Appendix A

Model of Risky Behavior

Consider an individual who has initial resources (wealth) w and a probability p^0 of surviving a single period. Following Linnerooth (1982), we assume that his depends on the state of the world: if the individual dies he will enjoy no utility regardless of his wealth.[1] If the individual survives, he will enjoy a utility from leisure (i.e., "consumption" of resources that have no marginal social cost) and from consumption of his endowed resources.[2] For simplicity, we assume that the utility from leisure and consumption are additive. We further assume that the individual is risk averse or neutral with respect to wealth so that $u'(w) > 0$ and $u''(w) \leq 0$. Later on we will simplify the analysis and focus only on risk neutrality, so we could write $u(w) = w$. Thus the individual expected utility v can be written as:

$$v = p^0[L + u(w)] \tag{A1}$$

Investment in safety

Suppose that the individual can invest his resources $x \in [0, w]$ in precautions which will increase the probability of survival. Assume that the probability of survival $p(p^0, x)$ is concave in x for all p^0, so that $p_x > 0$ and $p_{xx} < 0$. Suppose also that p_x is independent of p^0.[3] The problem for the individual is to choose x to maximize his expected utility:

$$v(x) = p(p^0, x)[L + u(w - x)] \tag{A2}$$

The optimal private care, assuming an interior solution, denoted $\tilde{x}$, satisfies the following FOC:[4]

[1] In the literature, this is equivalent to assuming that the individual has no bequest motive. However, we think that even if the individual has a bequest motive, this should add utility during life and not in the event of death.

[2] To the best of our knowledge, aside from Linnerooth (1982), the literature do not distinguish between the utility from the enjoyment of life and from consumption.

[3] This, however, cannot be strictly true, because for $p^0 = 0$, $p(0, x) = 0$ for all x. We ignore these possibilities.

[4] It is easy to check that the second order considtion is satisfied $v_{xx}(x) < 0$.

$$p_x(p^0, x)[L + u(w - x)] = p(p^0, x)u'(w - x) \quad \text{(A3)}$$

The LHS of (A3) is the marginal benefit from spending the last dollar on care in terms of increasing the probability of survival and the resulting enjoyment of leisure and consumption. The RHS of (A3) reflects the marginal cost of spending the last dollar on care. As can be seen, the marginal costs equal the marginal utility of income *discounted by the ex-post probability of death.* This reflects the fact that if the individual dies, he will not enjoy the last dollar anyway. At the optimum, these marginal benefit and cost should be equal.[5]

Comparative statics

To analyze how optimal care taken by the individual changes with the initial probability of survival p^0 and with wealth w, we simply use the implicit function theorem and immediately obtain that:

$$\frac{d\tilde{x}}{dp^0} = -\frac{v_{xp^0}}{v_{xx}} = \frac{p_{p^0}u'(w-x)}{v_{xx}} < 0 \iff \frac{d\tilde{x}}{d(1-p^0)} > 0 \quad \text{(A4)}$$

and

$$\frac{d\tilde{x}}{dw} = -\frac{v_{xw}}{v_{xx}} = \frac{pu''(w-x) - p_x u'(w-x)}{v_{xx}} > 0 \quad \text{(A5)}$$

The explanation for these results are simple. (A4) As the initial probability of survival is higher, the marginal cost of spending the last dollar for the individual, $p(p^0, x)u'(\cdot)$, for any x, is higher, while the marginal benefit is unchanged; that is, as the initial probability of death is higher, it is more likely that the costs of care will come from the state of the world in which resources are worthless for the individual (this eventually depends on the ex-post probability of death). This reflects the "discounting costs effect" or what Pratt and Zeckhauser (1996) call "the dead anyway effect". Therefore, the individual will invest

[5] The problem the individual faces need not have an interior solution $x \in (0, w)$. The individual may decide to spend his entire wealth on care, $\tilde{x} = w$. This will happen if $p'(p^0, w)L > p(p^0, w)u'(0)$. Thus, the budget constraint w may be effective in the sense that the individual will benefit from investing more in precautions but he simply does not have any resoureces left.

