decision-maker is uncertain about the value of the propability of accident. This uncertainty is represented following the KMM model with a second-order probability distribution $F(\pi)$, where π is a possible value of the unknown probability. We can now write the expected utility

$$EU(a, I; \pi) = (1 - \pi)U(W_0 - a - pI) + \pi U(W_0 - a - pI + h(a, I))$$

We assume that the insurer has unbiased beliefs on the probability of accident on the one hand, and that he is risk-and-ambiguity neutral on the other hand. Moreover, we assume the price of insurance to be actuarial in the experimental setting. Therefore, the price of insurance p is fixed

[8]We do not model the behavior of risk loving agents in this paper. Risk lovers typically arbitrate between full insurance and risk retention as documented in Pannequin et al. (2014).

and equal to the prior q in the ambiguity context. The expected utility can be rewritten

$$EU(a, I; \pi) = (1 - \pi)U(W_0 - a - qI) + \pi U(W_0 - a - qI + h(a, I)) \qquad (2)$$

In presence of ambiguity, the expected utility at π of the decision-maker is evaluated by a function ϕ with $\phi'(.) > 0$, with $\phi''(.) = 0$ for an ambiguity-neutral agent, $\phi''(.) < 0$ for an ambiguity-averse agent and $\phi''(.) > 0$ for an ambiguity-loving agent. Based on Snow (2011), we make the assumption that the agent has unbiased beliefs i.e. $E_F[\pi] = q$. This assumption allows to disentangle the effect of beliefs and the effect of attitudes towards ambiguity on the agent's behavior.
Therefore, the expected utility of an ambiguity-averse or ambiguity-loving agent can be written

$$E_F[\phi\left(EU(a, I; \pi)\right)] \qquad (3)$$

Whereas the expected utility of an ambiguity-neutral agent is

$$(1 - E_F(\pi))U(W_0 - a - qI) + E_F(\pi)U(W_0 - a - qI + h(a, I))$$

Indeed, when the agent is ambiguity neutral, $\phi(.)$ is a linear function. Consequently, under the assumption of unbiased beliefs on the probability of accident, the evaluation under ambiguity of the expected utility of an ambiguity-neutral agent becomes

$$(1 - q)U(W_0 - a - qI) + qU(W_0 - a - qI + h(a, I))$$

Choices of an ambiguity-averse and an ambiguity-loving agent It is straightforward to see that the decisions of the ambiguity-neutral agent are identical under risk and ambiguity. Concerning the ambiguity-averse agent, to compare the self-insurance and insurance choices under risk and ambiguity, we apply the proposition by Rothschild and Stiglitz (1970) according to which the expected value of any concave function of a random variable increases with a mean-preserving contraction, and decreases with a mean-preserving spread. Similarly, the expected value of any convex function of a random variable decreases with a mean-preserving contraction, and increases with a mean-preserving spread in the distribution of this random variable.

Let $(a*, I*)$ be the optimal decision of the agent under risk. If an increase in a (resp. I) at point $(a*, I*)$ results in a mean-preserving contraction in the distribution of the expected utility at point $(a*, I*)$, we know that $E_F[\phi(EU(a, I; \pi))]$ is increasing in a (resp. I) at point $(a*, I*)$. In this event, the agent is willing to increase her demand for a (resp. I) under ambiguity compared to risk.

The increase in a results in a mean-preserving contraction in the distribution of the expected utility at point $(a*, I*)$ if

$$\forall \pi,\ \frac{\partial^2 EU}{\partial a \partial \pi}|_{(a*,I*)} > 0$$

Indeed, under this condition at $\pi = q$, $EU'_a(a^*, I^*; \pi) = 0$, at $\pi > q$, $EU'_a(a^*, I^*; \pi) > 0$, and $\pi < q$, $EU'_a(a^*, I^*; \pi) < 0$. [9] Thus, for $\pi = q$ the mean EU is unchanged. For high values of the EU ($\pi < q$), an increase in a evaluated at point a^* decreases the EU. For low values of the EU ($\pi > q$), an increase in a evaluated at point a^* increases the EU. Then, $E_F[\phi\,(EU(a, I; \pi))]$ increases in a at a^*, which gives $E_F[\phi'(EU(a, I; \pi))\, EU'_a(a, I; \pi)] > 0$. In this case, this means that the ambiguity-averse agent is willing to invest in a higher amount of self-insurance a (resp. I) under ambiguity compared to risk, while the prior q is unchanged. Meanwhile, the ambiguity-loving agent is willing to decrease her demand for a (resp. I). Conversely, if $\forall \pi$, $\frac{\partial^2 EU}{\partial a \partial \pi}|_{(a*,I*)} < 0$, an increase in a (resp. I) at point $(a*, I*)$ results in a mean-preserving spread in the distribution of the expected utility. Hence, in this event an ambiguity-averse agent is willing to decrease her demand for a (resp. I) at point $(a*, I*)$ under ambiguity, while the ambiguity-loving agent is willing to increase her demand.

Social welfare function In this setting, we assume that the social planner is risk-and-ambiguity neutral on the one hand, and that he minimizes the expected social cost of accident $SC(a) = qx(a) + a$. Therefore, the socially optimal level of self-insurance is a^s $s.t.$ $\frac{1}{q} = -x'(a^s)$, both under risk and ambiguity. We also assume that the negligence rule sets a legal standard $\bar{a}$ equal to the social optimum a^s previously defined, both under risk and ambiguity.

However, it can be argued that both risk and ambiguity aversion could be included in the social welfare function, as shown by Franzoni (2014) and Teitelbaum (2007). We leave this question for further research. Nevertheless, these simplifying assumptions help us to create a reliable experi-

[9] At point $(a*, I*)$ and for $\pi = q$, $EU'_a(a^*, I^*; \pi) = 0$ corresponds to the first-order condition in the risky context.

mental setting. Indeed, they allow to create the same legal standard for negligence rule both in the risk and ambiguity treatments. Therefore, the amount of self-investment required to comply with the legal standard is the same in these two treatments. Hence, we can compare the results for the negligence rule regime under the risk and the ambiguity treatments. Indeed, in this experimental setting we are interested in how ambiguity modifies the demand for self-insurance, other things being equal.

3 Behavioral predictions

3.1 Demand for self-insurance and insurance under risk

We sum-up here the results of the standard model of civil liability. These behavioral predictions under risk are derived from equation (**??**). Details are given in appendix **??**. As explained in section **??**, these results also hold under ambiguity for the ambiguity-neutral agent.

H1: Equivalent deterrence effect of strict liability and negligence rule In a risk context, both risk-neutral and risk-averse individuals invest in the same amount of self-insurance. The level of investment is equal to the socially optimal level of self-insurance a^s. This result holds under both availability and unavailability of insurance, if the price of insurance is set at the actuarial level q when insurance is available. Hence, the introduction of the opportunity to buy insurance coverage does not modify the deterrence effect of both liability regimes, when the price of insurance is actuarial.

H2: Differences in demand for insurance coverage In a risk context, if the strict liability regime is implemented, a risk-averse individual has a full insurance coverage such that her demand I^* is equal to $x(a^*)$, the potential level of damages she would face in the event of an accident, given she takes the socially optimal level of self-insurance investment. On the contrary, a risk-neutral agent is indifferent to her level of insurance coverage, and her demand $I^* \in [0; x(a^*)]$ under strict liability. If the negligence rule is implemented, both the risk-neutral and the risk-averse individuals choose a null insurance coverage $I^* = 0$.

3.2 Demand for self-insurance and insurance under ambiguity

We present the result of our model which introduces ambiguity in the standard model of civil liability, and we consider alternatively the availability and the unavailability of insurance coverage. These behavioral predictions correspond to the theoretical results for the ambiguity-averse and the ambiguity-loving individuals. These results are derived from equation (**??**). Details of computation are given in appendices **??** and **??**.

H3: Differences in the deterrence effect of the liability regimes

H3Av: Ambiguity-averse individual The strict liability regime induces an overprovision of self-insurance. On the contrary, the negligence rule induces a socially optimal level of investment in self-insurance. This result holds both for the risk-averse and risk neutral individuals, and both for availability and unavailability of insurance purchase.

H3Lv: Ambiguity-loving individual The strict liability regime induces an underprovision of self-insurance. This result holds both for the risk-averse and risk neutral individuals, and both for availability and unavailability of insurance purchase. The results are undetermined under the negligence rule.

