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Multiple Losses, EX ANTE Moral Hazard, and the Implications for Umbrella Policies

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Michael Breuer

Institutions: University of Zurich

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Breuer, M

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Michael Breuer *

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* University of Zurich
Socioeconomic Institute
Hottingerstr. 10

8032 Zurich
Switzerland

Email: mbreuer@soi.unizh.ch
Phone: 0041 1 634 45 95
Fax: 0041 1 634 49 87

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ABSTRACT:

Under certain cost conditions the optimal insurance policy offers full coverage above a deductible, as Arrow and others have shown. However, many insurance policies currently provide coverage against several losses although the possibilities for the insured to affect the loss probabilities by several prevention activities (multiple moral hazard) are substantially different. This paper shows that optimal contracts under multiple moral hazard generally call for complex reimbursement schedules. It also examines the conditions under which different types of risks can optimally be covered by a single insurance policy and argues that the case for umbrella policies under multiple moral hazard is limited in practice.

Keywords: Insurance, Multiple Losses, Moral Hazard

JEL: D 80, D 82

1. Introduction

In the real world many insurance contracts cover different kinds of losses although insured's prevention activities affect the probability of each kind of loss in different ways. Take health insurance as an example, where one finds that a single policy covers risks like rectal cancer (where prevention does not have much effect) and lung cancer (where protection is highly effective). Other insurance contracts cover different losses although prevention technologies vary for each kind of loss. Consider a household contents policy, covering the risk of burglary (the prevention of which requires one type of technology) as well as the risk of a lightning strike (which can be reduced by an entirely different type of technology). In both situations, intuition would suggest a different treatment of different types of risk in insurance contracts to give scope for well-directed incentives for prevention to be in the insured's interest, even though each risk might lead to the same monetary amount of loss. On the other hand, indemnity payments that depend on the type of loss suffered contradict the insured's preferences for a safe income in exchange for a single premium. Therefore, as has been stressed in the principal-agent literature (Holmstrom 1979; Laffont and Martimort 2002), an optimal insurance contract has to strike a balance between providing appropriate incentives for prevention and the individuals' demand for insurance protection.

Optimal insurance contracts have been discussed widely in the literature since the early contribution by Arrow (1963). Arrow, not taking into account informational asymmetries, states that under certain conditions concerning a risk-neutral insurer's cost function, an optimal insurance policy will offer full coverage above a nonnegative deductible. While full insurance (a deductible of zero) is optimal at actuarially fair premiums that cover exactly the expected value of indemnities, partial insurance turns out to be attractive if premiums contain a constant loading. Compared to any other feasible insurance arrangements a deductible policy concentrates indemnity on higher losses and thereby minimizes risk averse insured's loss of expected utility due to the cost of insurance. We will refer to this result as the standard insurance contract.[1] Authors like Raviv (1979) and others[2] have confirmed and extended Arrow's result. At the end of his article Raviv (1979, 261) addresses the question of how to deal with multiple losses and concludes that "the results regarding optimal insurance policies hold unchanged when the insured faces more than one risk, when the loss considered is the loss from all those risks". This first-best result for multiple losses is also confirmed by Gollier and Schlesinger (1995). As a consequence, they stress the desirability of an extremely simple form of an umbrella policy that contains a single deductible but provides protection against the full range of risks individuals are exposed to.

In this paper, it will be shown that the introduction of multiple ex-ante moral hazard generally changes the optimal insurance schedule in a way that is significantly more complex than insurance contracts we usually find in practice. Multiple ex-ante moral hazard refers to a situation where several prevention activities affect the probabilities of different kinds of losses in different ways. Generally, an optimal insurance arrangement under multiple moral hazard should neither contain a single deductible for all losses nor let the indemnity depend solely on the amount of losses. Instead, an optimal umbrella policy covering a range of risks has to be defined in a broader sense and is likely to feature different cost-sharing provisions for each type of risk. The properties of an optimal umbrella policy depend on the combination of losses and the ways probabilities of different losses are affected by prevention activities rather than on the amount of total loss, which alone does not contain much information about the insured's prevention activities. The determinants of an optimal umbrella policy under multiple moral hazard will be analyzed in more detail.