less in precautions. (A5) As the individual has more resources, the marginal benefits from life (i.e., leisure and consumption) are higher and, at the same time, the marginal costs of investing in precautions (if the individual is risk averse) are lower. Therefore as wealth increases the individual invests more in precautions. To summarize:

Proposition 1 *The optimal level of care taken by an individual who faces risk to his own life increases with the initial probability of death and with wealth.*

Appendix B

The social perspective

Consider now the problem of investing in risk reduction from the perspective of a social planner who aims at maximizing social welfare. From this perspective, the death of an individual results in the loss of his life and the therefore the loss of his enjoyment of life (leisure). However, the death of an individual does not result in the loss of his resources. Those resources are not buried along with the individual. Therefore, these resources can be used by other individuals. Assuming that all individuals have the same (linear) utility functions, the social problem is to choose $x \in [0, W]$, where W reflects aggregate social resources, to maximize:

$$SW = p(p^0, x)L - x \tag{B1}$$

There are several differences between the social and the individual maximization problems: (1) *Cost of care*: from the social perspective the costs of care are the full costs of care, while from the individual perspective the costs of care are discounted by the ex-post probability of death. (2) *Benefit of care*: for the individual, the benefits from care include the utility he derives from leisure and consumption of his resources discounted by the probability of death, while from the social perspective the utility from consumption of resources can be ignored, since others will enjoy consuming these resources. (3) *Budget constraint*: for the individual the budget constraint is his resources, while from the social point of view the budget constraint is presumably the aggregate social resources. These differences leads to a divergence between the social optimal and the individual optimal choice of care.

From the social perspective optimal care, x^*, is implicitly defined by:

$$p_x(p^0, x)L = 1 \tag{B2}$$

The RHS of (B2) is the marginal cost of the last dollar spent on care, which is 1. More generally, it will depend on the marginal costs of funds. The LHS of (B2) reflects the marginal benefit from this last dollar stemming from the increased probability of survival and the value for the individual of life. In the optimum, these marginal cost and benefit should be equal. Inspection of (B2) reveals immediately the following proposition:

Proposition 2 *The socially optimal level of care is independent from the initial probability of death and wealth.*[6]

Moreover, comparison of Proposition (1) and (2) leads to the following conclusions:

Proposition 3 *(1) An individual who faces a risk to his life will take more than the socially optimal care level* [7] *(2) The difference between care taken by the individual and the socially optimal care increases with the initial probability of death and with wealth.*

If the initial probability of survival (death) is very high (low), there will be small divergence between care taken by the individual and socially optimal care. This is due to the fact that as the probability of survival (death) is very high (low), the individual internalizes almost all of the costs of taking care, and so the "discounting costs effect" is negligible. However, even in this situation, there will still be a divergence between the individual care and the socially optimal care levels, which may even be large. This is because the individual still puts a premium on being alive, since he will be the one who will enjoy consumption of his resources. Therefore, individuals with significant amount of resources may still invest inefficiently high in their safety.

[6] Clearly, this assumes an interior solution. If p^0 is sufficiently small, society may choose to spend less or even to send noting on risk reduction.

[7] This is strictly true if the individual is not wealth constraint. Otherwise he might take more or less than the socially optimal care level.

Appendix C

Solving the problem - complete markets

Thus far we analyzed the behavior of an individual who faces risk to his life and demonstrated that he behaves inefficiently. As prior writers have identified, the problem arises because markets are incomplete in the sense that the individual can not transfer wealth from the two states of the world: life and death. If a complete, fair contingent claims market exists then the individual will behave efficiently (compare Pratt and Zeckhauser, 1996). To illustrate this in the present context, observe that with complete, fair contingent claims market, the individual can sell his bequest for its expected value. Since the individual expected utility is $p^0[L + w]$, he will get:[8]

