Ambiguity and Accident Law[1]

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Abstract

This paper analyzes liability rules, when agents, both the potential injurer and the potential victim can perceive ambiguity, i.e., they are not aware of the probability of a possible enironmental accident. Both the injurer and the victim invest in care, which is commonly observable, and they derive utility from the activity, which is unobservable, which may lead to the accident. Here we analyze the welfare implications of the tort rules, first when agents only under take investment in care and second, when agents choose care and activity levels. When agents only choose level of care, under negligence ambiguity averse agents are more likely to choose the optimal amount of care. When agents choose both care and unobserved action negligence we propose a system of punitive damages which gives optimal level of both care and unobserved action by both injurers and victims.

1 Introduction

Environmental disasters can cause severe private damage and harm. A number of such disasters are accidents and can be attributed to error or lack of care by agents involved as in Exxon Valdez oil spill or British Petroleum (BP) Deepwater Horizon oil spill. Such environmental accidents and disasters are regulated and governed broadly by law of tort.[1] Tort and liability rules help society by giving potential environmental injurers and victims an incentive to endogenize the social cost of their actions (Calabresi, 1970, Posner, 2007, Shavell, 1980 and Calcott and Hutton, 2006). A significant part of the literature on tort has focused on the efficiency implications of using different tort rules, like negligence and strict liability. In the standard framework of tort, the agents involved are modelled as rational subjective expected utility (SEU from now on) decision makers (Savage, 1954). In this paper, we relax the assumption of SEU, more precisely we allow the agents to be affected by perceptions of ambiguity (unknown probabilities). We explain ambiguity below. We argue that in order to analyse tort law for environmental accidents, modelling agents whose preferences are affected by ambiguity, provides us with a more complete analysis of the tort rules. Agents involved are likely to have poor information about the probability of environmental events given the very low frequency of such accidents and major environmental accidents often have unique circumstances. Thus it is not implausible that they perceive the risks to be ambiguous.

With such agents, we analyse welfare implications of the tort rules, negligence and strict liability. We show that it may be possible to get closer to ex-post Pareto efficiency when there is ambiguity.

[1] Tort law decides the liability in case of private harm due to act of negligence or lack of duty of care by the injurer. Environmental accident can cause both public and private harm. For the purpose of our analysis here we are going to ignore the difference between private and public harm. Victims are assumed to suffer damage and we are going to model them as a single player.

We state the optimal tort rule with ambiguity, considering agents invest in care levels and choose activity levels. Our analysis here is motivated by examples similar to BP Deepwater Horizon oil spill where the injurer due to the new and advanced technology being used perceives ambiguity about the accident occurring moreover both the potential injurer (BP) and the victims also view the care levels taken by each other as ambiguous.

In most standard law and economics tort analysis, agents, potential injurers and victims, are modelled as having subjective beliefs about the probability of the accident. However, this may not be fully realistic.[2] Agents may fail to correctly consider the probability of the accident or in some cases may be unaware of the probability. This problem may be exacerbated for some cases of environmental accidents like the BP oil spill. This inability to correctly consider the probability of the accident may lead decision makers to over or under weight the probabilities of the future events and thus behave optimistically or pessimistically. Such beliefs may cause agents to choose their actions differently from SEU agents and as a result cause a different outcome.

Experiments (Camerer and Weber, 1992) have shown that agents often do not follow SEU. Ellsberg (1962) showed that decision makers avoid risks with unknown probabilities and prefer risks with known probabilities. More generally decision makers behave differently when probabilities are unknown. For the rest of the paper, events with unknown probabilities are called ambiguous and decisions under unknown probabilities are called ambiguous decisions. In case of such unawareness of the probabilities, decision makers may under-weight and or over-weight the probability of the events. As a result if they over-weight the chances of good (bad) outcomes then they are likely to

[2] In law and economics of tort, Shuman (1993) argues that assumptions that agents are rational and are fully aware of the probability of the accident and the consequence of their actions may not be able to provide a complete analysis of the tort rules.

behave optimistically (pessimistically).

In potential tort situations, we may have injurers and victims, who before choosing their actions, may not be able to correctly attribute the probability of a potential accident or estimate the damage caused as a result of the accident. Agents may not have sufficient information or time to assign precise probabilities to accidents. For example, an oil company, such as BP, may not be able to form correct beliefs about the probability of an accident given the depth of drilling. Since accidents are rare events companies may not have enough observations to base subjective probabilities on relative frequencies. The potential injurer, if he does not know the probability of the accident given his actions, will likely choose an action which is quite different from an injurer who knows the probability. Similarly ambiguity may change the behaviour of the victim. Thus ambiguity in analysing tort rules is relevant since if we accept that accidents are likely to be perceived as ambiguous events it is desirable that the tort rules are robust to ambiguity.

We shall model ambiguity using neo-additive preferences, (Chateauneuf, Eichberger, and Grant, 2007). This is a special case of Choquet Expected Utility (CEU) developed by Schmeidler (1989). In this model, ambiguity has the effect of causing the best and worst outcomes of any given action to be over-weighted, (compared to SEU). We believe this model is suitable for studying tort, since in an accident there are focal best and worst outcomes, i.e. no accident and being found liable for an accident respectively. More specifically we consider a situation where a potential injurer and victim undertake specific activities which may result in an accident and loss. Both may choose a care level and a non-observable action to reduce the chance of an accident. The injurer and the victim have ambiguous beliefs regarding the likelihood of an accident and damage resulting from their care level and non-observable action. Care levels can be observed by the third party but not the non-observable action.

The solution concept, we use, allows us to model both, ambiguity averse and ambiguity preferring agents (Eichberger and Kelsey (2009)). If an agent is pessimistic then he/she will over weight the bad outcomes. This would also imply that an agent would expect the other agent to choose lower care levels (strategy) and if the game between the two agents has increasing differences then the agent will have a lower best response and thus choose a lower care level. If the agents have ambiguity preference then the equilibrium strategy will increase.

Agents do not consider the social cost of their actions but only the private costs. The aim is to design tort rules such that the agents take into account the negative externality due to their actions. They have to be provided incentives so that they take care and choose the optimal level of the activity. The design of the tort rules is based on the economic losses caused by the action of the injurer and minimizing the social loss due to the action.

The tort regimes which have been analysed extensively over the last few decades have been strict liability and negligence and both strict liability and negligence with contributory negligence. Strict liability is when the injurer is liable for the damages from the accident independent of the investment in care by the victim or the injurer and negligence is when the injurer is liable for the damages when the injurer fails to take the assigned level of care. Shavell (1987) has shown that strict liability and negligence both result in optimal care by the potential injurer and the victim if activity levels are not considered. But if activity levels of the agents are included in the analysis then both the injurer and the victim undertake higher than optimal levels of activity under negligence and the victim will undertake more than optimal activity level under strict liability.

In this paper, potential injurers and victims choose an observable action and an unobservable action.[3] The observable action is the investment in care, for example, safety standards on the

[3] Observability here means that the action is observable and verifiable by a third party like a court of law.

drilling rig and the unobservable could be depth of drilling. We show that in case of strict liability, pessimistic injurers and victims will invest in more than optimal/stipulated care because pessimism causes them to overweight the bad outcome, which in this case means having an accident. If negligence is used then the pessimistic injurer invests the stipulated or optimal amount in care and the optimistic injurer may under invest. In case of strict liability, ambiguity aversion increases the injurer's perceived liability, so he invests more in care. In case of negligence, since the injurer is held liable if he fails to invest the stipulated care, then the pessimistic injurer will invest the stipulated amount since the cost of investing the stipulated amount will be lower than the expected cost of damages. The optimistic injurer, under weighs the event where an accident occurs and ignores the cost of the damage. Hence he will find the expected cost of damages lower than the cost of investing the stipulated amount and thus not invest the stipulated amount.

We then proceed to discuss the optimal rule when agents choose both an observable action and an unobservable action at the same time. We show that negligence rule coupled with punitive damages can give optimal levels in both the observable and the unobservable action by both injurer and victim. Here the injurer is held liable for loss if he fails to take the stipulated observable care, and otherwise the victim bears the loss. The main difference from the standard negligence rule is that, if the loss is excessive, that is, higher than some threshold, then the injurer is held liable for the loss and also pays a punitive fine. *The threshold is chosen so that if it is exceeded it is clear that both parties have chosen excessive non-observable actions.* Note that if the loss is in excess of the threshold then the punitive damage dominates the negligence rule.

1.1 Organization of the paper

Next we briefly discuss some of the relevant literature, after which we discuss the model of ambiguity. In Section 3 we set up the model of accidents, first without unobserved actions and then with unobserved actions. Finally we discuss the optimal tort rule given ambiguity aversion and conclude.