H4: Differences in the demand for insurance coverage

H4Av: Ambiguity-averse individual Similarly to the demands in risk context, the demand for insurance is null under negligence rule. On the contrary, if the strict liability regime is implemented, the demand for insurance increases compared to the risk context and is positive, both for risk-averse and risk-neutral individuals.

H4Lv: Ambiguity-loving individual If the strict liability regime is implemented, the demand for insurance decreases compared to the risk context. The results are undetermined under the negligence rule.

4 Experiment

The objective of this experiment is to test the theoretical predictions of our model. Therefore, the experiment consists of three parts. The first part is dedicated to the measure of attitudes towards risk and ambiguity. The second part brings a choice laboratory situation that reproduces the features of the theoretical model. The third part collects data on the socio-demographic characteristics and other control variables.

Attitudes towards risk and ambiguity To measure the attitudes towards risk and ambiguity, we used a multiple price list procedure *à la* Holt and Laury (2002; 2005) and Chakravarty and Roy (2009). The attitudes towards risk and ambiguity are measured with an ordinal variable between 0 and 11. The higher this coefficient is, the more risk or ambiguity averse the subject is. The individual is neutral towards risk or ambiguity for a coefficient equal to 6 or 7 (see table **??** in appendix **??**.) The subjects could randomly begin with the elicitation of attitudes towards risk or ambiguity. This sequence, involving the two multiple price lists, was randomly selected by the computer. At the beginning of this first part of the experiment, it was announced that the players could win up to 10 euros in this section. The computer would select randomly one of the decisions that the player had taken during this part. The result of this draw was communicated at the end of this part of the experiment for each participant and the gains were disclosed at the end of the experiment.

Liability game The second part of the experiment consisted of a series of decisions split into two groups, one group corresponding to negligence rule ("NR" treatment), and the other group corresponding to strict liability ("SL" treatment). We implemented eight different treatments, which differ in the liability regime (NR or SL), the availability or unavailability or insurance ("I" and "NI") and finally the presence of risk or ambiguity ("RK" and "AM"). Each treatment was repeated three times in a row. All treatments were played by all participants. However, the appearance order of the treatments was randomly selected by the computer to eliminate any order bias. The computer selected either the participant would begin with the negligence rule decisions group or the strict liability. Once a group was chosen, the participant had to play all the possible treatments of this group before being allowed to play with the other decisions group. Then, for each of these groups, the computer chose randomly and independently for each group either to begin with availability or unavailability of insurance. Finally, for each of these latter case, the computer randomly and independently selected to begin with risk or ambiguity. This way we collected 24 self-insurance decisions and 12 insurance decisions per participant.

In each of the three decision periods, with a probability of 10% in the RK treatment and with a probability $\pi \in \{0\%; 10\%; 20\%\}$ in the AM treatment, an accident would occur and result in a loss for the participant, depending on the treatment and her self-insurance and insurance choices. It was explained to the participants that they exercised an activity that was exposed to a 10% risk (RK) or an *a priori* unknown probability (AM) to generate an accident. They were told that if the accident occurred, the environment would suffer damages and that they would have to pay compensations, resulting in a loss in their wealth. At the beginning of each decision period, participants were endowed with 10,000 Experimental Currency Units (ECU). 10,000 worth 10 euros. When an accident occurred, the participant could lose her entire wealth if she had not invested in self-insurance or insurance. In each period, the participant made her self-insurance and insurance choices.

After these choices were made, the occurrence of the accident was simulated with a draw from an urn and the participant was informed whether she generated an accident or not. To simulate risk and ambiguity, we used draws from an urn. The description of the urn was common to both treatments RK and AM: " *A ten different color balls urn is used for the lottery. These balls can be colored in red, black, blue or yellow. The urn contains: 1 red ball; 7 yellow balls; 2 balls whose color is unspecified but which can be both blue or both black, or one black and one blue.*"

In RK treatments, we completed this description followingly: "*A draw will take place. If the red ball is picked, an accident occurs. The accident probability is therefore 10 %.*" In AM treatments, it was not the draw of the red ball which generated accident. The participant was asked to pick between the colour blue and the colour black. If she picked colour blue and a blue ball was drawn by the computer, an accident occured. If a different colour was drawn, there was no accident. The same holds for the black colour. Given the previous description of the urn, there are consequently three possible urns. The description of these urns was given to the participants (see table **??**).

The participants had to choose their level of self-investment in each decision period with the help of a decision table, providing them ten possible different levels from 0 ECU to 1,000 ECU. The more one invested in self-insurance, the less important the damage was, as shown in the table **??**. The effect of self-insurance on the environmental damage was identical between the SL and NR treatments. However, the corresponding loss in wealth for the participant differed as shown in table **??**. In the SL treatment, the individual loss equaled the damages. In the NR treatment, if the participant invested a positive amount equal or superior to 400, the loss in wealth was reduced to zero. If the level of self-insurance was inferior to 400, then the loss equaled the damages. This threshold was labelled as a "critical value" for the participants, and we did not mention the term of "legal standard" - we did not as well mention other terms refering to liability or a legal framework of any kind. Given the values of the parameters in this experiment, 400 is also the value of self-insurance that minimizes the social cost of accident.

When insurance was available, the participants could purchase insurance coverage up to the amount of possible loss they could suffer in the event of an accident. Table **??** displays the characteristics of the different insurance contracts the participants could choose.

Control variables At the end of the experiment, we collected socio-demographic data on the participants, and we gave a questionnaire aimed at measuring the degree of altruism and attitudes towards the environment. Our measures of altruism is based on the Schwartz theory of basic values (Schwartz, 2012) and especially on the version of the Schwartz survey used in the European Social Survey. This survey allows to distinguish between universalism and benevolence. Benevolence corresponds to the willingness to preserve and enhance the welfare of people with whom one is in frequent personal contact, whereas universalism is about the welfare of all people and nature. We measure attitudes towards the environment by constructing an ecocentric scale (see Milfont and Duckitt, 2010). This scale indicates the degree of concern or regret over environmental damage.

5 Results

5.1 Descriptive statistics

Sample We conducted the experiment between May and September 2015 at the École Normale Supérieure de Cachan, in the Paris area. Overall, 124 subjects participated in the experiment. Among the participants, 2 are removed from the data analysis because of the inconsistency of their behavior in the first part of the experiment. Indeed, an inconsistent behavior in this part of the experiment prevents from correctly eliciting their attitudes towards risk or ambiguity. Thus, the final sample contains 122 subjects. As each subject is asked to participate to each treatment with three decision periods, we collected 2,928 self-investment choices and 1,464 insurance choices. The summary statistics of the sample are displayed in table **??**. Table **??** shows the distribution of the risk and ambiguity attitudes in the sample under study. The sample contains 40.98% of risk-loving subjects, 47.54% of risk-neutral and 11.48% of risk-averse subjects. The sample contains 42.62% of ambiguity-loving subjects, 49.18% of ambiguity-neutral and 8.20% of ambiguity-averse subjects. Therefore, the average demand for self-insurance or insurance under risk will be mainly driven by risk-loving and risk-neutral attitudes, while under ambiguity, they will be driven mostly by ambiguity-loving and ambiguity-neutral attitudes.

General results The experiment reproduces the decision context of the theoretical model to understand the specific effects of ambiguity and availability of insurance on the deterrence effect of the liability regimes. In this setting, the social optimum is set at 400 ECU. At the sample level, figure **??** shows the average demand for self-insurance for the 8 different treatments of the experiment across each decision period. The average demand is superior to 400 for the SL-RK-NI and SL-AM-NI treatments. Meanwhile, the investment in self-insurance is below the social optimum in average under the other treatments, which are SL-RK-I, SL-AM-I and the negligence rule. Consequently, figure **??** points out that the combination of strict liability and unavailability of insurance leads to over-provision in average at the sample level, whereas the other treatments lead to under-provision. This figure seems to indicate that under strict liability, the introduction of insurance is a substitute to self-insurance both under risk and ambiguity.