$$I = \frac{1 - p^0}{p^0} w \tag{C1}$$

If the individual can take care, this will affect the I in two ways: it will reduce the amount of wealth that is left upon death, and the probability of death itself. To overcome these "moral hazard" problems, we assume I depends on care taken by the individual in the following way:

$$I(x) = \frac{1 - p(p^0, x)}{p(p^0, x)}(w - x) \tag{C2}$$

Observe that $I(x)$ is positive for all $x < w$. Therefore, the possibility for "reverse insurance" necessarily improves the individual expected utility. In addition, observe that:

$$I'(x) = -\frac{1 - p(p^0, x)}{p(p^0, x)} - \frac{p_x(p^0, x)}{p(p^0, x)^2}(w - x) < 0 \tag{C3}$$

so the amount of "reverse insurance" declines with care.

With reverse insurance the problem an individual faces is to choose $x \in [0, w]$ to maximize his expected payoff given by:

[8] To understand this observe that at first the individual can get $(1-p)w$ (wealth times the probability of death). However, if he gets this his wealth upon death will increase to $w + (1-p)w$, which means that the individual can get currently $(1-p)w + (1-p)^2 w$. This process will continut on and on. Therefore the individual can get for selling his wealth upon death: $(1-p)w + (1-p)^2 w + + + (1-p)^n w + ...$

This is a geometrical series with $a_1 = (1-p)w$ and $q = 1 - p$ which converges. Its sum is: $S = \frac{1-p}{p} w$.

$$v = p(p^0, x)(L + w - x + I(x)) = p(p^0, x)L + w - x \tag{C4}$$

Inspection of (C4) and (B1) reveals that the private and the social problems differ by the constant w. Therefore, their optimal (interior) solutions are the same. That is x^* (defined implicitly by (B2)) which maximizes the social problem also maximizes the individual problem with complete, fair contingent market. In addition, it is straightforward to show that the optimal care taken by the individual is independent of the initial probability of survival or wealth.[9]

Appendix D:

Willingness to pay for risk reduction and risk elimination

In Appendix A we derived the optimal private care an individual takes to save his own life. In this part we consider a similar but slightly different question: what is the maximum amount of resources the individual, who will be assumed risk neutral, is willing to pay (WTP) to increase his probability of survival p by r. This amount, c, which reflects the "compensating variation", is given implicitly by equating expected utility after the risk has been reduced and with payment with the expected utility before the risk has been reduced and without payment:

$$(p + r)[L + w - c] = p[L + w] \tag{D1}$$

Rearrangement of (D1) yields:

$$(p + r)c = r(L + w) \tag{D2}$$

WTP is such that the benefits for the individual from increasing the probability of survival by r stemming from the enjoyment of leisure and consumption (the RHS of (D2)) are equal to the costs for the individual from increasing the probability of survival (the LHS of (D2)). As before, these costs are discounted by the ex-post probability of death.

[9] However, for this result to strictly hold, it is necessary that there will be no wealth constraint on the part of the "insurer". This is so becasue as the probability of survival approaches zero, the amount of "reverse insurance" approaches infinity. $\lim_{p->0} \frac{1-p}{p} w = \infty$

From (D2) it follows immediately that:

$$c = \frac{r[L+w]}{p+r} \tag{D3}$$

From (D3) it follows that WTP for risk reduction depends, among other things, on the initial probability of survival and wealth. Thus, we can write $c = c(p, w)$, and show that:[10]

$$c_p(p,w) = -\frac{r[L+w]}{(p+r)^2} < 0 \text{ and } c_{pp}(p,w) = \frac{2r[L+w]}{(p+r)^3} > 0 \tag{D4}$$

$$c_w(p,w) = \frac{r}{p+r} > 0 \text{ and } c_{ww} = 0 \tag{D5}$$

Thus we have the following proposition.

Proposition 4 *WTP to reduce risk of death by a small amount is (a) increasing with the initial probability of death in increasing rates and (b) increases linearly with wealth.*

(D3) leads immediately to the following result.