2 Literature

The literature on tort is extensive and old. With Coase (1960) providing the analysis how property rights can solve the problem of assigning correct incentives to internalize the social costs. The law and economic of analysis of tort rules includes papers by Calabresi (1970), Brown (1973), Landes and Posner (1987), Shavell (1987), Cooter and Ullen (1999) and more recently Teitelbaum (2007). Much of the analysis has been to what extent the injurer should be held liable; for example Lander and Posner (1987), and Shavell (1987) show that a negligent injurer should bear the full cost of damages caused. Apart from analysing the efficient tort rule, the literature has also focused on the issues of causation, and to what extent the actions by the injurer and the victim lead to the damages (Burrows (1999) and Ben-Shahar, (2000)). The analysis in this paper will focus on the efficiency of liability rules.

Over the last couple of decades, contributions to economic theory have modelled risk and ambiguity differently. Here we consider players who perceive ambiguity about future outcomes. In addition players may be pessimistic (ambiguity averse) or optimistic about their future outcomes. If there is ambiguity, then depending on their perception, they may over weigh the good outcomes, in case of optimistic beliefs, or over weigh the bad outcomes, in case of pessimism. In this paper, our analysis could be linked with that of Eichberger and Kelsey (2009) and Eichberger et al. (2009)

which look at ambiguity in strategic settings including games where both parties choose quantity in Cournot oligopoly game and a public good contribution game.

With this paper we intend to add to the recent literature in behavioural law and economics (Jolls, Sunstein and Thaler (1998), Arlen (1998), Korobkin and Ullen, (2000) and Parisi and Smith (2005) where decision making assumptions in mainstream economics are relaxed to include behavioural insights from psychology and experimental economics. For example, due to the endowment effect (Kahneman, Knetsch, and Thaler 1990), the Coase theorem may fail as the endowment effect may create biases in valuation by the agents. Thus behavioural assumptions made in the analysis may have important implication for legal policy recommendations. Various scholars such as Jolls, Sunstein and Thaler (1998) and Bar-Gill (2006) have pointed out that behavioural aspects such as loss aversion or optimism have a role in designing legal rules.

The paper closest to ours is Teitelbaum (2007), which analyses the tort rules, when the injurer has ambiguous beliefs. He specifically looks at the case when the victim does not take any care or the actions of the victim has no bearing on the outcome. The analysis is concerned with the effect of ambiguity on the decision making of the injurer and the implications for the efficient tort regime. Here in this paper we extend the analysis to the case when the victim's action, the amount of care he chooses to take and the amount of participation, effects the amount of damage.[4] Thus we model the interaction between the parties as a strategic game using a theory of games with ambiguity developed by Eichberger, Kelsey and Schipper (2009). We derive the implication of this for tort rules.

[4] Chakravarty and Kelsey (2008) provides an explanation using ambiguity why strict liability may not apply in case of an unexpected events.

3 Preferences

One of the classic pieces of evidence for ambiguity is the three-ball Ellsberg paradox. In this experiment, a ball is drawn from an urn which contains 90 balls, 30 of which are red. The remaining balls are either blue or yellow in unknown proportion. There are four possible acts a, b, c and d, as described in the table below:

		30	60	
		R	B	Y
Choice 1	a	100	0	0
	b	0	100	0
Choice 2	c	100	0	100
	d	0	100	100

Subjects are offered two choices. In first, they have to choose between acts a and b, while in the second they choose between acts c and d. It is found that most subjects prefer option a in the first choice and option d in the second. These preferences are not compatible with SEU or indeed any other plausible decision theory in which decision-makers assign conventional subjective probabilities to events. Here we can see that the decision maker who prefers choice a to b and d to c is averse to choices where the probabilities are not known. It is worth noting ambiguity preference, i.e., choosing b and c also violates SEU. Ambiguity preference is common in choices involving unlikely events and choices involving losses.

Schmeidler (1989) introduces non-additive probabilities (or capacities) to characterize uncertainty. The decision maker is uncertain over the state space Ω. An act is defined as $f : \Omega \rightarrow \Re$. The agent has beliefs represented by a capacity ν which is similar to a subjective probability except it is not required to be additive. It has the following characteristics (i) $\nu(\varnothing) = 0$, (ii) $B \subseteq A \Longrightarrow \nu(B) \leq \nu(A)$ and (iii) $\nu(\Omega) = 1$. Using capacities can depict subjective beliefs which are pessimistic as well as optimistic. We shall assume that the beliefs be in the following class of capacities, which has been axiomatised by Chateauneuf et al. (2007).

Definition 1 *Let α, δ be real numbers such that $0 \leq \alpha \leq 1, 0 \leq \delta \leq 1$, then a neo-additive capacity ν is defined by $\nu(A) = \delta(1-\alpha) + (1-\delta)\pi(A), \emptyset \subsetneqq A \subsetneqq \Omega; \nu(\varnothing) = 0$ and $\nu(\Omega) = 1$.*

Here π is conventional probability. We can think about π as the agent's belief about the event. But due to ambiguity, the agent lacks confidence in his belief. Hence, to compute expectation of the agent's choice we use the non additive capacity. The capacity ν captures the optimism and pessimism the decision maker may have in her beliefs. So, if $\delta = 0$ then the decision maker is a standard subjective expected utility decision maker.

The individual in order to make a decision about her future, chooses her action by computing her expectation of her utility with respect to capacity ν. So if her utility is given by function u, then the expectation of the decision maker is the Choquet integral of u with respect to ν. The Choquet integral of the decision maker with utility function $u_i : \Omega \rightarrow \Re$ with respect to the neo-additive capacity ν is given by

$$\int u_i d\nu = \delta\left(1-\alpha\right) M_i + \delta\alpha m_i + (1-\delta)\mathbf{E}_\pi u_i$$

where $\mathbf{E}_\pi u_i$ denotes the expected utility of u_i with probability distribution π on Ω and $M_i = \max_\Omega u_i$ and $m_i = \min_\Omega u_i$ (See Chateauneuf et al. (2007)).

Thus the Choquet integral is a convex combination of the maximum pay-off, the minimum pay-off and the average pay-off. So here Choquet expectation captures optimism and pessimism of the decision maker. In case of $\delta > 0$ and $\alpha = 1$, we can interpret this as decision makers are pessimistic. And if $\delta > 0$ and $\alpha = 0$ then the decision maker is optimistic and tends to ignore the worst outcome.

4 Model:

There are three agents, an injurer, a victim and a court of law or the third party. The injurer undertakes an activity which may cause harm or damage to the victim. The injurer can take an action, care or precaution, x. The cost of precaution is $a(x)$, where $a(\cdot)$ is increasing in x and is convex. The victim can also take an action, precaution y, and incur a cost of $b(y)$, and $b(\cdot)$ is increasing in y and convex. The court of law implements the damage rule. The levels of precaution are observable by all parties including the third party or court of law. The injurer and the victim believe that accidents occur with probability π, but as discussed earlier either injurer or victim do not trust their belief about the accident. The injurer and the victim, when they choose the level of precaution and their activity, view this probability as ambiguous. *Let $D(x, y)$ be the damage caused by the accident such that D decreases with x and y. We assume that the marginal change in D due to x also decreases in x and the marginal change in D due to y also decreases in y.* Let the utility in case of no accident be $U_o = 0$. So the social cost from the accident is

$$L(x, y) = \pi D(x, y) + a(x) + b(y).$$

Therefore the optimal precaution x^* will be given by the condition $ML_x \leq 0$, where $ML_x = \pi\left[D(x_1, y) - D(x_2, y)\right] + \left[a(x_1) - a(x_2)\right]$, is the marginal loss function for $x_1 > x_2$. The optimal y^* is given by $ML_y \leq 0$, where $ML_y = \pi\left[D(x, y_1) - D(x, y_2)\right] + \left[b(y_1) - b(y_2)\right]$, is the marginal loss function for $y_1 > y_2$.

The problem here is to design incentives so that the injurer chooses the optimal level of precaution. Let the expected utility of the SEU maximizing injurer be $u_i(x, y)$ and that of the SEU maximizing victim be $u_v(x, y)$. Note that here $u_i(x, y) = -L_i(x, y)$ and $u_v(x, y) = -L_v(x, y)$, where L_i and L_v are the expected loss functions. So the precaution taken by such an injurer will be x, which maximizes $u_i(x, y)$ and the precaution taken by such a victim will be y, which maximizes $u_v(x, y)$. In this very basic set up, let us analyse the effect of use of negligence and strict liability. Given that care levels are observable, under negligence, the injurer has to pay the damage caused by the accident if the care taken is less than the assigned or required care. Let the required care be x^*, and assume that the court knows x^*. So under negligence, the injurer and the victim have the following utility functions

$$\begin{aligned} -L_i^n(x, y) &= -a(x) \text{ if } x \geq x^* \\ &= -\pi D(x, y) - a(x) \text{ if } x < x^*, \end{aligned}$$

$$\begin{aligned} -L_v^n(x, y) &= -b(y) \text{ if } x < x^* \\ &= -\pi D(x, y) - b(y) \text{ if } x \geq x^*. \end{aligned}$$

So with negligence $x_n \in \arg\max_i -L_i^n(x, y)$, $x_n = x^*$ and $y_n \in \arg\max -L_v^n(x, y)$, $y_n = y^*$, so we get efficient investment in precaution by the injurer and the victim.