Table **??** provides a more nuanced picture, by presenting the percentage of under-provision, over-provision and socially optimal decisions in the experiment. Table **??** shows that the percentage of socially optimal decisions is maximized with the negligence rule, other things being equal. Hence, if the objective is to maximize the number of socially optimal decisions, rather than the average level of investment, the negligence rule is the preferred liability regime. Negligence rule treatments produce a percentage of socially optimal decisions superior to 50% for each negligence rule treatments. That means that a majority of investment choices under the negligence rule is exactly equal to 400 ECU. Meanwhile strict liability fails to induce the subjects to invest this amount of 400 ECU. The probability of the subjects to invest in the socially optimal level of investment is below 50% in this case. The strict liability treatments produce higher rates of over-provision choices, in the sense that the investment is greater than 400 ECU. The percentage of over-provision choices across the three decision periods is equal to 51.37%, 68.93%, 28.14% and 28.96% respectively for the "SL-RK-NI", "SL-AM-NI", "SL-RK-I" and "SL-AM-I" treatments, while it is equal to 3.55%, 4.10%, 2.19% and 4.37% respectively for the "NG-RK-NI", "NG-AM-NI", "NG-RK-I" and "NG-AM-I".

Consequently, these descriptive statistics document the differences in the deterrence effect of the strict liability and the negligence rule for different decision contexts, characterized by the presence or absence of ambiguity and liability insurance. They show that differences in deterrence effect particularly appear in the absence of any opportunity to buy insurance coverage. In our sample, if one wants to maximize the average amount of self-insurance, strict liability is preferred to negligence rule in the absence of liability insurance. This result holds both under risk and ambiguity. When liability insurance is available, both under risk and ambiguity, if one wants to maximize the average amount of self-insurance, there is an equivalence between the strict liability and the negligence rule. This result holds both under risk and ambiguity. On the contrary, in this sample, if one wants to maximize the percentage of socially optimal decisions, the negligence rule is preferred to the strict liability regime, whatever is the opportunity of insurance coverage and the degree of ambiguity.

Concerning the demand for liability insurance, figure **??** shows that in average, the demand for insurance coverage is higher in the strict liability treatments than under the negligence rule treatments. Figure **??** completes this graphical analysis with the density of the demand for insurance coverage by treatment. Figure ?? indicates that a majority of null insurance coverage is observed in the negligence rule, whatever is the degree of ambiguity. Whereas the distribution of the demand for insurance coverage is more spread in the strict liability treatments, both under the risk and the ambiguity treatments.

Nevertheless, these results may be due to the particular composition of this sample, as displayed in table ??. Indeed, in this sample, risk-neutral, risk-loving, ambiguity-neutral and ambiguity-loving subjects are over-represented, with only 11.48% of risk-averse and 8.20% of ambiguity-averse subjects in the sample. Consequently, we test now the differences in the demand for self-insurance and insurance by differentiating between the attitudes towards risk and ambiguity.

5.2 Test of the deterrence effect of the liability regimes under risk

In a risk context, our data set shows that the strict liability and the negligence rule are not equivalent. The negligence rule maximizes the number of socially optimal decisions among both risk-neutral and risk-averse individuals. Hypothesis H1 declares the equivalence between both liability regimes, both for the risk-averse and risk-neutral individuals, in the presence or absence of the opportunity to purchase insurance coverage. Particularly, H1 states that both liability regimes lead to the socially optimal level of self-insurance. To examine this behavioral prediction, table ?? displays the summary statistics for the propensity to adopt a socially optimal level of self-insurance. Meanwhile, table ?? completes this analysis with a sign test of the demand for self-insurance conditional on treatment and risk-attitudes.

Provision of self-insurance by the risk-neutral subjects Concerning the risk-neutral subjects, table ?? shows that for "SL-RK-NI" the median of the differences between the demand for self-insurance and the socially optimal level 400 ECU is significantly positive at 90% confidence level. Hence, in the "SL-RK-NI" treatments, most of the choices of the risk-neutral agents over-provides or provides the socially optimal level of self-insurance. Meanwhile, for the risk-neutral agent, other treatments have a significant negative difference in median at 99% confidence level. Thus, "SL-RK-I", "NG-RK-NI" and "NG-RK-I" mostly induce under-provision or socially optimal decisions. Consequently, under the strict liability regime, the introduction of liability insurance decreases the average demand for self-insurance ie. the average demand is higher under "Sl-RK-NI" than under "SL-RK-I". The introduction of liability insurance modifies the deterrence effect of the strict liability regime for the risk neutral individuals.

This latter result contradicts the theoretical prediction for risk-neutral subjects. Indeed, risk-neutral subjects are supposed to maintain their self-insurance at the socially optimal level, whatever is the availability of insurance. Given these results, when facing risk-neutral individuals, to maximize the number of socially optimal decisions, it would be preferrable to implement the negligence rule, while to maximize the average demand for self-insurance, it is preferrable to implement strict liability with unavailability of insurance.

Provision of self-insurance by the risk-averse subjects Concerning the risk-averse subjects, table **??** shows that with 99% confidence, we can reject the hypothesis that the median of the self-insurance demand equals the socially optimal level for treatments "SL-RK-NI" and "NG-RK-I". "SL-RK-NI" leads to a majority of over-provision or socially optimal decisions while "NG-RK-I" leads to a majority of under-provision or socially optimal decisions for the risk-averse subjects. Table **??** indicates that the percentage of socially optimal decisions equals 4.8% for "SL-RK-NI" and 59.5% for "NG-RK-I". Therefore, the risk-averse subjects provide in majority the socially optimal level of self-insurance under "NG-RK-I" and over-provide under "SL-RK-NI".

On the contrary, we cannot reject the hypothesis that the median demand equals the socially optimal level for treatments "SL-RK-I" and "NG-RK-NI". This does not mean that a majority of decisions are socially optimal for both treatments, but rather than the distribution is equally distributed around the median. Indeed, table **??** shows that the risk-averse subjects provide in majority the socially optimal level of self-insurance under "NG-RK-NI" (88.1%) but not under "SL-RK-I" (21.4%).

Consequently, the risk-averse subjects over-provide under the strict liability treatments - particularly in the absence of insurance, while they provide in majority the socially optimal level under the negligence rule. The deterrence effect of the strict liability and the negligence rule is different for the risk-averse subjects, contrary to the theoretical predictions.

Provision of self-insurance by the risk-loving subjects Table **??** also provides the experimental results for risk-loving subjects. It indicates that the risk-loving subjects have a probability to adopt the socially optimal level of self-insurance superior to 50% under the negligence rule treatments. Meanwhile, this probability is significantly inferior to 50% under the strict liability treatments. Hence, the strict liability regime performs less than the negligence rule for any observable risk-attitude.

5.3 Test of the deterrence effect of the liability regimes under ambiguity

Hypothesis H3 predicts differences in the deterrence effects of liability regimes under ambiguity depending on the attitudes towards ambiguity. Particularly, for the ambiguity-averse individual, the strict liability regime is supposed to induce an overprovision of self-insurance. While for the ambiguity-loving individuals, the strict liability regime is supposed to induce an underprovision of self-insurance. To test these predictions, we run a sign test, which results are displayed in table **??**. We complete this analysis with summary statistics on the number of socially optimal investments in self-insurance presented in table **??**.

Strict liability and ambiguity-averse subjects Table **??** shows, concerning the ambiguity-averse subjects, that the median of the demand for self-insurance is superior to the socially optimal level of 400 ECU for the treatment "SL-AM-NI". Therefore, a majority of ambiguity-averse subjects either over-provides or provides the socially optimal level of self-insurance under "SL-AM-NI". Table **??** indicates that the percentage of socially optimal decision in this case is significantly below 50%. Thus, the ambiguity-averse subjects over-provide under "SL-AM-NI".
Meanwhile, the sign test does not provide significative results for the treatment "SL-AM-I". The demand for self-insurance is equally distributed around the socially optimal level of 400 ECU. However, only a small percentage of subjects invest in this level of self-insurance under "SL-AM-I": table **??** indicates that the percentage of socially optimal decision equals 3.3%.
Consequently, under strict liability, the ambiguity-averse subjects over-provide self-insurance if insurance is not available, meanwhile the distribution of the demand is flat if insurance is avail-

able. These experimental results confirm our theoretical predictions in the absence of insurance opportunity but they do not correspond to our expectations in the presence of insurance.