An associated question is when the standard insurance contract prescribing a single deductible for all kinds of losses is still optimal under multiple ex-ante moral hazard. Indeed, for a single loss and one prevention activity Holmstrom (1979)

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[1] Other authors argue that the standard insurance contract might also turn out to be optimal for other reasons. Townsend (1979) and more recently Picard (2000) point out that a deductible can make sense if the insured can misrepresent the loss and verification is costly. Depending on the technology and cost function of verification, the standard insurance contract without co-insurance (i.e. full marginal indemnity) might well lead to a second-best optimum.

[2] See e.g. Mossin (1968), Moffet (1977) or Schlesinger (1981). Gollier and Schlesinger (1996) show that Arrows result can be proved using only second-degree stochastic-dominance arguments.

and Winter (2000) prove the standard contract to remain optimal if the insured can only affect the probability of the occurrence of a loss, but not its amount. This somewhat surprising result is driven by the fact that it is efficient in this case to punish the insured for every occurrence of a loss in order to give them some incentives for prevention. However, it would not be optimal to let the punishment depend on the size of the loss, since it does not contain any additional information about the insured's level of prevention activities. As will be shown explicitly, the optimality of the standard insurance contract still holds when only one type of loss is concerned and various prevention activities affect the probability of this loss.

It will also be shown that the standard insurance contract can never be optimal if two different losses can occur separately or simultaneously. Instead, our model indicates that for optimality the insured's net wealth has to be lower if they have has to suffer both losses than in the case of one loss only. On the other hand, it is also not optimal to apply two deductibles for each loss if an individual has to suffer both during one period.

However, for practical purposes insurance arrangements must not be too complicated; otherwise they become worthless to the insured that may not be able to calculate and predict their claims to insurers any more. Therefore, simple indemnity schedules prescribing, say, a deductible and a co-insurance rate that depends on the amount of the loss, are likely to dominate in practice although they will generally not be optimal. We will develop some criteria for the combination of losses that can efficiently be covered by a single policy under multiple moral hazard. For this purpose, the paper explicitly states some specific conditions under which the optimal design continues to be the standard insurance contract and gives some criteria for the appropriateness of a co-insurance policy. In the light of our argument, some insurance policies found in reality may turn out to be ill-designed.

Since a contract with a single deductible (and a single co-insurance rate) for all losses is not guaranteed to be superior to separate indemnity schedules each having a separate deductible and a separate co-insurance rate, it is worth to question the advantage of combining different indemnity schedules into one umbrella policy. It will be argued that, in theory, several indemnity schedules, not providing full coverage against one type of each loss, cannot be optimized independently of

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each other. However, this does not imply that the optimal portfolio of insurance contracts should be purchased from one insurer only. Consequently, the case for encompassing insurance contracts is very limited, which might explain why they are rarely observed in practice.

The paper continues as follows: Section 2 uses a framework introduced by Schlesinger (1987). After reporting the fundamental result concerning the optimal design of an insurance contract for multiple losses without moral hazard in section 2.1, section 2.2 introduces multiple ex-ante moral hazard; i.e. it is assumed that the insured's self-protection activities cannot be observed by the insurer, who has to rely on proper incentives for self-protection instead. Section 3 looks at some two special cases that provide some more specific insights for optimal indemnity schedules under multiple moral hazard. The analyses by Raviv (1979), Schlesinger (1987), and Winter (2000) will turn out to be special cases of the broader model developed in this paper. A discussion of the consequences of our analysis for practical purposes follows in section 4. Section 5 concludes.