The second liability rule is strict liability, under which the injurer has to pay the damage no matter what level of ex ante precaution he takes. So the expected utility/loss under strict liability is $-L_i^s(x, y) = -\pi D(x, y) - a(x)$ and $-L_v^s(x, y) = -b(y)$, hence $x_s \in \arg\max -L_i^s(x, y)$, $x_s = x^*$ and $y_s \in \arg\max -L_v^s(x, y)$, $y_s = y^*$and the precaution taken by both the injurer and the victim under the rule of strict negligence will be efficient. In both cases for strict liability and negligence, the injurer bears the full cost of the externality/accident he/she causes. The injurer invests in care until the marginal reduction in expected loss equals the marginal cost of care.

4.1 With ambiguity

Now let both the victim and the injurer perceive ambiguity, where both agents' preferences are parameterized by ambiguity attitude α_j and degree of ambiguity δ_j (for $j = i, v$) such that if $\alpha_j = 1$ and $\delta_j > 0$ then the agents are pessimistic and if $\alpha_j = 0$ and $\delta_j > 0$ agents are optimistic. Here the victim and the injurer are ambiguity averse regarding the accident and each others actions. The loss from the worst realization for the injurer if the injurer bears the cost of the accident is $a(x) + D(x, 0)$. Note here the minimum payoff (highest damage) for the injurer is $D(x, 0)$, that is, when the injurer bears liability for not investing x^* and the victim invests zero in care. The utility/loss from the best realization is $a(x)$. For the victim the loss from the worst realization is $b(x) + D(x^*, y)$ which may arise in case of negligence rule. Here the minimum payoff for the victim is when he bears the cost of the damage since the injurer has invested in stipulated care x^*. The utility from the best realization is $b(y)$. The stipulated care for the agents, is going to be the optimal welfare maximizing amount x^* and y^*. Under negligence, the injurer who perceives ambiguity will have the following (Choquet) expected utility,

$$\begin{aligned} -L^n_{iA}(x, y) &= -\delta_i \alpha_i D(x, 0) - (1 - \delta_i)\pi D(x, y) - a(x) \text{ if } x < x^*, \\ &= -a(x) \text{ if } x \geq x^*. \end{aligned}$$

For the victim under negligence we get

$$\begin{aligned} -L^n_{vA}(x, y) &= -\delta_v \alpha_v D(x^*, y) - (1 - \delta_v)\pi D(x, y) - b(y) \text{ if } x \geq x^*, \\ &= -b(y) \text{ if } x < x^*. \end{aligned}$$

Note here that we assume that there is no ambiguity for the court regarding the measurement of x^* and y^*. The marginal benefit, MB_{iA}^n, for the injurer for a change in x, for $x_1 > x_2$, is

$$\begin{aligned} \delta_i \alpha_i \left[D(x_2, 0) - D(x_1, 0)\right] + (1 - \delta_i) \left(\pi \left[D(x_2, y) - D(x_1, y)\right]\right) + \left[a(x_2) - a(x_1)\right] \text{ if } x_1 &< x^*, \\ \left[a(x_2) - a(x_1)\right] \text{ if } x_2 &\geq x^*. \end{aligned}$$

So the injurer will increase x as long as $MB_{iA}^n \geq 0$. Similarly, marginal benefit of the victim, MB_{vA}^n, for a change in $y, y_1 > y_2$, is

$$\begin{aligned} \delta_v \alpha_v \left[D(x^*, y_2) - D(x, y_2)\right] + (1 - \delta_v) \left(\pi[D(x, y_2) - D(x, y_1)]\right) + \left[b(y_2) - b(y_1)\right] \text{ if } x &< x^*, \\ \left[b(y_2) - b(y_1)\right] \text{ if } x &\geq x^*. \end{aligned}$$

The victim will increase investment in care as long as $MB_{vA}^n \geq 0$. While under strict liability for the injurer the expected utility if he/she is ambiguity averse is

$$-L_{iA}^s(x, y) = -\delta_i \alpha_i D(x, 0) - (1 - \delta_i) \left(\pi D(x, y)\right) - a(x).$$

For the victim under strict liability we get

$$L_{vA}^s(x, y) = -b(y).$$

So the injurer will increase x as long as

$$MB_{iA}^s = \delta_i \alpha_i \left[D(x_2, 0) - D(x_1, 0)\right] + (1 - \delta_i) \left(\pi \left[D(x_2, y) - D(x_1, y)\right]\right) + \left[a(x_2) - a(x_1)\right] \geq 0,$$

for $x_1 > x_2$ and the victim increases y as long as $MB_{vA}^s \geq 0$, where $MB_{vA}^s = [b(y_2) - b(y_1)]$ for $y_1 > y_2$. So from above we get Proposition 1.[5]

[5] Note, here that under strict liability, the game between the injurer and the victim is such that the payoffs of each agent is increasing in (x, y). We use Theorem 3.1 from Eichberger and Kelsey (2009), which shows that with

Proposition 1: (i) *Under strict liability, injurers, pessimistic (respectively optimistic) injurers, are going to invest in more care than the socially optimal level,* x^*, *and the victims will invest in care level as long as* $[b(y_2) - b(y_1)] \geq 0$ *for any* $y_1 > y_2$.

(ii) *Under negligence, if both agents are pessimistic* ($\alpha_j = 1$ *and* $\delta_j > 0$, for $j = i, v$) *then the injurer will likely invest the stipulated amount in care and victim will invest in care as long as* $[b(y_2) - b(y_1)] \geq 0$ *for any* $y_1 > y_2$. *If both agents are optimistic* ($\alpha_j = 0$ *and* $\delta_j > 0$, *for* $j = i, v$), *then agents under invest in care.*

Proof: All proofs can be found in the Appendix.

If $\delta_i > 0$ and the injurer perceives ambiguity, then his/her marginal benefit of care is going to be higher than that of a SEU injurer. The marginal increase in benefit when care level goes up from x_2 to x_1 for the injurer who perceives ambiguity is $\delta_i \alpha_i [D(x_2, 0) - D(x_1, 0)] + (1 - \delta_i)(\pi [D(x_2, y) - D(x_1, y)])$ is greater than the marginal benefit, $(\pi [D(x_2, y) - D(x_1, y)])$, of the injurer who is a SEU maximizer. This is true as long as $\alpha_i [D(x_2, 0) - D(x_1, 0)] \leq \pi [D(x_2, y) - D(x_1, y)]$. So under strict liability the injurer will invest more in care. If the stipulated care is set at x^*, then the SEU injurer will invest x^* in care but with ambiguity the injurer will invest $x < x^*$. Since in strict liability the injurer bears the damage costs, the victim will invest $y = 0$. For strict liability we can see from Figure 1, showing the best response functions of the ambiguity averse victim and the ambiguity averse injurer, the equilibrium is at point S. Under strict liability, since the injurer bears all the liability the victim's best response is $y = 0$ for all x. The ambiguity averse injurer will

parameters δ and α, and if the game is such that the payoff of player $i, \Pi_i(s_i, s_{-i})$,where $s_i \in S_i$ is the strategy of player $i, s_{-i} \in S_{-i}$ is the strategy of the other player $-i$, is increasing in s_{-i}, and has increasing differences in $\langle s_i, s_{-i} \rangle$ the equilibrium of the game will exist. For the game under negligence, if we consider mixed strategies then we can show existence of an equilibrium. Therefore the game under either damage rule will have an equilibrium. The definition of the equilibrium is provided in the Appendix.

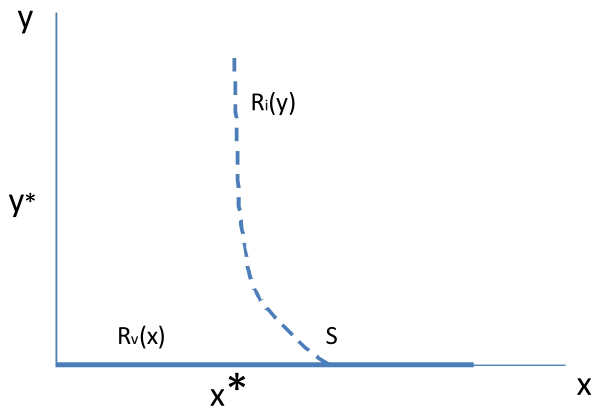

Figure 1: Thick line $R_v(x)$ is the best response function of the victim and dashed line $R_i(y)$ is the best response function of the injurer. S is the equilibrium.

over-invest at $y = 0$, and as y increases will reduce the level of x. Note here that as the injurer and the victim become more ambiguity averse, the equilibrium point S will shift to the right, since the best response of the victim will remain the same but the best response of the injurer will also sift further to the right.