Corollary 1 *The ratio of the WTP of two individuals who differ only by their initial probability of survival is equal to the inverse of the ratio of ex-post probabilities of death.*

The ratio of the WTP of individuals A and B is given by:

$$\frac{c_A}{c_B} = \frac{r[L+w]}{p_B+r}\frac{p_B+r}{r[L+w]} = \frac{p_B+r}{p_A+r} \tag{D6}$$

The RHS (D6) is the inverse ration of the ex-post probabilities of death.

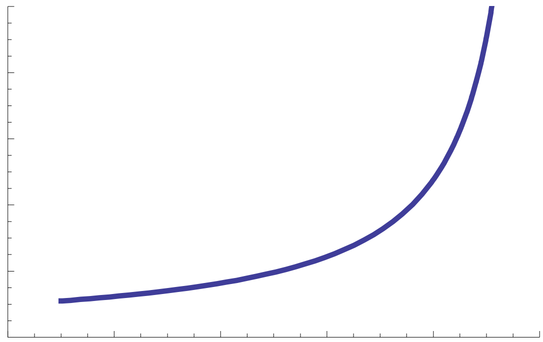
D(5) implies that WTP to reduce risk by some small amount, say 1%, is non-linear with the initial probability of death, and therefore has the 'regular' convex shape.[11]

INSERT FIGURE 1

[10]Denoting the initial probability of death $q = 1-p$, (D3) and (D4) become:$c(q,w) = \frac{r[L+w]}{1-q+r}$, $c_q(q,w) = \frac{r[L+w]}{(1-q+r)^2} > 0$ and $c_{qq}(q,w) = \frac{2r[L+w]}{(1-q+r)^3} > 0$

[11]Observe, however, that WTP in the graph captures the notion of how much an individual with a given resources is willing to pay to redcue the risk of death by say 1%, if he were subject to different magnitude of risks.

Figure 1: Figure 1: WTP to reduce risk by 1% as initial risk changes



However, it does not follow from D(3), D(5) or from figure 1, that WTP to eliminate risks of different magnitudes is non-linear. Quite to the contrary, in the case of risk elimination, we have that $r = 1 - p$, and therefore, (D3) becomes:

$$c = (1 - p)(L + w) \tag{D7}$$

From (D7) it is clear that WTP to eliminate risks of death is linear with the magnitude of risk to be eliminated.

Proposition 5 *Willingness to pay to completely eliminate risk of death is increasing linearly with the magnitude of the risk of death.*

Moreover, we can verify that for all $r < 1 - p$ (i.e., for all risk reduction that does not eliminate risk completely) (D7) is greater than (D3), that is, $(L + w)(1 - p) > \frac{r[w+L)}{p+r}$.[12]. This has the intuitive meaning that an individual's WTP is always greater for eliminating risk than only for reducing it. Furthermore, we can show that WTP to reduce risk is additive in the sense that an individual's WTP to reduce risk by r is equal to the sum

[12]**Proof.** $r < 1 - p \qquad / * p$
$rp < p - p^2 \qquad / + r$
$r + rp < r + p - p^2$
$r < p + r - rp - p^2$
$r < (p + r)(1 - p)$
$\frac{r}{p+r} < 1 - p \qquad / * (w + L)$
$\frac{r(w+L)}{p+r} < (w + L)(1 - p)$ ■

of his WTP to reduce the risk successively by r_1 and then by r_2 where $r_1 + r_2 = r$. This implies that WTP is path-independent.

Proof. WTP depends on p, r, and w. Denote the WTP to reduce risk of death by r as $c(p, r, w) = \frac{r(w+L)}{p+r}$.