2. A general model for studying the optimal design of insurance contract

2.1 Optimal insurance contract without moral hazard

In order to provide a fairly general framework for studying the optimal design of insurance contracts, Schlesinger (1987) introduces a model in which there are one state (no. 1) of no loss and three states (nos. 2,3,4) of loss with size L_2, L_3, and L_4 which are arranged such that $L_2 \leq L_3 \leq L_4$. This framework (although conveniently simple) is flexible enough to allow analyses of a wide range of insurance contracts. For example one is free to define L_2, L_3 and L_4 as the occurrence of a loss A, a loss B, and the simultaneous occurrence of both losses, respectively.

The probability of these four states is $p_1 \ldots p_4$ with $\sum_{i=1}^{4} p_i = 1$. The expected utility (EU) of an insured consequently reads as:

$$EU = p_1 U(W-P) + \sum_{i=2}^{4} p_i U(W-P-L_i+I_i), \tag{1}$$

with W denoting the exogenous wealth of the individual, P the premium paid to the insurance, and $I_i \geq 0$ the indemnity received from the insurance in state i. The utility function U is assumed to be twice differentiable with $U' > 0$ and $U'' < 0$, indicating risk-aversion. Furthermore, let absolute risk aversion be decreasing in wealth (DARA).

Insurers are risk neutral and the insurance industry is assumed to be competitive; i.e. given public information on the probability of losses, the premium cannot exceed the actuarially fair premium times a proportional loading $(1+\kappa)$ in the long run, with $\kappa > 0$ representing the loading factor. This leads to the constraint:

$$(1+\kappa)\sum_{i=2}^{4} p_i I_i - P = 0. \tag{2}$$

Finally, indemnities cannot be negative:

$$I_i \geq 0 \text{ for } i = 2..4. \tag{3}$$

Ignoring the non-negativity constraint for the moment, the optimal insurance contract without moral hazard can be derived by maximizing (1) w.r.t. all I_i, s.t. (2). The first-order conditions read for a fixed premium

$$\frac{U'(W-P-L_i+I_i)}{(1+\kappa)} = \mu \quad \text{for } i = 2\ldots4, \tag{4}$$

where μ is the Lagrange multiplier for the premium function (2). FOC (4) states that an individual's marginal utility should be the same in all loss states if $I_i > 0$. However, due to the loading, full insurance cannot be optimal. On the other hand, according to (4), the insured's out-of pocket loss should be the same in each state of loss, calling for a deductible rather than a co-insurance rate. Finally, observing the non-negativity constraint (3), I_i has to be zero for small losses. This leads to the optimal indemnity function prescribing a deductible $d > 0$ and full reimbursement for losses that exceed the deductible:

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$$I_i^* = \begin{cases} 0 & \text{for} \quad L_i \le d \\ L_i - d & \text{for} \quad L_i > d \end{cases} \tag{5}$$

This result has been proved by Arrow (1963), Raviv (1979), Schlesinger (1987), and Gollier and Schlesinger (1996) and does not depend on the expected utility framework employed here. Note that losses L_i are arbitrary. As mentioned before, we are free to define L_2, L_3, and L_4 as the occurrence of a loss A, a loss B, and the simultaneous occurrence of both losses, respectively. For the optimal indemnity being zero or offering full marginal reimbursement the sum of both losses is decisive.

2.2 Optimal insurance contract for multiple losses and multiple prevention activities

To investigate the effects of moral hazard in a more general model, we now allow for self-protection activities. To be more concrete, let there be two self-protection activities, called x_a and x_b, causing discomfort costs of $C(x_a, x_b)$, with $\partial C/\partial x_a > 0$ and $\partial C/\partial x_b > 0$ as well as $\partial^2 C/\partial^2 x_a > 0$ and $\partial^2 C/\partial^2 x_b > 0$, rather than monetary costs. Discomfort costs reflect the disutility it causes e.g. to abstain from smoking or alcohol, to drive slowly or simply to spend time on prevention activities like exercises to reduce the probability of a heart attack. Discomfort costs enter individuals' utility separately from the monetary terms.[3] The two self-protection activities affect the probabilities of the four states in the model, rather than the amount of loss in any particular state. A fairly general formulation to capture this effect is:

$$\begin{aligned} EU &= p_1(x_a, x_b) \cdot [U(W-P) - C(x_a, x_b)] \\ &+ \sum_{i=2}^{4} [p_i(x_a, x_b) \cdot U(W - P - L_i + I_i) - C(x_a, x_b)] \end{aligned} \tag{6}$$