For negligence, with ambiguity averse injurer and victim, we see in Figure 2, that the equilibrium is at point N. The best response function for the injurer suggests, injurer will invest the stipulated amount since this will ensure that it bears no liability. For high values of y, since this will lower the probability of accident, the injurer will reduce x. For the victim's best response, first y decreases as x increases, then at x^*, y increases and then after a discontinuity resulting from the negligence rule y falls. Here is both, injurer and the victim become more ambiguity averse, the equilibrium N shifts up along the vertical line on x^*. The increased ambiguity aversion will result in the best response function of the victim to shift up, while for the injurer only the section of the best response

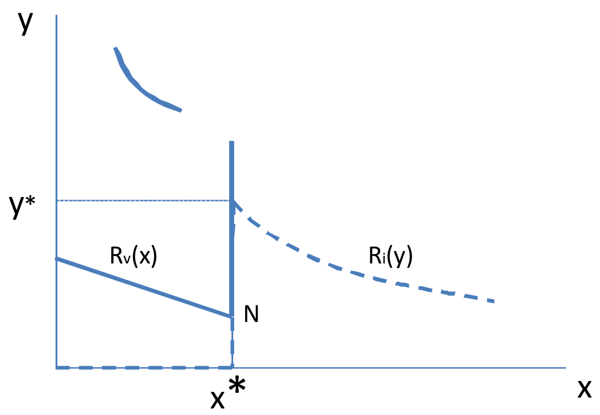

Figure 2: Thick line $R_v(x)$ is the best response function of the victim and dashed line $R_i(y)$ is the best response function of the injurer. N is the equilibrium.

function sloping downwards will shift up.

In Figure 3, we can see how the pessimistic or the ambiguity averse injurer will choose the optimal care level under negligence. Such an injurer will have the expected cost ABCD in Figure 3, and will therefore choose x^*. While under strict liability such an ambiguity averse injurer will have expected cost ECD and will choose $x' > x^*$.

Example 1 *Let* $a(x) = x^2, b(y) = y^2$, $D(x,y) = (1 - x - y)$, $\alpha_j = \alpha, \delta_j = \delta$ *for* $j = i, v$ *and let* $0 \leq x + y \leq 1$. *The optimal investment level* $x^* = \frac{\pi}{2}$ *and* $y^* = \frac{\pi}{2}$. *If strict liability is used as the damage rule then* $x^s = \frac{\delta\alpha + \pi(1-\delta)}{2}$ *and* y *such that* $MB^s_{vA} \geq 0$ *or* $y = 0$. *For* $\alpha = 1$ *and* $\delta < 1, x^s > x^*$.

Note that this result is the different from Teitelbaum (2007). Since the damages are influenced by the investment in care, the injurer due to ambiguity aversion does not *correctly* account for the expected loss due to his actions. So the care he takes, is higher ($x^s > x^*$, if $\alpha_i > \pi$) than the

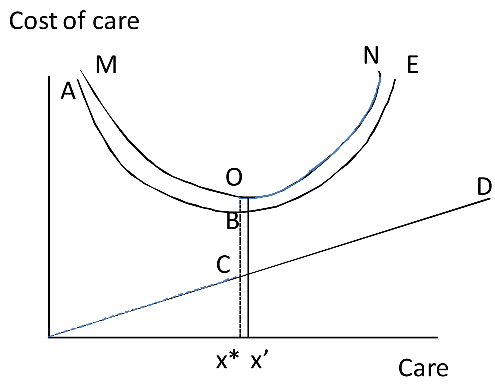

Figure 3: Injurer's expected cost of care. Curve ABE: Expected cost under strict liability when injurer is SEU maximizer. Curve MON: Expected cost under strict liability when injurer is ambiguity averse. MOBCD: Expected cost under negligence when injurer is ambiguity averse.

optimal care. The victim expects that given strict liability he does not have to incur the damage of the accident, therefore minimizes just the cost of effort $b(y)$.

In case of negligence, the injurer bears the cost of damages if the care taken is lower than the stipulated care. If the stipulated care is x^*, the injurer will choose x^* if the expected cost from choosing x^* is less than the expected from cost from choosing any other x. So if $\delta_i \alpha_i D(x,0) + (1-\delta_i)(\pi D(x,y)) + a(x) > a(x^*)$, the injurer will invest x^*. Now if we consider behavioural attitudes of the agents, if the injurer is pessimistic ($\alpha_i = 1, \delta_i > 0$), he/she can completely protect himself from ambiguity by investing x^*, so such an injurer will invest x^*. Otherwise, if the injurer is optimistic, he will under weight the possibility of the damage, so he may choose $x < x^*$, if $\delta_i \alpha_i D(x,0) + (1-\delta_i)(\pi D(x,y)) + a(x) < a(x^*)$.[6] Since the pessimistic injurer will invest x^*, the victim will increase y as long as $MB_{vA}^n \geq 0$ or choose y^* if $\delta_v \alpha_v D(x^*,y) + (1-\delta_v)(\pi D(x,y)) + b(y) > b(y^*)$. In case of an optimistic injurer, the victim knows that the injurer will incur liability and

[6] A slightly optimistic injurer will still choose x^* due to the kink in the pay-off function.

therefore invest $y = 0$. Therefore, unless the victim is completely optimistic, he will invest $y < y^*$.

Example 2 *Let the cost function of care be* $a(x) = x^2$, $b(y) = y^2$, $\alpha_j = \alpha$ *and* $\delta_j = \delta$ *(for* $j = i, v$*). And* $D(x, y) = (1 - x - y)$*. The optimal care is therefore,* $x^* = \pi/2$ *and* $y^* = \pi/2$*. Assume both the injurer and the victim perceive ambiguity. (i) Let* $\alpha = 1$ *and* $\delta > 0$*, then the cost function for the injurer is* $\delta(1 - x) + (1 - \delta)(\pi(1 - x - y)) + x^2$ *if he fails to take the stipulated care and the cost is* $(x^*)^2$ *if he takes stipulated care. If* $\delta(1-x)+(1-\delta)(\pi(1 - x - y))+x^2 > (x^*)^2$*, the injurer will take stipulated care. (ii) Let* $\alpha = 0$ *and* $\delta > 0$*, for the injurer the loss function is* $(1-\delta)\pi(1-x-y)+x^2$*. So the care taken will be* x^* *if* $(1 - \delta)\pi(1 - x - y) + x^2 > x^{*2}$ *. Note that while in case of strict liability* $\alpha = 1$ *and* $\delta < 1$ *results in excessive care by the injurer, here under negligence if* $\alpha = 0$ *and* $\delta > 1 - \frac{x^{*2} - x^2}{\pi(1-x-y)}$ *then the injurer will under invest in care.*

In case of negligence the injurer who is significantly optimistic may ignore the damage he would have to incur if he invests $x < x^*$, as a result he ignores the damages while choosing care. In the case where injurer is pessimistic, he overweights the event where a loss occurs, and therefore will find it cheaper, to take stipulated care x^*. We find that under negligence if the injurer is significantly optimistic then we move away from optimality towards under investment in care but if the injurer is slightly optimistic then due to the kink in the injurer's constraint set the injurer still invests x^*. Negligence, therefore is more robust to ambiguity preference than strict liability. So if the negligence rule is used it is more likely to result in optimal care by the parties if we take into account possibility of ambiguity preferences. Negligence is the most common tort rule used in common law in Britain and America and the robustness to ambiguity may provide a possible reason.

4.2 With unobservable action

Next we introduce the case when the damage is not only influenced by the care taken by the parties but increases with another unobservable action of the injurer and the victim. This action is not observable by any third party or the court of law.[7] In some cases we can think about this unobservable action as the activity level of the agents. For instance this can be the level of drilling in the BP oil spill, or the activity of the nuclear reactor in Windscale nuclear reactor in UK.[8] Let us say the activity of the injurer is s, and that of the victim is t. The maximum amount of activity level for the injurer and the victim is $\overline{s}$ and $\overline{t}$ respectively. Here we assume that the activity levels are unobservable by the court, but as earlier the damage from the accident is observed.[9] This gives the injurer utility $u(s)$ and victim utility $w(t)$ such that u and w are increasing in level of activity and concave. The damage increases with the activity such that the damage function is $\widetilde{D}\left(x,y,s,t\right), \widetilde{D}$ is non decreasing in s and t, $\widetilde{D}$ increases more in s the higher t is, and finally $\widetilde{D}\left(s,t\right)$ has increasing differences in (s,t). The social surplus is given by

$$S(x,y,s,t) = u(s) + w(t) - \pi\left[\widetilde{D}\left(x,y,s,t\right)\right] - sa(x) - tb(y).$$

[7] Here we can also think about unobservability as something which the third party can find out but at a cost, and not as complete unobservability. Secondly, we undertake our analysis under this assumption because we believe that this gives us stronger results.

[8] The BP rig was the deepest oil well in history (http://www.timesonline.co.uk/tol/news/world/us_and_americas/article7128842 And in case of the Windscale nuclear reactor accident in Cumbria, UK, the reactor was being used to build material for a H-bomb which it had not been constructed for (http://news.bbc.co.uk/1/hi/sci/tech/7030281.stm).

[9] The informational assumptions regarding the care level and activity level, reflect the typical case of environmental accident. While the court may find it difficult to find out the amount of care taken by the oil company while drilling for oil, the court will find it easier to get informed about the amount of drilling. Note if we relax this assumption of activity level being observed then our results still hold.