Strict liability and ambiguity-loving subjects Concerning the ambiguity-loving subjects, table **??** confirms that the ambiguity-loving subjects under-provide self-insurance under the "SL-AM-I" with a median of the demand for self-insurance statistically below the threshold of 400 ECU. Nevertheless, this median of the demand is superior to the socially optimal level of 400 ECU for the "SL-AM-NI" treatment. Moreover, table **??** confirms that the strict liability leads to a probability of choosing the socially optimal level inferior to 0.5 at a 95% level of confidence for the ambiguity-loving subjects. Hence, the ambiguity-loving subjects under-provide care under "SL-AM-I" and over-provide under "SL-AM-NI". This overcompliance of ambiguity-loving subjects under "SL-AM-NI" contradicts our theoretical predictions, while our theoretical predictions are confirmed in presence of insurance.

Negligence rule under ambiguity Concerning the ambiguity-averse agent, table **??** indicates at 95% confidence level that we cannot reject the hypothesis that the probability to comply with the social optimal level of self-insurance is equal to 0.5. Indeed, the confidence interval at 95% confidence level contains the value 0.5. Hence the probability to achieve the social optimum is higher under the negligence rule than under the strict liability for the ambiguity-averse agent, both for the availability and unavailability of liability insurance. Concerning the ambiguity-loving, at 95% confidence level the probability of adopting the socially optimal level of self-insurance is superior to 0.5 as table **??** shows.
Hence, the negligence rule provides better incentives to adopt the socially optimal level of self-insurance both for the ambiguity-averse and ambiguity-loving subjects.

5.4 Experimental results on the demand for insurance

Propensity to buy insurance coverage under risk In the treatments characterized by the presence of risk, table **??** shows that the probability to buy insurance is significantly superior to 50% at a 95% confidence level under the strict liability regime for any type of risk-attitude. Therefore we can conclude that the strict liability regime induces a willigness to buy insurance coverage. Meanwhile, under risk and negligence rule, the propensity to buy insurance coverage is significantly inferior to 50% under the negligence rule for both risk-neutral and risk-loving subjects. On the contrary, we cannot reject at a 95% confidence level that the risk-averse subjects have a 50% probability to buy insurance coverage under NG-RK-I. However, the propensity of the risk-averse subjects to buy insurance is higher under SL-RK-I than under NG-RK-I, with respective probabilities equal to 88.1% and 35.7%.

For the record, the model concludes that the demand for insurance coverage is null under the negligence rule in risk treatments, while the demand is positive under the strict liability regime. Hence, our experimental results confirm these theoretical predictions.

Ambiguity's puzzling effect on the demand for insurance Concerning the demand for insurance under ambiguity, table **??** shows, for any type of attitude towards ambiguity, that strict liability induces a majority of subjects to buy an insurance contract. Meanwhile the negligence rule leads a majority of subjects to have a null insurance coverage.

Nevertheless, the experimental results fail to confirm completely the theoretical predictions for both the ambiguity-averse and ambiguity-loving agents. Table **??** displays the results of a Dunn's test on the distribution of the demand for insurance of the ambiguity-averse agents. Table **??** allows to test the hypothesis H4Av. The results show that there is no statistically significant difference between the demands under SL-RK-I and SL-AM-I on the one hand: ambiguity does not increase the demand for insurance under the strict liability regime for the ambiguity-averse subjects, contrary to the predictions of hypothesis H4Av. However, table **??** shows also that there is no statistically significant difference between the demands under NG-RK-I and NG-AM-I. This confirms H4Av theoretical prediction, which states that the demand for insurance does not vary under the negligence rule for the ambiguity-averse agents.

Concerning the ambiguity-loving agents, the experimental results contradicts hypothesis H4Lv: table **??** shows that the ambiguity-loving subjects increase their demand for insurance coverage under ambiguity when the strict liability regime is implemented, compared to the risk context. Indeed, the Dunn's test confirms that the distribution of the demand for self-insurance is statistically different between SL-RK-I and SL-AM-I at a 90% confidence level, and that in average the demand for insurance is higher under SL-AM-I. Moreover, the experimental results show that there is no statistically significant difference of the demand for insurance between the treatments NG-RK-I and NG-AM-I for the ambiguity-loving subjects.

5.5 Further analysis

We run a random effects logit regression of the variable "*optimum*", which value is 1 if the subject complies with the social optimum and 0 otherwise. The independent variables in this regression are the treatment variables (SL,I,AM), other characteristics of the context of decision (number of accident, period of decision), the socio-demographic characteristics of the individual and the attitudes towards risk and ambiguity. The regression is run on the complete data set, and also on the observations characterized by risk on the one hand, and ambiguity on the other hand.
Concerning the treatment variables, SL (respectively I and AM) equals 1 if strict liability (respectively availability of insurance and ambiguity) is implemented, and 0 otherwise. We collected also the number of previous accidents that the subject has faced at the time of the decision, and the period of decision (value between 1 and 24).
The results of the regression are displayed in table **??**. The results confirm that, other things being equal, the negligence rule increases the probability to adopt the socially optimal level of care. Indeed, the coefficient of SL is statistically significant at 1% confidence level, and negative in our three regressions. Therefore, the strict liability and the negligence rule have different deterrence effect both under risk and ambiguity.
Table **??** shows that the the moral concerns of the subjects do not have a significant effect on the probability to comply. Indeed, the variables related to benevolence, universalism and ecocentrism are non significant in the regression. Meanwhile, among the socio-demographic variables, only the variable "female" is significant. This variable is significant at a 1% confidence level in our regressions and negative, meaning that in average the male subjects have a higher probability to comply than the female subjects. Moreover, as moral concerns are not significant, the subjects seem to be only responsive to the monetary incentives induced by the different implemented treatments.
The regression allows to test for any order bias or learning effect. We include a dummy variable for each order implemented in the experiment, and the estimation shows that their coefficients are

not statistically significant. Hence, no order bias is present in the experimental results.
Furthermore, table **??** indicates that the period of decision is also non significant, suggesting that there is no learning effect in the experiment. Nevertheless, there is a memory effect in the experiment, as the cumulative number of accident is significant in our three regressions, with a positive coefficient. Hence, facing an accident in previous periods of decision enhance the propensity to adopt the socially optimal level of care.

6 Concluding remarks

The purpose of this article is to compare negligence rule and strict liability under ambiguity. Both the theoretical and experimental approaches are aimed to understand to what extent the deterrence effect of these tort rules differ on the one hand, and how ambiguity modulates the incentive properties of each liability regime on the other hand. Under risk, the model predicts that strict liability and negligence rule are equivalent in their deterrence effect, since they both induce the agents to adopt the socially optimal level of prevention or self-insurance. This remains true whether insurance is available or not. Our experimental data cast into doubt this standard result of the Economics of tort law. Indeed, the likelihood of the socially optimal level of self-insurance is higher under the negligence rule than under the strict liability regime.
Under ambiguity, experimental evidence and theory seem to be more in adequation. In line with the theoretical predictions, we find that the strict liability regime induces over-provision by ambiguity-averse subjects, but only if insurance is not available. If insurance is available, contrary to our predictions, the demand of ambiguity-averse subjects has a flat distribution around the socially optimal level of self-insurance.
For the ambiguity-loving individuals, the experiment confirms that strict liability induces under-provision under ambiguity, but only when insurance is available. Otherwise, if insurance is unavailable, over-provision is observed. Meanwhile, the negligence rule leads to a socially optimal level of self-insurance for both ambiguity-averse and ambiguity-loving subjects, as predicted by the model.
Our experimental observations do not completely fit our theoretical predictions and contradict a major result of the standard analysis of civil liability. According to our experimental sample, strict

liability and negligence rule are not equivalent in their deterrence effect. Hence, our experiment contributes to the Law and Economics literature on the analysis of tort law. This paper plea in favour of the negligence rule, since it provides better incentives to invest in prevention. Nevertheless, the tort law is also designed to compensate and remedy potential damages. Regarding environmental liability, applying the strict liability to most hazardous activities, even if it can either lead to under- or over-provision of prevention, guarantees the compensation of potentially catastrophic environmental damages. The trade-off between deterrence and compensation is a matter of public policy.