[3] If prevention activities cause mainly monetary costs (like a more solid lock at the front door of a house), it is, of course, more appropriate to treat them in the exactly same way as other monetary costs, e.g. the premium. In this case one can still show the non-appropriateness of the standard insurance contract but can make less clear statements about the optimal insurance schedule under multiple moral hazard.

Since individuals decide on prevention before a loss occurs, $C(x_a, x_b)$ is the same in all four states of the world. If not stated otherwise, it is assumed that $\frac{\partial p_i}{\partial x_j} \le 0$ and $\frac{\partial^2 p_i}{\partial x_j^2} \ge 0$ for $i = 2 \ldots 4$ and $j = a,b$. For reasons of tractability we concentrate on activities that can unambiguously be regarded to be preventive activities and rule out that one of the activities, x_a or x_b, might reduce the probability of one loss but increase the probability of another loss. To assure an interior solution, it is also assumed that $\left.\frac{\partial p_i}{\partial x_j}\right|_{x_j = 0} = -\infty$ for $j = a,b$ and at least one $i = 2 \ldots 4$. Since $\sum_{i=1}^{4} p_i = 1$, consequently $\frac{\partial p_1}{\partial x_j} \ge 0$ and $\frac{\partial^2 p_1}{\partial x_j^2} \le 0$ for $j = a,b$.[4]

According to (6) the effect of each self-protection activity on all probabilities may be identical or different for each of the three loss states of the world. It is also possible that one self-protection activity affects one probability only; as analyzed below in section 3.2. However, since the insurer cannot observe the self-protection activities of the insured, the insured will invest in self-protection only if (and as much as) they have an incentive to do so. This leads to the incentive compatibility constraints

$$
\begin{aligned}
x_a = \arg\max_{x_a} \; & p_1(x_a, x_b) \cdot [U(W-P) - C(x_a, x_b)] \\
& + \sum_{i=2}^{4} p_i(x_a, x_b) \cdot [U(W - P - L_i + I_i) - C(x_a, x_b)]
\end{aligned} \tag{7}
$$

and

$$
\begin{aligned}
x_a = \arg\max_{x_b} \; & p_1(x_a, x_b) \cdot [U(W-P) - C(x_a, x_b)] \\
& + \sum_{i=2}^{4} p_i(x_a, x_b) \cdot [U(W - P - L_i + I_i) - C(x_a, x_b)].
\end{aligned} \tag{8}
$$

Besides the incentive compatibility constraints, the break-even constraint for the risk-neutral insurer has to be met. It serves as the insurer's participation constraint. As before, insurers are risk neutral and act in a competitive environment.

4 For reasons of tractability all cross effects of preventive activities are assumed to be zero.

The premium P is fixed and must, at least, cover expected indemnities and the loading:

$$(1+\kappa)\sum_{i=2}^{4} p_i(x_a,x_b)I_i - P \leq 0. \tag{9}$$

The final constraint, as before, states that the indemnity must not be negative:

$$I_i \geq 0. \tag{10}$$

Under the assumptions we made about the prevention technology, it is guaranteed that the optimal effort for prevention is positive and that the first-order conditions of (7) and (8) indeed indicate an optimum. Consequently, the incentive compatibility constraints (7) and (8) can be replaced by their first order conditions. These read

$$\sum_{i=1}^{4}\frac{\partial p_i}{\partial x_a}U_i - \frac{\partial C(x_a,x_b)}{\partial x_a} = 0 \tag{11}$$

and

$$\sum_{i=1}^{4}\frac{\partial p_i}{\partial x_b}U_i - \frac{\partial C(x_a,x_b)}{\partial x_a} = 0, \tag{12}$$

with U_i being shorthand for the insured's utility in state i. Equations (11) and (12) state that in an optimum the change in expected utility due to an increase of the self-protection activity has to equal the marginal discomfort costs caused by these activities.