The first best care and activity, (x^*, y^*, s^*, t^*) is given by the following conditions

$$MS_x \geq 0 : MS_x = s\left[a(x_2) - a(x_1)\right] + \pi\left[\widetilde{D}(x_2, y, s, t) - \widetilde{D}(x_1, y, s, t)\right], \text{ for } x_1 > x_2,$$

$$MS_y \geq 0 : MS_y = t\left[b(y_2) - b(y_1)\right] + \pi\left[\widetilde{D}(x, y_2, s, t) - \widetilde{D}(x, y_1, s, t)\right], \text{ for } y_1 > y_2,$$

$$MS_s \geq 0 : MS_s = \left[u(s_1) - u(s_2)\right] + \pi\left[\widetilde{D}\left(x, y, s_2, t\right) - \widetilde{D}\left(x, y, s_1, t\right)\right] + \left[s_2 - s_1\right]a(x) = 0, \text{ for } s_1 > s_2,$$

$$MS_t \geq 0 : MS_t = \left[w(t_1) - w(t_2)\right] + \pi\left[\widetilde{D}\left(x, y, s, t_1\right) - \widetilde{D}\left(x, y, s, t_2\right)\right] + \left[t_2 - t_1\right]b(y) = 0 \text{ for } t_1 > t_2.$$

If the damage increases with the activity of the agents, and if the court applies strict liability, then with ambiguity the injurer and the victim, respectively, have the following expected utility

$$U_{iA}^s(x, y, s, t) = u(s) + \alpha_i \delta_i \widetilde{D}(x, 0, s, \overline{t}) + (1 - \delta_i)\pi \widetilde{D}\left(x, y, s, t\right) + sa(x),$$

$$U_{vA}^s(x, y, s, t) = w(t) + tb(y).$$

4.2.1 Strict Liability

First we discuss strict liability when damages increase with activity levels and agents perceive the chances of accident to be ambiguous.

Proposition 3 *(i) Under strict liability, when the damage increases with increased activity by the injurer and the victim, the ambiguity averse injurer will be less active than optimal, but the victim will participate more in the activity than the optimal level. (ii) Under strict liability the injurer invests more than stipulated care* x^* *and the victim invests* $y = 0$, *if they are sufficiently ambiguity averse.*

The marginal benefit level of activity of the injurer for $s_1 > s_2$, is given by the first order condition,

$$\begin{aligned} MB^s_{iA}(s) &= [u(s_1) - u(s_2)] + \alpha_i\delta_i \left[\widetilde{D}(x, 0, s_2, \bar{t}) - \widetilde{D}(x, 0, s_1, \bar{t})\right] \\ &\quad + (1 - \delta_i)\pi \left[\widetilde{D}\,(x, y, s_2, t) - \widetilde{D}\,(x, y, s_1, t)\right] + [s_2 - s_1]\, a(x). \end{aligned}$$

Note that under ambiguity the injurer faces an additional marginal cost compared to SEU if $\alpha_i\delta_i \left[\widetilde{D}(x, 0, s_2, \bar{t}) - \widetilde{D}(x, 0, s_1, \bar{t})\right] - \delta_i\pi \left[\widetilde{D}\,(x, y, s_2, t) - \widetilde{D}\,(x, y, s_1, t)\right] > 0$. So under ambiguity the injurer decreases the level of activity s in comparison to the SEU maximizing injurer if he/she is very pessimistic and the probability of accident is very small. The victim is going to undertake an activity level $t > t^*$, since he is not liable, he will ignore the externality caused by his activity and does not consider $\pi \left[\widetilde{D}\,(x, y, s, t_2) - \widetilde{D}\,(x, y, s, t_1)\right]$, for $t_1 > t_2$, the additional marginal cost his activity causes. The analysis of the choice of the care levels is quite similar to the case of strict liability without activity levels. The injurer over-invests in care as $x > x^*$ as long as $\alpha_i \neq 0, \delta_i > 0$, since the marginal benefit of an increase in x is given by

$$\begin{aligned} MB^s_{iA}(x) &= \alpha_i\delta_i \left[\widetilde{D}(x_2, 0, s, \bar{t}) - \widetilde{D}(x_1, 0, s, \bar{t})\right] + \\ &\quad (1 - \delta_i)\pi \left[\widetilde{D}\,(x_2, y, s, t) - \widetilde{D}\,(x_1, y, s, t)\right] + s\,[a(x_2) - a(x_1)] \end{aligned}$$

for $x_1 > x_2$. Increasing differences implies $MB^s_{iA}(x)$ is higher than the SEU marginal benefit. Thus the injurer's best response curve is higher with ambiguity. Since the victim does not have to face the damage, he invests $y = 0$ in care.

Further, due to ambiguity, the injurer will use a lower non-observable action. While the victim will do more. The reduced non-observable action will compensate for the reduced care. The reason is that due to pessimism, for the injurer the marginal cost of the non-observable action will increase, since he will put extra weight on the damage.

4.2.2 Negligence

Now if the damage rule is negligence, then the agents have the following Choquet expected utility:

$$
\begin{aligned}
U_{iA}^{n}(x,y) &= u(s) - \alpha_i \delta_i \widetilde{D}(x,0,s,\overline{t}) - (1-\delta_i)\pi \widetilde{D}\,(x,y,s,t) - sa(x) \text{ if } x < x^*, \\
&= u(s) - sa(x) \text{ if } x \geq x^*,
\end{aligned}
$$

$$
\begin{aligned}
U_{vA}^{n}(x,y) &= w(t) - \alpha_v \delta_v \widetilde{D}\,(x^*,y,\overline{s},t) - (1-\delta_v)\pi \widetilde{D}\,(x,y,s,t) - tb(y) \text{ if } x \geq x^*, \\
&= w(t) - tb(y) \text{ if } x < x^*.
\end{aligned}
$$

The marginal benefit for change in x, y, s and t and for $x_1 > x_2, y_1 > y_2, t_1 > t_2$ and $s_1 > s_2$ are given below. Note these are derived such that when choosing x and y, non-observable action s and t are taken as given, and when choosing s and t, level of care x and y are taken as given.

$$
x : \alpha_i \delta_i \left[\widetilde{D}(x_2,0,s,\overline{t}) - \widetilde{D}(x_1,0,s,\overline{t})\right]
$$

$$
+(1-\delta_i)\pi \left[\widetilde{D}(x_2,y,s,t) - \widetilde{D}(x_1,y,s,t)\right] + s\left[a(x_2) - a(x_1)\right] \quad \text{if } x_1 < x^*,
$$

$$
s\left[a(x_2) - a(x_1)\right] \text{ if } x_2 \geq x^*,
$$

$$
y : \alpha_v \delta_v \left[\widetilde{D}\,(x^*,y_2,\overline{s},t) - \widetilde{D}\,(x^*,y_1,\overline{s},t))\right]
$$

$$
+(1-\delta_v)\pi \left[\widetilde{D}\,(x,y_2,s,t) - \widetilde{D}\,(x,y_1,s,t)\right] + t\left[b(y_2) - b(y_1)\right] \text{ if } x \geq x^*,
$$

$$
t\left[b(y_2) - b(y_1)\right] \text{ if } x < x^*,
$$

$$
s : \left[u(s_1) - u(s_2)\right] + \alpha_i \delta_i \left[\widetilde{D}(x,0,s_2,\overline{t}) - \widetilde{D}(x,0,s_1,\overline{t})\right] +
$$

$$
(1-\delta_i)\pi \left[\widetilde{D}(x,y,s_2,t) - \widetilde{D}(x,y,s_1,t)\right] + \left[s_2 - s_1\right] a(x) \text{ if } x < x^*,
$$

$$
\left[u(s_1) - u(s_2)\right] + \left[s_2 - s_1\right] a(x) \text{ if } x \geq x^*,
$$

$$t:[w(t_1)-w(t_2)]+\alpha_v\delta_v\left[\widetilde{D}\left(x^*,y,\overline{s},t_2\right)-\widetilde{D}\left(x^*,y,\overline{s},t_1\right))\right]$$

$$+(1-\delta_v)\pi\left[\widetilde{D}\left(x,y,s,t_2\right)-\widetilde{D}\left(x,y,s,t_1\right))\right]+[t_2-t_1]\,b(y)\text{ if }x\geq x^*,$$

$$[w(t_1)-w(t_2)]+[t_2-t_1]\,b(y)\text{ if }x<x^*.$$

We get the following proposition;

Proposition 4 *(i) Under negligence when both the injurer's and victim's activity increases the damage, the non-observable action of the pessimistic injurer will be above the optimal level and for the optimistic injurer the non-observable action may also be above the optimal level. The victim will choose a lower non-observable action if $x \geq x^*$ and in case the injurer chooses $x < x^*$, the victim will choose a higher non-observable action. (ii) Under negligence the pessimistic injurer will invest the stipulated amount of care. The optimistic injurer will may not invest in the stipulated amount of care. The victim will invest y such that the marginal benefit is greater than or equal to zero if the injurer invests x^* or if $x < x^*$ then the victim will invest $y = 0$.*

The pessimistic injurer will choose $x = x^*$, since the cost of investing x^* in care will be less than the expected cost of bearing the liability in case $x < x^*$. So the pessimistic injurer will choose $s > s^*$ since he will no longer be liable due to his choice of $x = x^*$. While the victim will choose $t < t^*$, as the pessimistic victim overweights the damage. In case the injurer is optimistic and is ambiguity averse (δ_i is close to 1), then the injurer may ignore the possibility of the damage and hence invest $x < x^*$. However, if the optimistic injurer has ambiguity preference, $\alpha_i = 0$, then he will invest x^*. The optimistic injurer who invests below x^* will select $s < s^*$, since he will be facing liability. The victim will choose $t > t^*$ since the victim will realize that the injurer will choose

$x < x^*$ and bear the damage. So the victim will ignore the marginal cost of damage caused due to t.