Further experimental research needs to be done on ambiguity and liability regimes. Especially, this paper does not include the possibility for the insurer to charge the premium above the actuarial price when there is ambiguity. Moreover, our operational definition of the social cost only includes the cost of preventing and remedying damages, following the objectives of the ELD. It can be argued that the social cost may include the cost of risk allocation via the purchase of insurance coverage or the psychological costs of ambiguity. Despite these drawbacks, this paper sets a framework for the experimental study of tort rules under ambiguity, which can be improved to deepen our understanding of environmental liability.

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7 Appendices

7.1 Demand for self-insurance and liability insurance under risk

7.1.1 Strict liability

If an accident occurs, the agent is held liable whatever the level of safety measures that have been taken. Therefore $h(-x(a)+I) = -x(a)+I$. The expected utility can be written $EU(a,I) = (1-q)U(W_0 - a - pI) + qU(W_0 - a - pI - x(a) + I)$. The optimal choice is described by the first order conditions[10]

$$\frac{\partial EU}{\partial a} = -(1-q)U'(W_N) + q(-1-x'(a))U'(W_A) = 0$$

$$\frac{\partial EU}{\partial I} = (1-q)(-p)U'(W_N) + q(1-p)U'(W_A) = 0$$

Therefore, at the optimum of the agent, we have the equality of the marginal benefit and cost of insurance on the one hand and the equality of the marginal benefit and cost of self-insurance on the other hand. Indeed, the first-order conditions can be rewritten[11]

$$-qx'(a)U'(W_A) = EU'$$

$$qU'(W_A) = pEU'$$

The optimal level of self-insurance is characterized by the following equation

$$\frac{1}{q} = -x'(a^*)$$

[10]The second order conditions are

$$\frac{\partial^2 EU}{\partial a^2} = (1-q)U''(W_N) + (-1-x'(a))^2 qU''(W_A) < 0$$
$$\frac{\partial^2 EU}{\partial I^2} = p^2(1-q)U''(W_N) + (1-p)^2 qU''(W_A) < 0$$

[11]with $EU' = (1-q)U'(W_N) + qU'(W_A)$

Indeed, the first order condition $\frac{\partial EU}{\partial a} = 0$ and $U''(W) = 0$ imply $\frac{1}{q} = -x'(a^*)$. Hence, the risk neutral agent provides the socially optimal level a^s, with $\frac{1}{q} = -x'(a^s)$.

Moreover, the unavailability of liability insurance would have no effect on the demand for self-insurance of the risk-neutral agent as $\frac{\partial^2 EU}{\partial a \partial I} = 0$.

Concerning the demand for insurance, for $p = q$, we have $\forall I$, $\frac{\partial EU}{\partial I} = 0$. Consequently, the agent is indifferent to her level of insurance coverage, and $I \in [0; x(a)]$.

Risk-averse agent The optimal level of self-insurance a^* of the risk-averse agent equalizes the marginal returns of insurance and self-insurance. Indeed, $\frac{\partial EU}{\partial a} = 0$ and $\frac{\partial EU}{\partial I} = 0$ induce an interior solution such that

$$\frac{1}{p} = -x'(a^*)$$

with $\frac{-x'(a^*)}{1}$ expressing the marginal decrease in harm generated by prevention at the optimal level of self-insurance a^* when buying an additional unit of self-insurance on the one hand, and $\frac{1}{p}$ expressing the increase in insurance coverage when buying an additional unit of insurance at price p. For an actuarial price of insurance $p = q$, the risk-averse agent provides the socially optimal level a^s, with $\frac{1}{q} = -x'(a^s)$.

Concerning the demand for insurance coverage, the risk-averse agent has a full coverage for an actuarial price of insurance, with $I^* = x(a^*)$.

Indeed, the first order condition on insurance demand states $(1-q)(-p)U'(W_N)+q(1-p)U'(W_A) = 0$. Thus, for $p = q$, this implies $I = x(a)$.

Insurance and self-insurance are substitutes. Indeed, the marginal value of self-insurance is decreasing in I, indeed

$$\frac{\partial^2 EU}{\partial a \partial I} = p(1-q)U''(W_N) + (-1 - x'(a))(1-p)qU''(W_A) < 0$$

An increase in the insurance coverage I will decrease the demand for self-insurance a. Consequently, unavailability of liability-insurance would increase the level of care exercised by the risk-averse agent under the strict liability rule.

7.1.2 Negligence rule

Under the negligence rule, when an accident occurs, the agent is held liable if the investment in prevention a is below a given legal standard $\bar{a}$. Therefore the decrease in wealth in case of an accident is $h(-x(a)+I) = -x(a)+I$ if $a < \bar{a}$ and $h(-x(a)+I) = 0$ if $a \geqslant \bar{a}$. Thus, the expected utility can be written

$$EU(a,I) = \begin{cases} U(W_0 - a - pI) & \text{if } a \geqslant \bar{a} \\ (1-q)U(W_0 - a - pI) + qU(W_0 - a - pI - x(a) + I) & \text{if } a < \bar{a} \end{cases}$$

The purchase of liability coverage under the negligence rule could be problematic. Indeed, the possibility for the potential injurer to get an indemnity if held liable could induce an under-provision of care (Tunc, 1974). The standard model of civil liability shows that under reasonable hypothesis, potential injurers do not purchase insurance coverage under the negligence rule. Therefore, the opportunity to purchase liability coverage does not affect the deterrence function of this liability regime, and it is not problematic to assume the existence of insurance under this liability regime in a risky context.

For the record, under the negligence rule the agent is held liable if the investment in prevention a is below a given legal standard $\bar{a}$. Therefore, the expected utility can be written

$$EU(a,I) = \begin{cases} U(W_0 - a - pI) & \text{if } a \geqslant \bar{a} \\ (1-q)U(W_0 - a - pI) + qU(W_0 - a - pI - x(a) + I) & \text{if } a < \bar{a} \end{cases}$$

Risk neutral agent A risk-neutral agent adopts a level of self-insurance $\bar{a}$ and has a null insurance coverage $I^* = 0$. Indeed, when maximizing the expression $(1-q)U(W_0 - a - pI) + qU(W_0 - a - pI - x(a) + I)$, we obtain $\forall I$, $\frac{1}{q} = -x'(\bar{a})$, which corresponds to a level of self-insurance $\bar{a}$. Once again, when maximizing $U(W_0 - a - pI)$, the utility is maximum for $I = 0$.

Risk averse agent For $p = q$, the risk averse agent chooses respectively $\bar{a}$ and $I = 0$ as levels of self-insurance and insurance under the negligence rule.

Indeed, when maximizing the expression $(1-q)U(W_0 - a - pI) + qU(W_0 - a - pI - x(a) + I)$, for $p = q$, the agent is willing to invest in a level a^* $s.t.$ $\frac{1}{p} = -x'(a^*)$. Now, the legal standard is $\bar{a}$ $s.t.$ $\frac{1}{q} = -x'(\bar{a})$. It is straightforward to see that when maximizing $U(W_0 - a - pI)$, the agent is also willing to invest in a level of self-insurance $\bar{a}$. Therefore, the agent's expected utility is maximum at $\bar{a}$.

When maximizing $U(W_0 - a - pI)$, the level of expected utility for an amount of self insurance $a \geqslant \bar{a}$, the utility is maximum for $I = 0$.

7.2 Strict liability under ambiguity

7.2.1 Demand for self-insurance

Ambiguity-neutral agent Given a strict liability rule, the ambiguity-neutral agent invests in the same amount of self-insurance a and insurance I under risk and ambiguity.

Ambiguity-averse demand for self-insurance and availability of insurance The individual chooses a and I to maximize $E_F[\phi(EU(a, I; \pi))]$ with

$$EU(a, I; \pi) = (1 - \pi)U(W_0 - a - pI) + \pi U(W_0 - a - pI - x(a) + I)$$

Moreover, in the experimental setting the insurer is assumed to be risk-and-ambiguity neutral and to charge actuarial prices, hence $p = E_F(\pi) = q$.