The optimization problem can now be stated as a problem of Lagrange: Maximize (6) with respect to $I_2 \ldots I_4$ s.t. (9), (10), (11), and (12). Disregard (10) for the moment and let $\lambda_a \geq 0$, $\lambda_b \geq 0$, and $\lambda_P \geq 0$ be the shadow prices on constraints (11), (12), and (9) respectively. The resulting first-order conditions are:

$$p_i U_i' + \lambda_a\left(\frac{\partial p_i}{\partial x_a}U_i'\right)_i + \lambda_b\left(\frac{\partial p_i}{\partial x_b}U_i'\right) - \lambda_P p_i(1+\kappa) = 0 \tag{13}$$

$$\text{for} \quad i = 2\ldots 4,$$

which can be rewritten as

$$\lambda_P = \frac{\left(1+\lambda_a \frac{\partial p_i/\partial x_a}{p_i} + \lambda_b \frac{\partial p_i/\partial x_b}{p_i}\right)\cdot U_i'}{1+\kappa} \tag{14}$$

for $\quad i = 2\ldots 4$,

Equation (14) implies that in equilibrium $\left(1+\lambda_a \frac{\partial p_i/\partial x_a}{p_i} + \lambda_b \frac{\partial p_i/\partial x_b}{p_i}\right) > 0$. Combining (14) for two states i and j, eliminating λ_P, and solving for U_i'/U_j' yields

$$\frac{U_i'}{U_j'} = \frac{1+\dfrac{\lambda_a \frac{\partial p_j}{\partial x_a} + \lambda_b \frac{\partial p_j}{\partial x_b}}{p_j}}{1+\dfrac{\lambda_a \frac{\partial p_i}{\partial x_a} + \lambda_b \frac{\partial p_i}{\partial x_b}}{p_i}}. \tag{15}$$

According to (11) and (12), each amount of prevention activity is chosen such that the marginal increase of expected utility due to prevention's effect on all probabilities equals the marginal costs of discomfort caused by prevention activities. The resulting bundle of prevention activities is generally not optimal for each kind of loss. Equation (15) mirrors the fact that probabilities and marginal effectiveness of preventive effort (fixed by the insured) in equilibrium need not to be the same for all states of loss. To get some more insights in the determinants of an optimal indemnity schedule assume that in equilibrium at least one of the prevention activities has a higher relative effect on the probability of state i $\left(\frac{\partial p_i/\partial x_k}{p_i}, k = a,b\right)$ relative to state j $\left(\frac{\partial p_j/\partial x_k}{p_j}, k = a,b\right)$. This causes the rhs of (15) to take a value greater than 1. Consequently, the relative effect of prevention on probabilities in equilibrium unambiguously leads to $U_i' > U_j'$, calling for a lower net wealth in state i than in state j in order to give the insured appropriate incentives to engage more in prevention activities where prevention's relative effect on probability is greater. Consequently, ignoring restriction (10), relative net wealth in each state of loss should not depend on the amount of loss but on relative effectiveness of prevention activities in equilibrium. This result is, of course, in line with the principal-agent model: If the insured can affect the amount of loss the insurance contract should be give them an incentive for adequate prevention.

Reintroducing the non-negativity constraint on indemnities, equation (10), can lead to substituting the equal signs in equations (15) and (16) by inequality signs and an indemnity of zero for some loss states if the loss occurred is too small. However, in contrast to the standard insurance contract the resulting indemnity schedule cannot meaningfully be described as a deductible schedule any more, since the share of the loss the insured have to bear as out-of pocket costs is generally different at each state of the world and depends on determinants which can differ significantly for each kind of loss.