Here we see that the analysis regarding the investment in care is similar to the earlier case of negligence when the damage was not influenced by level of activity. So what matters here is if the injurer is more pessimistic or more optimistic as earlier, where the pessimistic injurer will choose the stipulated care level. The victim in case of a pessimistic injurer will choose a higher level of care than when the injurer is more optimistic. In case the injurer is optimistic, he will ignore the damage in his decision making and therefore the level of care chosen is going to be $x < x^*$, which in turn will result in the victim ignoring the damage in his decision problem since, if $x < x^*$, after the accident the injurer will bear the cost of the accident. As a result this will not only reduce the level of care but also increase the level of activity. So here we can see that if the injurer is sufficiently optimistic negligence will do quite poorly in terms of social welfare if the stipulated care is the optimal level x^*.

5 Optimal Tort

Shavell (1987) points out that it is not possible to achieve efficient levels of non-observable actions. The problem being that it is not possible to make both parties face the full marginal cost of their actions and balance the budget. So this would mean in our example tort rules, negligence and strict liability, would fail to provide incentives to BP and the victims of the accident to undertake the correct amount of care and level of activity. In this section we show, if players are ambiguity averse ($\alpha_i = \alpha_v = 1$) then using the following liability rule, the optimal care and non-observable action by injurer and the victim can be implemented. We first discuss the case when only the unobservable action affect the damage level $\widetilde{D}(\overline{x},\overline{y},s,t)$, and the observed actions are held constant constant at $\overline{x}$ and $\overline{y}$. Note the level of damage is observed by all agents including the court. Consider a damage rule which imposes a liability on the injurer if the damage is above a certain threshold $\widehat{l}$, otherwise the victim is liable. The liability the injurer is held to, is the damage caused $\widetilde{D}$ and a fine F. If we ignore budget balancing then the fine, F, can be paid to the third party by the injurer or considering budget balance, F is paid by the injurer to the victim. This mechanism gives optimal level of non-observable action, if the threshold $\widehat{l}$ is appropriately chosen. The ambiguity averse injurer when faced with an ambiguous liability if the damage is excessive will limit the non-observable action to the optimal level. The ambiguity averse victim faced with the liability will choose his non-observable action in order to limit the size of the damage, and therefore internalize the damage in his non-observable action choice. Here the key thing is the ambiguous liability, which the victim and the injurer consider while making their decision. The expected utility for the injurer is

$$\begin{aligned} u(s) - \delta_i\left[\widetilde{D}(\overline{x},\overline{y},s,\overline{t}) + F\right] - (1-\delta_i)\pi\left[\widetilde{D}(\overline{x},\overline{y},s,t) + F\right] - sa(x) \text{ if } \widetilde{D}(\overline{x},\overline{y},s,t) &\geq \widehat{l}, \\ u(s) - sa(x) \text{ if } \widetilde{D}(\overline{x},\overline{y},s,t) &< \widehat{l}. \end{aligned}$$

For the victim, the expected utility, considering budget balance, is

$$\begin{aligned} w(t) - \delta_v\widetilde{D}(\overline{x},\overline{y},\overline{s},t) - (1-\delta_v)\pi\left[\widetilde{D}(\overline{x},\overline{y},s,t)\right] - tb(y) \text{ if } \widetilde{D}(\overline{x},\overline{y},s,t) &< \widehat{l}, \\ w(t) - tb(y) \text{ if } \widetilde{D}(\overline{x},\overline{y},s,t) &\geq \widehat{l}. \end{aligned}$$

The victim does not consider the fine F in his decision making because the fine is only paid out of equilibrium. Here the injurer in order to avoid bearing the loss caused by the damage will choose the optimal level of activity such that the size of the loss is not larger than the threshold loss $\widehat{l}$. Since in equilibrium the victim bears the loss, the victim will choose the optimal level of activity. We can see

Example 5 *Let $s \in \{\sigma_1, \sigma_2, \sigma_3\}$ and $t \in \{\tau_1, \tau_2, \tau_3\}$ and let the optimal action s be σ_2 and optimal t be τ_2. The damage from the activity level is $\widetilde{D}(s,t)$, and $\widehat{l}$ is the threshold. Assume that without ambiguity aversion both the injurer and the victim choose σ_3 and τ_3 respectively and assume $w(\tau_1) = 0$ and $u(\sigma_1) = 0$. Let $\widetilde{D}$ be such that the injurer has a bigger impact on the damage than the victim and $F > 0$. If $\widetilde{D}(\sigma_2, \tau_3) < \widehat{l} < \widetilde{D}(\sigma_3, \tau_1)$, we get the following*

$$w(\tau_2) - \delta_v \widetilde{D}(\sigma_3, \tau_2) - (1-\delta_v)\pi \left[\widetilde{D}(s, \tau_2)\right] - \tau_2 b(y)$$
$$\geq w(\tau_3) - \delta_v \widetilde{D}(\sigma_3, \tau_3) - (1-\delta_v)\pi \left[\widetilde{D}(s, \tau_3)\right] - \tau_3 b(y)$$

and $w(\tau_2) - \delta_v \widetilde{D}(\sigma_3, \tau_2) - (1-\delta_v)\pi \left[\widetilde{D}(s, \tau_2)\right] - \tau_2 b(y) \geq \delta_v \widetilde{D}(\sigma_3, \tau_1) - (1-\delta_v)\pi \left[\widetilde{D}(s, \tau_1)\right] - \tau_2 b(y)$

So that for the ambiguity averse victim the choice will be τ_2, since higher activity will lead to greater damage. Given τ_2, for the injurer, the injurer will face liability if damage is greater than $\widehat{l}$, so

$$\begin{aligned} u(\sigma_2) - \sigma_2 a(x) &\geq u(\sigma_3) - \delta_i \left[\widetilde{D}(\sigma_3, \tau_3) + F\right] - (1-\delta_i)\pi \left[\widetilde{D}(\sigma_3, \tau_2) + F\right] - \sigma_3 a(x) \\ u(\sigma_2) - \sigma_2 a(x) &\geq -\sigma_1 a(x) \end{aligned}$$

Note that the threshold is chosen so that is clear that both, injurer and victim, have taken inefficient actions.

5.1 With variable care levels

Next we discuss the optimal tort rule if both activity levels and care levels, i.e., the observed and the unobserved actions, are included in the analysis. So the liability rule has to be such that the injurer and the victim are induced to invest optimally in care as well as undertake the optimal level of activity.

First, the victim will be liable for all his losses if the injurer takes the stipulated care or the size of the damage is below a threshold. Let us define the loss incurred due to the accident as $L \equiv \widetilde{D}(x, y, s, t)$. So the victim with ambiguity averse preferences will have the following expected utility $w(t) - \delta_v \widetilde{D}(x^*, y, \overline{s}, t) - (1-\delta_v)\pi \widetilde{D}(x, y, s, t) - tb(y)$ only if $x \geq x^*$, otherwise will have $w(t) - tb(y)$. The injurer bears the loss if he fails to take the stipulated care. So in case of $x < x^*$ and there is an accident the injurer faces a liability equivalent to the loss. In addition if the the loss is beyond a threshold $L \geq \widehat{L}$, then the injurer faces a liability equivalent to the loss and a punitive fine $F > 0$. So the injurer knows the expected utility he will face if $x < x^*$, is $u(s) - \delta_i \widetilde{D}(x, 0, s, \overline{t}) - (1-\delta_i)\pi \left[\widetilde{D}(x, y, s, t)\right] - sa(x)$ and if the loss observed is $L \geq \widehat{L}$ then the expected utility he will face is $u(s) - \delta_i \left[\widetilde{D}(x, 0, s, \overline{t}) + F\right] - (1-\delta_i)\pi \left[\widetilde{D}(x, y, s, t) + F\right] - sa(x)$. The negligence rule that the injurer will face liability of the loss if $x < x^*$ will ensure that the injurer will invest x^*. This will be true since the injurer is pessimistic and the expected cost from investing x^* will always be lower than the expected cost from not investing x^* and bearing the liability. Given that the injurer will invest in stipulated care, we now check if the injurer will undertake the optimal level of activity. Since the injurer faces punitive penalty and liability $\left(\widetilde{D}(x, y, s, t) + F\right)$ if $L \geq \widehat{L}$, this threat will result in a pessimistic injurer restricting himself from excessive activity. The proposal works since it induces an ambiguity-averse injurer to take the correct action by making an ambiguous threat. The victim will bear all the losses unless there is excessive loss, $L \geq \widehat{L}$, which only occurs out of equilibrium. So for $L < \widehat{L}$, the marginal benefit from the care would be

$$\delta_v \left[\widetilde{D}(x^*, y_2, \overline{s}, t) - \widetilde{D}(x^*, y_1, \overline{s}, t)\right] + (1-\delta_v)\pi \left[\widetilde{D}(x, y_2, s, t) - \widetilde{D}(x, y_1, s, t)\right]$$
$$+t\left[b(y_2) - b(y_1)\right] \text{ for } y_1 > y_2$$

and the marginal benefit from activity level will be

$$[w(t_1) - w(t_2)] + \delta_v \left[\widetilde{D}(x^*, y, \overline{s}, t_2) - \widetilde{D}(x^*, y, \overline{s}, t_1)\right] + (1-\delta_v)\pi \left[\widetilde{D}(x, y, s, t_2) - \widetilde{D}(x, y, s, t_1)\right]$$
$$+ [t_2 - t_1]\, b(y) \text{ for } t_1 > t_2.$$

. For sufficient ambiguity aversion for the victim, he will invest optimally in care y^* and undertake t^*. This will ensure that the victim invests optimally in care and activity.