Under this condition, the first derivative of the EU respective to a is

$$\frac{\partial EU}{\partial a} = (1 - \pi)(-1)U'(W_0 - a - qI) + \pi(-1 - x'(a)U'(W_0 - a - qI - x(a) + I)$$

The second derivative of the EU respective to a and π is

$$\frac{\partial^2 EU}{\partial a \partial \pi} = U'(W_0 - a - qI) + (-1 - x'(a))U'(W_0 - a - qI - x(a) + I)$$

We can see that $\forall \pi$, $\frac{\partial^2 EU}{\partial a \partial \pi}|_{(a^*,I^*)} > 0$. As a reminder, the notation (a^*, I^*) refers to the optimal decision of the agent under risk. Under the assumption $p = q$, we have for the risk-averse agent

$$(a^*, I^*)\, s.t. \begin{cases} \dfrac{1}{q} = -x'(a^*) \\ I^* = x(a^*) \end{cases}$$

For the record, we have for the risk-neutral agent

$$(a^*, I^*)\, s.t. \begin{cases} \dfrac{1}{q} = -x'(a^*) \\ I^* \in [0; x(a^*)] \end{cases}$$

As $\forall \pi$, $\frac{\partial^2 EU}{\partial a \partial \pi}|_{(a^*,I^*)} > 0$, an increase in a at point (a^*, I^*) results in a mean-preserving contraction in the distribution of the EU. This result holds both for the risk averse and the risk neutral agent. Therefore, $E_F[\phi\,(EU(a, I; \pi))]$ increases in a at point (a^*, I^*) both for the risk averse and risk neutral agents. The agent is willing to increase her demand in self-insurance under ambiguity, compared to the risk context.

Ambiguity-loving demand for self-insurance and availability of insurance As previously, $\forall \pi$, $\frac{\partial^2 EU}{\partial a \partial \pi}|_{(a^*,I^*)} > 0$, an increase in a at point (a^*, I^*) results in a mean-preserving contraction in the distribution of the EU. This result holds both for the risk averse and the risk neutral agent. Therefore, $E_F[\phi\,(EU(a, I; \pi))]$ decreases in a at point (a^*, I^*) both for the risk averse and risk neutral agents. The agent is willing to decrease her demand in self-insurance under ambiguity, compared to the risk context.

Ambiguity-averse demand for self-insurance and unavailability of insurance When the insurance is unavailable, the agent chooses a to maximize $E_F[\phi(EU(a; \pi))]$ with

$$EU(a; \pi) = (1 - \pi)U(W_0 - a) + \pi U(W_0 - a - x(a))$$

The first derivative of the EU respective to a is

$$\frac{\partial EU}{\partial a} = (1 - \pi)(-1)U'(W_0 - a) + \pi(-1 - x'(a)U'(W_0 - a - x(a))$$

The second derivative of the EU respective to a and π is

$$\frac{\partial^2 EU}{\partial a \partial \pi} = U'(W_0 - a) + (-1 - x'(a))U'(W_0 - a - x(a))$$

We can see that $\forall\pi$, $\frac{\partial^2 EU}{\partial a \partial \pi}|_{(a^*)} > 0$. Under this condition, $E_F[\phi(EU(a;\pi))]$ increases in a at point (a^*) both for the risk averse and risk neutral agents. The agent is willing to increase her demand in self-insurance under ambiguity, compared to the risk context.

Ambiguity-loving demand for self-insurance and unavailability of insurance As $\forall\pi$, $\frac{\partial^2 EU}{\partial a \partial \pi}|_{(a^*)} > 0$, $E_F[\phi(EU(a;\pi))]$ increases in a at point (a^*) both for the risk averse and risk neutral agents. The agent is willing to decrease her demand in self-insurance under ambiguity, compared to the risk context.

7.2.2 Demand for liability insurance

Ambiguity-neutral agent The same results than under risk hold.

Ambiguity-averse agent Under the assumption of a risk-and-ambiguity neutral insurer who charges an actuarial price of insurance $p = q$, we have

$$\frac{\partial^2 EU}{\partial I \partial \pi} = qU'(W_N) + (1-q)U'(W_A) > 0$$

We know that under this condition, for $\pi = q$ the mean EU is unchanged and $\frac{\partial EU}{\partial I} = 0$. For high values of the EU ($\pi < q$), an increase in I evaluated at point I^* decreases the EU. For low values of the EU ($\pi > q$), an increase in I evaluated at point I^* increases the EU. Thus, we have mean-preserving contraction in the distribution of the EU. Consequently, the marginal value of insurance under ambiguity is

$$E_F[\phi'(EU(a, I;\pi))\, EU'_I(a, I;\pi)] > 0$$

The agent is willing to increase her demand for insurance coverage under ambiguity. This result holds both for the risk averse and the risk neutral agent.

Ambiguity-loving agent As previously shown, an increase in I evaluated at point I^* results in a mean-preserving contraction in the distribution of the EU. The agent is willing to decrease her demand for insurance coverage under ambiguity. This result holds both for the risk averse and the risk neutral agent.

7.3 Negligence rule under ambiguity

Let $\bar{a}$ be the legal standard such that $-x'(\bar{a}) = \frac{1}{E_F[\pi]} = \frac{1}{q}$. We assume that the legal standard under ambiguity is set in order to minimize the expected value of the social cost given the second-order probability $F(\pi)$ and under the assumption that the social planner has unbiased beliefs $E_F[\pi] = q$. Nevertheless, it can be argued that the social planner or the judge has biased beliefs or ambiguity aversion, which would modify the setting of the legal standard. However, an identical $\bar{a}$ under risk and ambiguity allows to analyze the behavior of the potential injurer ceteris paribus.

Ambiguity neutral agent Given the negligence rule, the ambiguity-neutral agent invests in the same amount of self-insurance a and insurance I under risk and ambiguity.

Ambiguity averse agent and availability of insurance For any price of insurance, a risk-neutral agent invests in a amount of self-insurance $\bar{a}$ and a null insurance coverage $I = 0$ if they are ambiguity averse.

For an ambiguity averse agent, the expected utility evaluated under ambiguity is

$$\begin{cases} U(W_0 - a - pI) & \text{if } a \geqslant \bar{a} \\ E_F[\phi(EU(a, I; \pi))] & \text{if } a < \bar{a} \end{cases}$$

And we have

$$\frac{\partial^2 EU}{\partial a \partial \pi} = U'(W_0 - a - qI) + (-1 - x'(a))U'(W_0 - a - qI - x(a) + I) > 0$$

Therefore, when maximizing $E_F[\phi(EU(a, I; \pi))]$, the ambiguity averse agent is willing to invest in a level of self-insurance superior to a^* with $\frac{1}{q} = -x'(a^*) = -x'(\bar{a})$.[12] Thus, the utility is at the highest for a level of self-insurance $\bar{a}$ and a null insurance coverage. This result holds both for risk averse and risk neutral agent.

[12]See Appendix **??**.

Ambiguity-loving agent and availability of insurance When maximizing $E_F[\phi(EU(a, I; \pi))]$, the ambiguity-loving agent is willing to invest in a level of self-insurance lower than $a^* = \bar{a}$. Therefore, the demand for self-insurance is undetermined for the ambiguity-loving agent. Similarly, we cannot conclude on the demand for liability insurance.

Ambiguity averse agent and unavailability of insurance For an ambiguity averse agent, the expected utility evaluated under ambiguity is

$$\begin{cases} U(W_0 - a) & \text{if } a \geqslant \bar{a} \\ E_F[\phi(EU(a; \pi))] & \text{if } a < \bar{a} \end{cases}$$

We have

$$\frac{\partial^2 EU}{\partial a \partial \pi} = U'(W_0 - a) + (-1 - x'(a))U'(W_0 - a - x(a)) > 0$$

Hence, it is straightforward to see that the agent is willing to invest in an amount $\bar{a}$.

Ambiguity-loving agent and unavailability of insurance When maximizing $E_F[\phi(EU(a; \pi))]$, the ambiguity-loving agent is willing to invest in a level of self-insurance lower than $a^* = \bar{a}$. Therefore, the demand for self-insurance is undetermined for the ambiguity-loving agent.