WTP to reduce risk of death by r_1 is $c(p, r_1, w) = \frac{r_1(w+L)}{p+r_1}$. After the risk has been reduced by r_1 and the individual paid $c(p, r_1, w)$, the WTP to reduce risk of death by additional r_2 is $c(p + r_1, r_2, w - c(p, r_1, w)) = \frac{r_2(w+L-\frac{r_1(w+L)}{p+r_1})}{p+r_1+r_2}$. Assuming that $r = r_1 + r_2$ we can show that $c(p, r_1, w) + c(p + r_1, r_2, w - c(p, r_1, w)) = c(p, r, w)$, that is, $\frac{r_1(w+L)}{p+r_1} + \frac{r_2(w+L-\frac{r_1(w+L)}{p+r_1})}{p+r_1+r_2} = \frac{r(w+L)}{(p+r)}$.[13] ■

Observe, however, that in this analysis the willingness to pay to reduce risk of death by r can not be computed from the function displayed in figure 1. That is, the willingness to pay to reduce the the risk of death from say q^0 to $q^0 - r$ (i.e., from $1 - p$ to $1 - p - r$) is not equal to $\int_{q^0-r}^{q^0} WTP(q)dq$. The explanation is that the function displayed in the figure 1 is if the WTP as a function of q for a given w. While wealth itself as can be seen from the proof changes, when the individual actually pays for consecutive risk reductions.

Appendix E:

Applications: Tort Liability

Unilateral Accidents

Standard unilateral care models assume that the injurer undertakes a dangerous activity and chooses care $y \in R_0^+$. Subsequently, with a probability of $1 - p(y)$, there is an accident and the victim suffers harm. The victim on his part can do noting to affect the probability of an accident. We assume that the harm is the loss of the victim's life. Therefore, the social problem is to choose y to minimizes the social costs of accidents:

$$SC = y + [1 - p(y)]L \tag{E1}$$

[13]**Proof.** $\frac{r_1(w+L)}{p+r_1} + \frac{r_2(w+L-\frac{r_1(w+L)}{p+r_1})}{p+r_1+r_2} =$
$= \frac{r_1(w+L)}{p+r_1} + \frac{r_2(w+L-\frac{r_1(w+L)}{p+r_1})}{p+r} =$
$= \frac{r_1(w+L)}{p+r_1} + \frac{pr_2(w+L)}{(p+r)(p+r_1)} = \frac{(r_1p+r_1r+pr_2)(w+L)}{(p+r)(p+r_1)} =$
$= \frac{(p(r_1+r_2)+r_1r)(w+L)}{(p+r)(p+r_1)} = \frac{(pr+r_1r)(w+L)}{(p+r)(p+r_1)} =$
$= \frac{r(p+r_1)(w+L)}{(p+r)(p+r_1)} = \frac{r(w+L)}{(p+r)}$ ■

The optimal care level should satisfies

$$p'(y)L = 1 \tag{E2}$$

In unilateral care models there is no problem with the behavior of the victim, since by assumption he cannot do anything to affect the likelihood of an accident. To induce optimal care by the injurer it is necessary that damages, under a strict liability rule, and due care, under a negligence rule, will be set in accordance with the social perspective. This means that damages D should equal L and that due care, $\bar{y}$, will be set equal to y^* (implicitly defined by (E2)).

Bilateral care models

Bilateral care models differ from unilateral care models in assuming that it is optimal for both the injurer and the victim to take care. Denoting the victim and the injurer's care by x and y respectively, and the probability of death by $1 - p(x, y)$, the social problem becomes choosing x and y to minimize:

$$SC = x + y + [1 - p(x, y)]L \tag{E3}$$

The socially optimal care levels, assuming an interior solution, x^* and y^*, should satisfy the following FOCs:

$$p_x L = p_y L = 1 \tag{E4}$$

No liability

Absent institutional arrangements the injurer will take no care. In contrast to standard analysis, however, the victim, because he is not compensated, will take excessive rather than efficient care, given the care taken by the injurer.