The analysis here can be related to example of an environmental accident like BP in Gulf of Mexico. An injurer like BP can be induced to take the optimal observable action or care in this case by negligence rule and can be induced to take the optimal level of the unobservable action or activity by the threat of punitive damages. And perhaps the amount BP paid to the local businesses is in excess of the true loss incurred by the businesses. So the payment may have some punitive component it it. Assuming that all victims are modelled as one player, will take the optimal amount of care and activity.[10]

Proposition 6 *The tort rule (a) victim is liable for the loss L below a threshold $\widehat{L}$ and if the injurer invests in stipulated care, (b) the injurer is liable for the loss $L \leq \widehat{L}$ if he fails to invest in the stipulated care, (c) the injurer is liable for the loss L and punitive fine F, if the loss is $L > \widehat{L}$, results in a sufficiently pessimistic injurer investing in the stipulated/optimal care levels, x^* and y^* respectively.*

So we find that here while negligence rule gives optimal care levels by the agents, a punitive fine borne by the injurer in case of excessive damage is results in optimal level of activity from the injurer and the victim if they are sufficiently pessimistic[11]. Since the activity level is not observed

[10] We believe that the many victims case is a straight forward extension of this.

[11] A related point is made in Kelsey and Spanjers (2004), who show that ambiguity may increase the set of outcomes

by the court or the third party, a high enough fine levied on the pessimistic injurer will restrict the injurer's activity level while the negligence rule will induce the injurer to take stipulated or optimal care. So if we have agents who are ambiguity averse, we can get the optimal levels of care and activity if in addition to negligence punitive damages are used. We should note that is ex-post optimality is achieved, and this is due to the threat of the punitive fine F which induces the injurer to choose the optimal activity level. Note this rule may not be ex-ante optimal, taking into account the any utility loss due to ambiguity aversion. Here the analysis assumes the agents are ambiguity averse, but this result can be extended to ambiguity preferences if ambiguous rewards are used instead of ambiguous punishments. In light of our previous example of the BP oil spill and its qualitative similarity with our model, we can see how the liability rule may apply; if the damage is not substantial then the liability is borne by the victims as long as BP takes stipulated care, but if the damage is extremely large then BP would not only bear the liability but also a substantial fine.

6 Conclusion

Shavell (1987) analyses the tort rules, and shows that negligence and strict liability give efficient investment in care if the stipulated level of care is set at the efficient level. At the same time, if the levels of activity are included in the analysis, then with stipulated care equal to the optimal level, we cannot get optimal investment in care and optimal level of activity by both the injurer and the victim. In our analysis, the corresponding actions to care and activity levels are the observable action and the non-observable action. Here motivated by environmental accidents we analyze tort

which can be implemented in a context of team production. They show that with non-additive beliefs, it is possible to make both parties face the full marginal cost of their actions.

rules when the potential injurer and the victim is ambiguous. We have seen that with ambiguity, if the non-observable action is not included in the analysis then for strict liability, injurers invest more than the optimal in the observable action or care. With negligence, in case of pessimistic players, we see the optimal care by the injurer may be obtained. This is due to the fact that the pessimistic injurer will find it less costly to invest in the stipulated care than the expected cost when he is liable. But if the agents are optimistic then they may ignore the possibility of the damages and they fail to take adequate care. So clearly for social welfare, if the agents are pessimistic then negligence dominates strict liability.

From the analysis with non-observable action, we find that if strict liability is used, there is over investment in the observable action by the injurer, but the ambiguous injurer also restricts the amount of non-observable action. This is due to the fact that with ambiguity the injurer puts extra weight on the likelihood of the damage and since the damage is influenced by the non-observable action, this will increase the marginal cost of non-observable action. While the non-observable action may not be optimal, there may be an improvement over the case when the injurer is just a SEU decision maker. The injurer may choose the observable action above the optimal level but as discussed the non-observable action is lower, due to ambiguity. For negligence, if the injurer is pessimistic then he will invest optimally in the observable action but will increase his non-observable action. The victim will over invest in the observable action but will also reduce the non-observable action. Interestingly if the injurer is optimistic and does invest less than the optimal level, then the victim will not invest in any observable action and also increase the non-observable action. This suggests that with sufficiently optimistic injurers, negligence does not seem to work well, while with pessimistic injurers negligence seems to do better in terms of social welfare, subject to the earlier comments made on negligence and optimism.

In the paper we have left out the analysis of defence with contributory negligence. This is when the victim in order to recover the damage of the accident needs to have taken a stipulated amount of care. The analysis is similar to the one above. If the analysis is without the non-observable action, then the injurer will be liable and over-weigh the potential losses and thus over-invest in observable action. Ambiguity-aversion will give the victim an incentive to choose the stipulated observable action or care level which gives a certain pay-off. If the victim is pessimistic then he will find it cheaper to invest in stipulated care. Thus, the injurer will be held liable if an accident occurs. So the ambiguity averse injurer will invest more. Note, here, too, if stipulated care is lower than optimal care, then the injurer may be provided with incentives to invest closer to optimal care.

With negligence and defence with contributory negligence, we find that if the victim is pessimistic and the injurer is also pessimistic we get optimal investment in care. This is due to the fact that both the injurer and the victim will find it cheaper to invest in the stipulated care. But when the victim is optimistic, he may invest less than the stipulated care, and due to this the injurer will also invest less than the stipulated amount since he will escape liability. For the analysis with activity level, we see here as earlier that due to ambiguity, under strict liability the marginal cost of activity goes up therefore the injurer will reduce his activity level. With negligence and contributory defence, we see that for the pessimistic victim and the injurer there will be optimal care but this may increase the activity level of the injurer since he is no longer liable.

We can observe from the above analysis is that if the agents are pessimistic then negligence as a tort regime does quite well in comparison to strict liability. But for sufficiently optimistic agents negligence fares quite poorly as agents ignore damages in their decision making problem. While with strict liability the ambiguity averse injurer will over invest in comparison to the optimal level.

Here we have attempted to raise the question how behavioural assumptions other than subjective expected utility may affect the analysis of optimal tort rule. Much of the law and economics literature assumes decision makers are SEU maximizers. However evidence such as Ellsberg (1961) suggests that decision makers may fail to act as SEU maximizers. This is the case when the decision makers are not aware of the probability distribution. The law should deal with actual individual decisions and not idealised rational decisions. Hence we need to study how legal rules are affected by behavioural issues. Therefore to relax the assumption of SEU decision makers and replace it with ambiguity averse decision makers may be specifically relevant in case of tort. Since the decision maker, either the injurer or the victim, may not be aware of the probability distribution of accident and therefore this ambiguity will affect the optimal tort. We find that the standard result that strict liability and negligence are efficient is no longer true but may be differently effective depending on ambiguity attitude of the agents. Instead we can show that a negligence rule coupled with punitive damages for excessive loss can give optimal care. Analysing legal rules by using a decision making model other than SEU will throw more light on the effectiveness of the legal rules.

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7 Appendix

Definition 2 *For a game* Γ *with externalities, and any exogenously given ambiguity attitudes* δ_j *and* α_j*, for* $j = i, v$*, has an equilibrium* $\nu = \langle \nu_i, \nu_v \rangle$*, where* $\nu_j = \delta_j(1-\alpha_j) + (1-\delta_j)\pi$ *for* $j = i, v$*,*

Proof of Proposition 1: The expected losses for the ambiguous injurer is $L^s_{iA}(x, y) = (\delta_i\alpha_i + (1-\delta_i)\pi)\, D(x, y) + a(x)$ the injurer will increase x as long as the marginal benefit from x is $MB^n_{iA} \geq 0$. If $(\delta_i\alpha_i + (1-\delta_i)\pi) > \pi$, the marginal cost to the CEU injurer is greater than ML_x, the marginal cost for the subjective expected utility maximizer, so $x > x^*$. Given the injurer bears the damage, the victim's choice is given by y as long as $MB^s_{vA} \geq 0$, or $y = 0$.