7.4 Experimental protocol

The elicitation of attitudes towards risk and ambiguity is realized on the basis of a multiple price list procedure *à la Holt and Laury (2002; 2005)* and *Chakravarty and Roy (2009)*. The corresponding utility functions are $u(x) = -(-x)^s$ for $x < 0$ and $\phi(x) = -(-z)^b$ for $x < 0$

Table 1: Risk and Ambiguity attitudes

Scale value	AM	RK
1	]-∞ ; -0.4307]	]-∞;0]
...	...	...
6	[0.8614 ;1]	[0,7122;1]
7	[1 ; 1.1133]	[1;1,3826]
8	[1.1133 ; 1.2091]	[1,3826;1,9310]
...	...	...
11	[1.3652 ;+∞[	[4,5701;+∞[

Table 2: Possible urns in the AM treatment

Possible urns	Urn A	Urn B	Urn C
Arrangement	1 Red 7 Yellow 2 Blue	1 Red 7 Yellow 1 Blue and 1 Black	1 Red 7 Yellow 2 Black
Accident probability if Blue chosen	20%	10%	0%
Accident probability if Black chosen	0%	10%	20%

Table 3: Self-insurance in the SL treatment

Investment	**Losses in the event of an accident**	**ECU amount of secured wealth**	**Incremental increase of secured wealth for 1 precautionary ECU**	**Wealth without accident**	**Wealth in the event of an accident**
0	10000	0	-	10000	0
100	8000	2000	20	9900	1900
200	6400	3600	16	9800	3400
300	5200	4800	12	9700	4500
400	4200	5800	10	9600	5400
500	3400	6600	8	9500	6100
600	2800	7200	6	9400	6600
700	2400	7600	4	9300	6900
800	2100	7900	3	9200	7100
900	1900	8100	2	9100	7200
1000	1800	8200	1	9000	7200

Table 4: Self-insurance in the NR treatment

Investment	**Damages in the event of an accident**	**Losses in the event of an accident**	**ECU amount of secured wealth**	**Incremental increase of secured wealth for 1 precautionary ECU**	**Wealth without accident**	**Wealth in the event of an accident**
0	10000	10000	0	-	10000	0
100	8000	8000	2000	20	9900	1900
200	6400	6400	3600	16	9800	3400
300	5200	5200	4800	12	9700	4500
400	4200	0	10000	52	9600	9600
500	3400	0	10000	0	9500	9500
600	2800	0	10000	0	9400	9400
700	2400	0	10000	0	9300	9300
800	2100	0	10000	0	9200	9200
900	1900	0	10000	0	9100	9100
1000	1800	0	10000	0	9000	9000

Table 5: Insurance contracts

Premium : P*I	**Insurance Payment : I**	**Incremental increase of insurance payment for 1 premium ECU**
0	0	-
100	1000	10
200	2000	10
300	3000	10
400	4000	10
500	5000	10
600	6000	10
700	7000	10
800	8000	10
900	9000	10
1000	10000	10

7.5 Experimental results

Table 6: Summary statistics

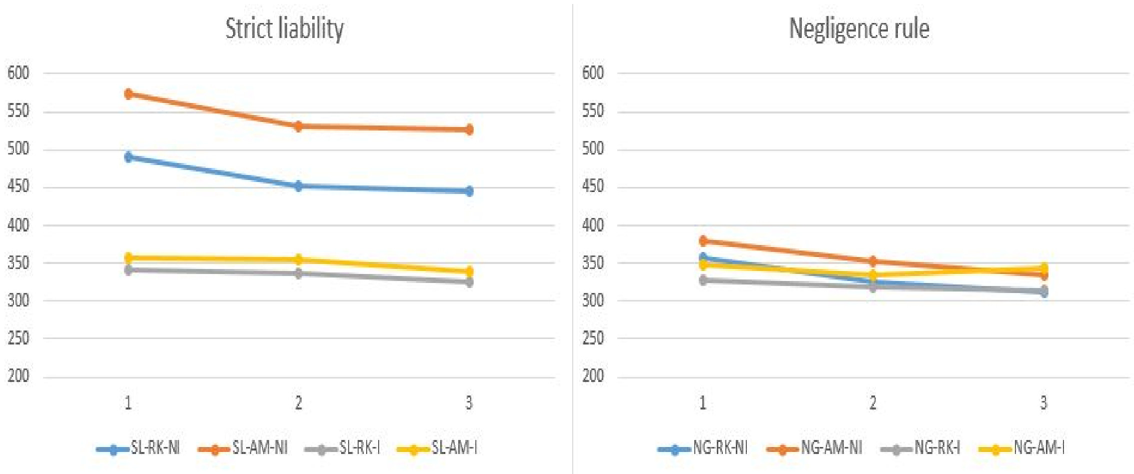
Variable	Obs	Mean	Std. Dev.	Min	Max
Female	122	.344	.477	0	1
Age	122	21.648	3.636	18	56
Risk attitude	122	5.844	1.42	2	11
Ambiguity attitude	122	5.672	1.434	0	11
Universalism	122	0	0.682	-2.663	0.813
Benevolence	122	0	0.786	-2.455	0.84
Ecocentrism	122	0	0.77	-2.582	0.831
Payoff	122	26.12	3.769	12.6	29.8
Field of study					
Econ./Management	76	62.29			
IT/Maths/Engineer.	27	22.13			
Natural sciences	6	4.92			
Other	13	10.66			

Table 7: Attitudes towards risk and ambiguity

Amb. att.	Risk att. loving	Neutral	Averse	Total
Loving	42.31	46.15	11.54	100.00
Neutral	38.33	50.00	11.67	100.00
Averse	50.00	40.00	10.00	100.00
Total	40.98	47.54	11.48	100.00

Percentage of risk and ambiguity attitudes in the sample, with 122 subjects.

Figure 1: Average demand for self-insurance



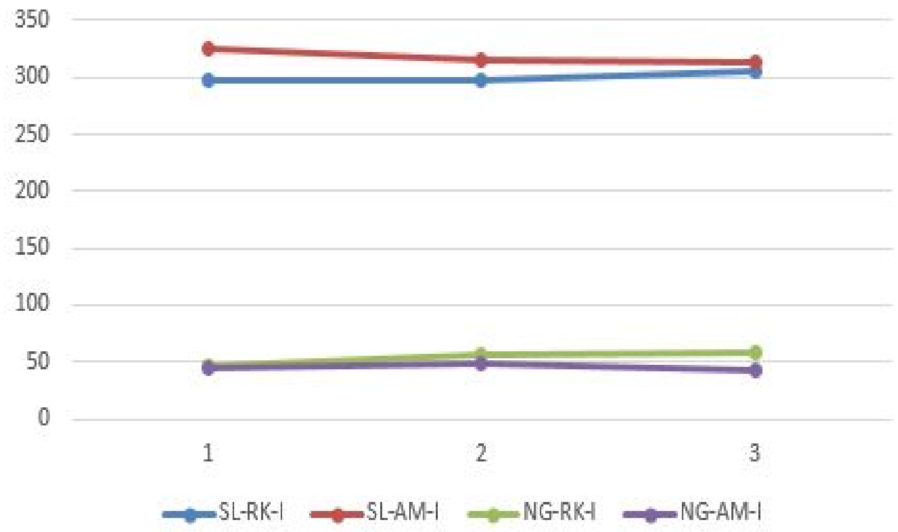
Average demand for self-insurance, by treatment, for the three decision periods of the experiment.

Table 8: Percentage of under-provision, over-provision and socially optimal level decisions per treatment

Treat.	Under-prov.	Optimum	Over-prov.	Total
SL-RK-NI	36.61	12.02	51.37	100.00
SL-AM-NI	25.68	10.38	63.93	100.00
SL-RK-I	54.64	17.21	28.14	100.00
SL-AM-I	48.63	22.40	28.96	100.00
NG-RK-NI	22.95	73.50	3.55	100.00
NG-AM-NI	19.95	75.96	4.10	100.00
NG-RK-I	27.87	69.95	2.19	100.00
NG-AM-I	26.23	69.40	4.37	100.00
Total	32.82	43.85	23.33	100.00