Strict liability

Under strict liability the injurer is liable to pay damages to the victim in case of an accident. In contrast to monetary losses, the victim cannot be compensated, since compensation are paid only if the victim dies, and, by assumption, the victim derives no utility upon death. Therefore the injurer faces the problem of choosing y to minimize (the subscript s denotes strict liability regime):

$$u^S = y + (1 - p(x, y))L \tag{E5}$$

while the victim faces the problem of choosing x to minimize (note the change of signs in the square brackets):

$$v^S = p(x, y)[x - w - L] \tag{E6}$$

We assume that both players, the injurer and the victim, choose care without observing the other player's care, and so the solution concept to their interaction is Nash Equilibrium. To find the NE we construct the best response curves of both players.

The injurer's best response function, $y_{br}(x)$, is the injurer's optimal care as a function of the victim's care. Given the victim's care x, the injurer will choose y to maximize (E5). The injurer's optimal choice is implicitly given by the FOC:

$$p_y(x, y)L = 1 \tag{E7}$$

Implicitly differentiating $u^s_y = 0$, with respect to x, and rearranging yields:

$$\frac{dy_{br}(x)}{dx} = -\frac{p_{xy}(x, y)}{p_{xx}(x, y)} \tag{E8}$$

Since $p_{xx}(x, y) < 0$, it follows that:

$$\frac{dy_{br}(x)}{dx} \geq\leq 0 \Longleftrightarrow p_{xy}(x, y) \geq\leq 0 \tag{E9}$$

The sign of $p_{xy}(x, y)$ reflects the interaction between the technology of care of the injurer and the victim. For simplicity, and without losing the essential of the interaction between both players, we will assume that $p_{xy}(x, y) = 0$, that is, the effectiveness of care of each player is independent on care taken by the other player. Thus, the best response function of the injurer does not depend on the care taken by the victim. This implies that from the perspective of the injurer, this is a game with *strategic independent.*

Similarly, the victim's best response function, $x_{br}(y)$, is the victim's optimal care as a function of the injurer's care. Given the injurer care y, the victim will choose x to maximize (E6).The optimal choice is implicitly defined by the FOC:

$$p_x(x, y)[L + w - x] = p(x, y) \tag{E10}$$

Implicitly differentiating $v^s_x = 0$, with respect to y, and rearranging yields:

$$\frac{dx_{br}(y)}{dy} = -\frac{p_{xy}(x, y)[L + w - x] - p_y(x, y)}{p_{xx}(x, y)[L + w - x] - 2p_x(x, y)} \tag{E11}$$

The sign of $\frac{dx_{br}(y)}{dy}$ depends on the sign of the numerator in (E11). Since we assume that $p_{xy}(x, y) = 0$, (E11) reduces to:

$$\frac{dx_{br}(y)}{dy} = \frac{p_y(x, y)}{p_{xx}(x, y)[L + w - x] - 2p_x(x, y)} < 0 \tag{E12}$$

This implies that the best response function of the victim is decreasing with care taken by the injurer, which reflects the notion that from the perspective of the victim the game is with *strategic substitutes.*

Finally, by the envelope theorem:

$$\frac{dv^s}{dx} = \frac{\partial v^s}{\partial x} > 0 \tag{E13}$$

and

$$\frac{du^s}{dy} = \frac{\partial u^s}{\partial y} > 0 \tag{E14}$$

That is, both players' expected payoff increase along their best response curves (i.e., as the other player's strategy increases). This reflects the notion that this is a game of cooperation.

The following observation summarizes the essential features of the interaction between the injurer and the victim.

Remark 1 *The game between an injurer and a victim in a bilateral care model governed by strict liability is a game of cooperation in which the players' strategies are substitutes from the perspective of the victim and independent from the perspective of the injurer.*

Having constructed the best response functions of the injurer and the victim, the NE occurs at the intersection of the best response functions. Thus, the NE solution of this game is y^{s*} and x^{s*} satisfying conditions (E7) and (E10). It is straightforward that x^{*s} is inefficiently high, while y^{s*} is efficient. To summarize:

Proposition 6 *Strict liability: In a bilateral care model, the injurer takes efficient care if damages are set equal to the social harm, while the victim takes excessive care.*

Second-best optimum

Thus far we analyzed strict liability if damages were set equal to the social harm. We demonstrate now the following proposition.