Under negligence, the expected loss for the injurer and the victim is $L^n_{iA}(x, y)$ and $L^n_{vA}(x, y)$ respectively. The injurer will choose x^* if

$$(\delta_i \alpha_i + (1 - \delta_i)\pi)(D(x, y)) + a(x) > a(x^*)$$

The victim's investment in care is given by $MB^n_{vA} \geq 0$ and this implies $y = 0$. If the injurer is pessimistic, $\alpha = 1$ and $\delta \to 1$, then the loss function of the injurer is $D + a(x) > a(x^*)$. So the completely pessimistic injurer will invest in stipulated x^* in care. In the case where the injurer is optimistic, $\alpha = 0$ and $\delta \to 1$, then $a(x) < a(x^*)$ thus $x < x^*$. If the victim knows that the injurer is optimistic then the care taken by the victim will be $y = 0$. And if the injurer is pessimistic then the victim will invests y such that $MB^n_{vA} \geq 0$ or y^* if $(\alpha_v \delta_v + (1 - \delta_v)\pi) D(x, y) + b(y) > b(y^*)$.

Proof of Proposition 3 :

In order to analyze the games with pessimistic and optimistic preferences with non-observable action and observable action the utilities, under strict liability, are,

$$U^s_{iA}(s, t, x, y) = u(s) - \alpha_i \delta_i \widetilde{D}(x, 0, s, \overline{t}) - (1 - \delta_i)\pi \widetilde{D}(x, y, s, t) - sa(x).$$

$$U^s_{vA}(s, t, x, y) = w(t) - tb(y).$$

The injurer will choose $s > 0$ and will increase non-observable action as long as $MB^s_{iA}(s) \geq 0$. But the level of activity, s, is lower than the optimal s^*, since under ambiguity the injurer takes into account a higher marginal cost. The victim is going to choose t such that $MB^s_{vA}(t) \geq 0$ and this $t > t^*$.

The injurer will increase the amount of care if $MB^s_{iA}(x) \geq 0$. If $\delta_i > 0$ and $s > 0$, then the marginal cost the injurer considers is higher than the actual marginal cost incurred. The victim invests $y = 0$, since the victim's marginal benefit from increase in care is zero.

Proof of Proposition 4: When agents choose activity levels given care under negligence, the payoffs are $U^n_{iA}(s,t,x,y)$ and $U^n_{vA}(s,t,x,y)$.Given a level of x and y, the injurer chooses s and the victim selects t. If $x \geq x^*$, then the level of activity s will be chosen such that the marginal benefit from the activity $[u(s_1) - u(s_2)] + [s_2 - s_1]\, a(x) \geq 0$ and $s > s^*$. And in case $x < x^*$, then s will be such that the marginal benefit, $[u(s_1) - u(s_2)] + \alpha_i \delta_i \left[\widetilde{D}(x, 0, s_2, \overline{t}) - \widetilde{D}(x, 0, s_1, \overline{t})\right] + (1 - \delta_i)\pi \left[\widetilde{D}(x, y, s_2, t) - \widetilde{D}(x, y, s_1, t)\right] + [s_2 - s_1]\, a(x) \geq 0$. If $x \geq x^*$, the victim will choose $t < t^*$ as the pessimistic victim overweights the damage and therefore considers an increased marginal cost of t. In case $x < x^*$, then $t > t^*$.

The injurer will invest in x^* if $-sa(x^*) < -\alpha_i \delta_i \left(\widetilde{D}(x, 0, s, \overline{t})\right) - (1 - \delta_i)\pi \widetilde{D}(x, y, s, t) - sa(x)$. If $s > 0$ and the injurer is pessimistic (in the extreme $\alpha = 1, \delta > 0$) then the injurer will choose x^*. The victim therefore will choose y such that $\alpha_v \delta_v \left[\widetilde{D}\left(x^*, y_2, \overline{s}, t\right) - \widetilde{D}\left(x^*, y_1, \overline{s}, t\right)\right)\right] + (1 - \delta_v)\pi \left[\widetilde{D}\left(x, y_2, s, t\right) - \widetilde{D}\left(x, y_1, s, t\right)\right] + t\,[b(y_2) - b(y_1)] \geq 0$. In case the injurer is optimistic (in the extreme $\delta > 0, \alpha = 0$), he ignores the possibility of the damage, and the injurer chooses $x < x^*$ such that $\alpha_i \delta_i \left[\widetilde{D}(x_2, 0, s, \overline{t}) - \widetilde{D}(x_1, 0, s, \overline{t})\right] + (1 - \delta_i)\pi \left[\widetilde{D}(x_2, y, s, t) - \widetilde{D}(x_1, y, s, t)\right] + s\,[a(x_2) - a(x_1)] \geq 0$. The victim therefore knows that the injurer will be liable and selects $y = 0$ since the decision is given by the condition $t\,[b(y_2) - b(y_1)] \geq 0$.

Proof of Proposition 5:

The pay-off of the victim is

$$w(t) - \delta_v \widetilde{D}(x^*, y, \overline{s}, t) - (1-\delta_v)\pi \widetilde{D}(x, y, s, t) - tb(y) \text{ if } x \geq x^* \text{ and } L < \widehat{L}$$

$$w(t) - tb(y) \text{ if } x < x^*$$

$$w(t) - tb(y) - F \text{ if } L \geq \widehat{L}.$$

The pay-off of the injurer is

$$u(s) - sa(x) \text{ if } \left(x \geq x^* \text{ and } L < \widehat{L}\right)$$

$$u(s) - \delta_i \left[\widetilde{D}(x, 0, s, \overline{t})\right] - (1-\delta_i)\pi \left[\widetilde{D}(x, y, s, t)\right] - sa(x) \text{ if } x < x^* \text{ and } L < \widehat{L}$$

$$u(s) - \delta_i \left[\widetilde{D}(x, 0, s, \overline{t}) + F\right] - (1-\delta_i)\pi \left[\widetilde{D}(x, y, s, t) + F\right] - sa(x) \text{ if } L \geq \widehat{L}.$$

The injurer will invest in care x^* if

$$u(s) - sa(x^*) \leq u(s) - \delta_i \left[\widetilde{D}(x, 0, s, \overline{t})\right] - (1-\delta_i)\pi \left[\widetilde{D}(x, y, s, t)\right] - sa(x).$$

So a sufficiently pessimistic injurer will always find it beneficial to invest in care levels x^*. If the damage level is too high, $L \geq \widehat{L}$, then the expected utility includes a large fine F.

$$u(s) - \delta_i \left[\widetilde{D}(x, 0, s, \overline{t}) + F\right] - (1-\delta_i)\pi \left[\widetilde{D}(x, y, s, t) + F\right] - sa(x).$$

The injurer is going to select s as long as $MB_i \geq 0$. If F can be set such that marginal benefit, MB, is equal to MS_s, then the level of s is going to be equal to the optimal level. Given that injurer is going to invest x^*, the victim has an expected cost

$$w(t) - \delta_v \widetilde{D}(x^*, y, \overline{s}, t) - (1-\delta_v)\pi \widetilde{D}(x, y, s, t) - tb(y).$$

So the victim's marginal benefit from choosing $t_1 > t_2$ and $y_1 > y_2$ is

$$t : w(t_1) - u(t_2) + \delta_v \left[\widetilde{D}(x^*, y, \overline{s}, t_2) - \widetilde{D}(x^*, y, \overline{s}, t_1)\right] +$$

$$(1 - \delta_v)\pi_v \left[\widetilde{D}(x, y, s, t_2) - \widetilde{D}(x, y, s, t_1)\right] + (t_2 - t_1)\, b(y) \text{ if } L < \widehat{L}$$

$$w(t_1) - w(t_2) + (t_2 - t_1)\, b(y) \text{ otherwise.}$$

$$y : \delta_v \left[\widetilde{D}(x^*, y_2, \overline{s}, t) - \widetilde{D}(x^*, y_1, \overline{s}, t)\right] +$$

$$(1 - \delta_v)\pi \left[\widetilde{D}(x, y_2, s, t) - \widetilde{D}(x, y_1, s, t)\right] + t\,[b(y_2) - b(y_1)] \text{ if } L < \widehat{L}$$

$$t\,[b(y_2) - b(y_1)] \text{ otherwise.}$$

The injurer will choose care and activity level such that the size of the damage, $L < \widehat{L}$. The victim will increase t and y as long as the respective marginal benefit is greater than or equal to zero. The levels of marginal condition for the optimal choice, t^* and y^*, is given by

$$w(t^*) - w(t) + \pi \left[\widetilde{D}(x, y, s, t) - \widetilde{D}(x, y, s, t^*)\right] + b(y) \geq 0$$

$$t\,[b(y) - b(y^*)] \geq -\pi \left[\widetilde{D}(x, y^*, s, t) - \widetilde{D}(x, y, s, t)\right]$$

So if $L < \widehat{L}$, and the victim will choose $y = y^*$ and $t = t^*$as long as he/she is at least ambiguity neutral and not ambiguity loving.