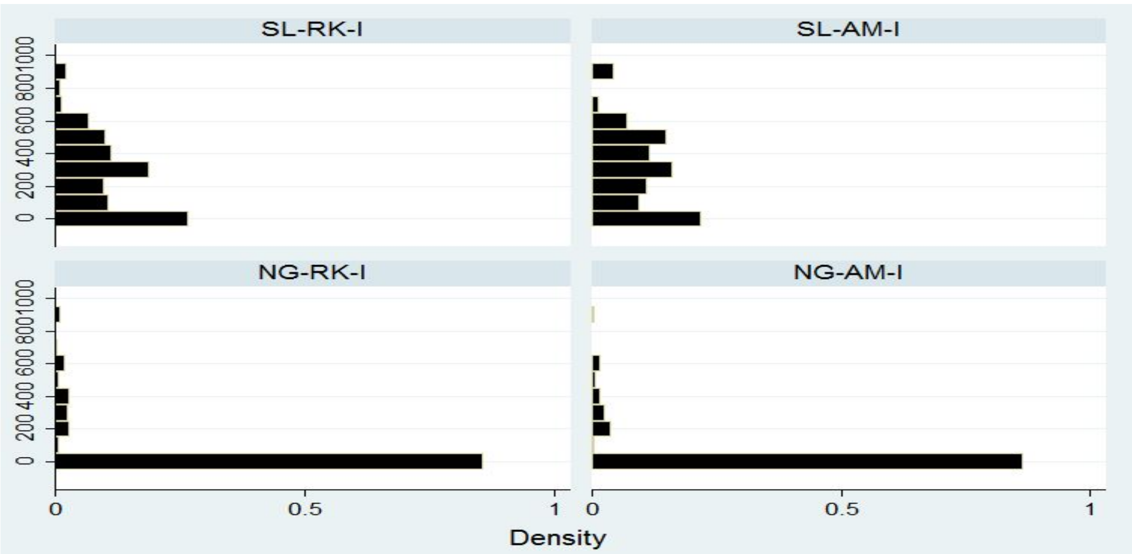
An investment choice is socially optimal if it equals 400 ECU.

Figure 2: Average demand for liability insurance



Average demand for insurance coverage, by treatment, for the three decision periods of the experiment. The vertical axis displays the premium $p * I$.

Figure 3: Density of the demand for liability insurance



Density of the demand for insurance coverage, by treatment, over the three decision periods of the experiment. The vertical axis displays the premium $p * I$.

Table 9: Sign test of self-insurance demand conditional on treatment

Treatment	H0: Median=400 Ha: Median>400	H0: Median=400 Ha: Median<400	H0: Median=400 Ha: Median≠ 400
Risk-neutral			
SL-RK-NI	0.081*	0.941	0.162
SL-RK-I	1.000	0.000***	0.000***
NG-RK-NI	1.000	0.000***	0.000***
NG-RK-I	1.000	0.000***	0.000***
Risk-averse			
SL-RK-NI	0.000***	1.000	0.000***
SL-RK-I	0.148	0.919	0.296
NG-RK-NI	0.969	0.188	0.375
NG-RK-I	1.000	0.000***	0.001***
Risk-loving			
SL-RK-NI	0.131	0.903	0.261
SL-RK-I	1.000	0.000***	0.000***
NG-RK-NI	1.000	0.000***	0.000***
NG-RK-I	1.000	0.000***	0.000***

The table displays the p-value of the one-sided and two sided tests. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 10: Socially optimal decisions by risk-attitudes and treatments

	Mean	Std. Err.	[95% Conf. Interval]
Risk-neutral			
SL-RK-NI	0.149	0.027	[0.096 ; 0.203]
SL-RK-I	0.213	0.031	[0.152 ; 0.274]
NG-RK-NI	0.753	0.033	[0.689 ; 0.817]
NG-RK-I	0.730	0.034	[0.664 ; 0.796]
Risk-averse			
SL-RK-NI	0.048	0.033	[-0.018 ; 0.113]
SL-RK-I	0.214	0.064	[0.089 ; 0.340]
NG-RK-NI	0.881	0.051	[0.782 ; 0.980]
NG-RK-I	0.595	0.077	[0.445 ; 0.746]
Risk- loving			
SL-RK-NI	0.107	0.025	[0.057 ; 0.156]
SL-RK-I	0.113	0.026	[0.062 ; 0.164]
NG-RK-NI	0.673	0.038	[0.598 ; 0.749]
NG-RK-I	0.693	0.038	[0.619 ; 0.767]

Table 11: Socially optimal decisions by ambiguity-attitudes and treatments

	Mean	Std. Err.	[95% Conf. Interval]
Amb.-averse			
SL-AM-NI	0.067	0.046	[-0.024 ; 0.158]
SL-AM-I	0.033	0.033	[-0.032 ; 0.099]
NG-AM-NI	0.533	0.093	[0.352 ; 0.715]
NG-AM-I	0.567	0.092	[0.386 ;0.747]
Amb.-loving			
SL-AM-NI	0.096	0.024	[0.050 ;0.143]
SL-AM-I	0.244	0.034	[0.176 ;0.311]
NG-AM-NI	0.769	0.034	[0.703 ;0.836]
NG-AM-I	0.686	0.037	[0.613 ;0.759]

Table 12: Sign test of self-insurance demand conditional on treatment by ambiguity-attitudes

Treatment	H0: Median=400 Ha: Median>400	H0: Median=400 Ha: Median<400	H0: Median=400 Ha: Median≠ 400
Amb.-averse			
SL-AM-NI	0.044**	0.982	0.087*
SL-AM-I	0.229	0.868	0.458
NG-AM-NI	0.994	0.029**	0.057*
NG-AM-I	1.000	0.000***	0.000***
Amb.-loving			
SL-AM-NI	0.002***	0.999	0.004***
SL-AM-I	1.000	0.000***	0.000***
NG-AM-NI	1.000	0.000***	0.000***
NG-AM-I	1.000	0.000***	0.000***

The table displays the p-value of the one-sided and two sided tests. *** p<0.01, ** p<0.05, * p<0.1.

Table 13: Propensity to buy insurance coverage by risk and ambiguity attitudes and treatments

	Mean	Std. Err.	[95% Conf. Interval]
Risk-neutral			
SL-RK-I	0.764	0.032	[0.701 ; 0.828]
NG-RK-I	0.103	0.023	[0.058 ; 0.149]
Risk-averse			
SL-RK-I	0.881	0.051	[0.782 ; 0.980]
NG-RK-I	0.357	0.075	[0.210 ; 0.504]
Risk-loving			
SL-RK-I	0.653	0.039	[0.577 ; 0.730]
NG-RK-I	0.127	0.027	[0.073 ; 0.180]
Ambiguity-Averse			
SL-AM-I	0.600	0.091	[0.421 ; 0.779]
NG-AM-I	0.267	0.082	[0.105 ; 0.428]
Ambiguity-loving			
SL-AM-I	0.788	0.033	[0.724 ; 0.853]
NG-AM-I	0.141	0.028	[0.086 ; 0.196]

Table 14: Dunn's Pairwise Comparison of insurance under ambiguity and risk

Col Mean-Row Mean	SL-RK-I	SL-AM-I	NG-RK-I
Ambiguity-averse			
SL-AM-I	0.070		
NG-RK-I	1.889**	1.819**	
NG-AM-I	2.087**	2.017**	0.198
Ambiguity-loving			
SL-AM-I	-1.302*		
NG-RK-I	10.264***	11.565***	
NG-AM-I	9.736***	11.037***	-0.528

The table displays the Dunn's z-test statistics.
*** p<0.01, ** p<0.05, * p<0.1.

Table 15: Random effect logit estimation for the propensity to adopt the socially optimal level of care

	(1) All	(2) Risk	(3) Ambiguity
SL	-4.080***	-4.433***	-4.149***
	(0.317)	(0.447)	(0.433)
I	-0.242	-0.432	-0.149
	(0.225)	(0.288)	(0.275)
AM	0.087		
	(0.139)		
Nb. Accid	0.423***	0.399**	0.517***
	(0.132)	(0.180)	(0.149)
Period	0.028	0.051	0.013
	(0.027)	(0.039)	(0.033)
Female	-1.047***	-1.096***	-1.118***
	(0.340)	(0.402)	(0.353)
Age	-0.037	-0.017	-0.072
	(0.035)	(0.040)	(0.055)
Univers.	-0.259	-0.293	-0.338
	(0.298)	(0.351)	(0.285)
Benevol.	-0.164	-0.164	-0.112
	(0.242)	(0.269)	(0.252)
Eco.	0.106	-0.009	0.097
	(0.236)	(0.265)	(0.252)
Order	Yes	Yes	Yes
Risk attitudes	No	Yes	No
Ambiguity attitudes	No	No	Yes
Constant	Yes	Yes	Yes
Observations	2,928	1,464	1,464

The table displays the coefficient estimates with *** p<0.01, ** p<0.05, * p<0.1. Cluster robust standard errors in parantheses.