Proposition 7 *In a second-best world in which the victim's behavior cannot be directly controlled, optimal damages under strict liability are more than social harm.*

Proof. The proof is by contradiction. Suppose that optimal damages were equal to social harm $D^* = L$, Then the social costs of accidents is: ■

$$x^{s*} + y^{s*} + [1 - p(x^{s*}, y^{s*})]L \tag{E15}$$

Consider now a slight increase in D (i.e., L). This will change the NE. The social costs of accidents will change by:

$$\Delta = \frac{dx^{s*}}{dy^{s*}}\frac{dy^{s*}}{dL} + \frac{dy^{s*}}{dL} - \frac{dp^{s*}}{dx^{s*}}\frac{dx^{s*}}{dy^{s*}}\frac{dy^{s*}}{dL}L - \frac{dp^{s*}}{dy^{s*}}\frac{dy^{s*}}{dL}L \tag{E16}$$

or equivalently by:

$$\Delta = \frac{dx^{s*}}{dy^{s*}}\frac{dy^{s*}}{dL}[1 - p_x(x^{s*}, y^{s*})L] + \frac{dy^{s*}}{dL}[1 - p_y(x^{s*}, y^{s*})L] \tag{E17}$$

By (E7), it follows that $1 - p_y(x^{s*}, y^{s*})L$, so (E17) reduces to:

$$\Delta = \frac{dx^{s*}}{dy^{s*}}\frac{dy^{s*}}{dL}[1 - p_x(x^{s*}, y^{s*})L] \tag{E18}$$

Now, $\frac{dx^{s*}}{dy^{s*}} < 0$ (from E12) and, by the implicit function theorem, $\frac{dy^{s*}}{dL} > 0$. In addition, since $x^{s*} > x^*$, it follows that $1 - p_x(x^{s*}, y^{s*})L < 0$ (see E4 and E10). Therefore, $\Delta > 0$, which contradicts the optimality of $D^* = L$.[14] This completes the proof.

Negligence

Under negligence, the injurer is liable for damages in the event of an accident if and only if he took less than due care. Assuming full liability, i.e., ignoring the legal requirement of causation, the injurer faces the problem of minimizing:

$$u^N = \begin{cases} y & \text{if } y \geq \bar{y} \\ y + (1 - p(x, y))L & \text{if } y < \bar{y} \end{cases} . \tag{E19}$$

where $\bar{y}$ is due care assumed to be set at optimal care, that is, $\bar{y} = y^*$.

Since the victim cannot be compensated, even if compensation are paid by the injurer, the victim still faces the problem in (E6). Therefore, the best response function for the victim $x_{br}(y)$ is the same as under strict liability. In addition, since by assumption $p_{xy}(x, y) = 0$, it follows that $y^* < y^* + (1 - p(x, y^*))L < y + (1 - p(x, y))L$ for all y, and therefore, the injurer's best response function is independent from x and is also the same as under strict liability (i.e., $y_{br}(x) = \bar{y} = y^*$). Therefore, the NE under negligence is identical to the NE under strict liability. To summarize:

Proposition 8 *In a bilateral care model strict liability and negligence induce the same behavior from the injurer and the victims. In particular, under negligence, the injurer abides by due care and takes efficient care, while the victim takes excessive care.*

Proposition (8) should be contrasted with standard results in the law and economics literature concerning pecuniary losses. In bilateral care models, a negligence rule induces

[14] The explanation is as follows. The injurer behaves efficiently given that the victim takes too much care. However, the victim does not behave efficiently given the care taken by the injurer. Therefore, if damages are increased slightly, the injurer will increase his care, but this would have no significan effect on social welfare. However, since the injurer increases his care, the victim would *decrease* his care, because from his perspective this is a game with strategic substitues. The victim decreases his care not because his care becomes less effective as the injurer takes more care. This possibility is ruled out by the assumption that $p_{xy}(x, y) = 0$. Rather, it is becasue more care taken by the injurer increases the probability that the victim will survive, and therefore the marginal costs of taking care for the victim is higher (see Proposition 1). Now, the reduction in care taken by the victim will increase social welfare, because his care level is inefficiently high given care taken by the injurer.

the injurer to take efficient care by the threat of liability, and since the victim is not compensated, the victim bears the residual harm and therefore takes efficient care as well. Under strict liability, on the other hand, the victim is compensated, and therefore he does not take care at all. If, however, the risk is to the victim's life and not to his property, as we explained above, the victim is not compensated, even if compensation are paid. In addition, as we explained, the lack of compensation implies that the victim takes excessive care relative the social optimum. This is because of the discounting costs and inflating benefits effects.

Second-best optimum

Thus far, we analyzed the negligence rule assuming that due care is set at the socially optimal level. This, however, is not socially optimal given that the victim does not take efficient care. Instead, as we will now explain, social welfare can be increased by setting due care higher than optimal care.[15]

The proof is again by contradiction. Suppose that due care is set at the socially optimal care level, $\bar{y} = y^*$. Then, the social costs of accidents are given in (E15). Consider now a slight increase in due care. This will change the NE. The social costs of accidents will change by:

$$\Delta = \frac{dx^{s*}}{dy^{s*}}\frac{dy^{s*}}{d\bar{y}} + \frac{dy^{s*}}{d\bar{y}} - \frac{dp^{s*}}{dx^{s*}}\frac{dx^{s*}}{dy^{s*}}\frac{dy^{s*}}{d\bar{y}}L - \frac{dp^{s*}}{dy^{s*}}\frac{dy^{s*}}{d\bar{y}}L \tag{E20}$$

or equivalently by:

$$\Delta = \frac{dx^{s*}}{dy^{s*}}\frac{dy^{s*}}{d\bar{y}}[1 - p_x(x^{s*}, y^{s*})L] + \frac{dy^{s*}}{d\bar{y}}[1 - p_y(x^{s*}, y^{s*})L] \tag{E21}$$

By (E7), it follows that $1 - p_y(x^{s*}, y^{s*})L$, so (E17) reduces to:

$$\Delta = \frac{dx^{s*}}{dy^{s*}}\frac{dy^{s*}}{d\bar{y}}[1 - p_x(x^{s*}, y^{s*})L] \tag{1}$$

[15] This, however, depends on the assumption that negligence does not account for causation and insteads takes the form of full liability. If causation is taken into account, then increasing due care will not alter the behavior of the injurer (see Kahan, 1989). However, social welafre can be increased by simultaneuously increasing the standard of care and damages.

Now, $\frac{dx^{s*}}{dy^{s*}} < 0$ (from E12) and, if the increase in $\bar{y}$ is sufficiently small, $\frac{dy^{s*}}{d\bar{y}} > 0$. In addition, since $x^{s*} > x^*$, it follows that $1 - p_x(x^{s*}, y^{s*})L < 0$ (see E4 and E10). Therefore, $\Delta > 0$, which contradicts the optimality of $\bar{y} = y^*$. This completes the proof.

If due care is set slightly above optimal care, the injurer will abide by due care and, for similar reasons discussed in the previous section, the victim would decrease his behavior. Social welfare will increase because the injurer takes efficient care given that the victim takes too much care, while the victim takes too much care given the care level taken by the injurer. Indeed, due care should be set at exactly the level of care induced by a strict liability rule with optimal damages awards.[16] Indeed, optimal negligence and strict liability rule induce the same behavior from injurers and victims.

The above analysis is summarized in the following proposition.

Proposition 9 *Negligence: in a bilateral care model, due care should be set above optimal care. In particular, due care should equal the level of care induced by strict liability with optimal damages awards. Moreover, optimal negligence and strict liability rules induce the same behavior from injurers and victims.*

Figure 1

[16] The qaulification is that this care level may be sufficiently high so that the injurer will prefer to act negligently. However, this problem can be remedied if damages under negligence will be increased to gaurantee that the increased due care will be respected.