It is worthwhile to note that that these findings give rise to the idea that some insurance contracts we find in practice may be ill-designed. Take car-insurance as an example, where the category 'car-accident' might be too coarse for designing an appropriate insurance policy since this sole category does not reflect the different possibilities of the insured to affect the probabilities of different kinds of accidents: While accidents can be caused by the slightest inattentiveness of drivers irrespective of how carefully they use to drive, driving significantly above the speed limit clearly increases the (relative) probability of an accident and could be prevented by the simple prevention measure of driving slower. According to the results developed above, for an interior solution, a more meaningful policy would grant insured a lower net wealth in state of accidents caused by driving too fast and a higher net wealth in states of accidents that, say, happen in a car park because of drivers being slightly unaware for a moment.

However, as a reference point, one can analyze the conditions under which the standard insurance contract, offering full coverage above a deductible, can be optimal under multiple moral hazard. A sufficient condition for the relative marginal utility U_i'/U_j' to be 1 is that the fractions in the nominator and the denominator of equation (15) are the same, i.e.,

$$\frac{\lambda_a}{\lambda_b} = \frac{\dfrac{\partial p_j / \partial x_a}{p_j} - \dfrac{\partial p_i / \partial x_a}{p_i}}{\dfrac{\partial p_i / \partial x_b}{p_i} - \dfrac{\partial p_j / \partial x_b}{p_j}}. \tag{16}$$

Since in an interior solution λ_a and λ_b are both nonnegative and so $\lambda_a / \lambda_b \geq 0$, for $U_i' = U_j'$ a higher relative effect of prevention activity a on p_j has to be compensated by a higher relative effect of prevention activity b on p_i and vice versa. In this case, an optimal insurance contract would still show one single deductible for both losses.

3. The case for different optimal indemnity schedules under multiple ex-ante moral hazard

In this section two special cases are investigated that serve to give some more theoretical insights and intuition into the limits of designing optimal insurance policies under multiple moral hazard in practice.

3.1 One loss of different amounts

For the first special case, we explicitly use the framework introduced above to assign different amounts of a loss to the states $2..4$ of the model, which cannot be affected by the insured. However, as before, the insured's prevention activities affect the probability of occurrence of the loss. Let the probability of occurrence be $pr(x_a, x_b)$ and let state 1 in section's 2.2 model represent the state of no loss which consequently has the probability $(1 - pr(x_a, x_b))$. The model's three other states then represent states of loss with different amounts of losses (see figure 1).

Note that self-protection has no effect on any $p_{h,i}$. The four states of our model therefore have the following probabilities:

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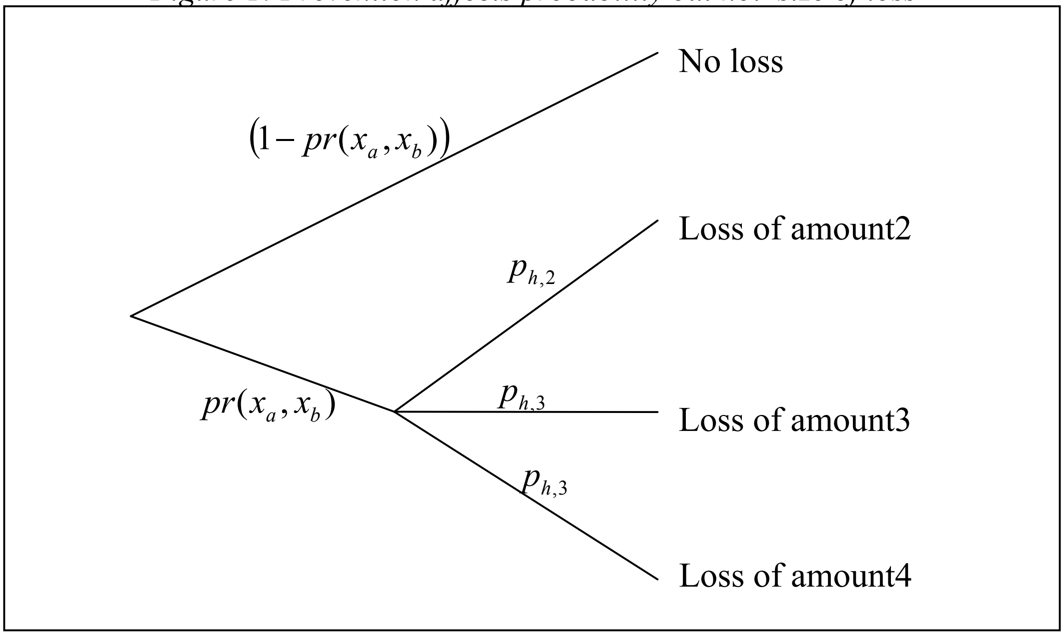
$$
\begin{aligned}
p_1 &= \left(1 - pr(x_a, x_b)\right) \\
p_2 &= pr(x_a, x_b) \cdot p_{h,2} \\
p_3 &= pr(x_a, x_b) \cdot p_{h,3} \\
p_4 &= pr(x_a, x_b) \cdot p_{h,4}
\end{aligned}, \tag{17}
$$

with $\sum_{i=2}^{4} p_{h,i} = 1$. Differentiating p_i, for the states of loss, $i = 2..4$, w.r.t. x_j, $j = a,b$, yields

$$
\frac{\partial p_i}{\partial x_j} = \frac{\partial pr(x_a, x_b)}{\partial x_j} p_{h,i} \quad \text{for } i = 2..4 \text{ and } j = a,b. \tag{18}
$$

Figure 1: Prevention affects probability but not size of loss



Plugging (18) into (15) reveals the critical terms on the rhs of (15) to be the same for all $i = 2..4$. Therefore, ignoring restriction (10), the insured should always suffer the same out-of-pocket loss. If restriction (10) is taken into account, the optimal insurance contract again has the form of the standard insurance contract,

$$
I_i = \begin{cases} L_i - D, & \text{if } L_i \geq D \\ 0, & \text{otherwise} \end{cases}, \tag{19}
$$

that is full reimbursement above a nonnegative deductible D. This is exactly in line with the solutions Holmstrom (1979) and Winter (2000) present for one prevention activity only. It turns out to be a special case of our more general analysis. In especially, the solution does not depend on the number of prevention activities. In order to depart from full insurance and to give the insured an incentive to invest in prevention, the deductible has to be nonnegative. In contrast to Arrow's analysis, the nonnegative deductible is necessary independent of a loading in the premium. Since the amount of loss is not affected by the insured and does not reveal any further information on the insured's effort for prevention, a deductible is sufficient.

However, the assumption that all states of losses are equally likely to occur irrespective of the insured's effort for prevention is rarely appropriate for all kinds of insurable losses. For example, it might be acceptable for losses due to burglary, where a well locked door is unlikely to affect the amount of stolen goods if burglars have managed to break the front door in the first place. In contrast, to return to the example of car insurance, the probability of high losses caused by car accidents might well correlate with the way people drive. While car driver can cause a small damage to their own cars or to other cars in a car park by being inattentive for a moment, the probability of large damages likely correlates with high speed or drinking of alcohol. An optimal insurance contract in this situation could either define a narrow range of differentiated categories of losses and prescribe a relative net wealth of the insured for each of the categories (as discussed above) or define a broader category of 'car accidents' and introduce a, linear or non-linear, co-insurance rate in addition to the deductible, which might be the more practicable form of an insurance policy.

3.2 Two different losses and accumulation of losses

For a second special case suppose that there are two different kinds of losses which can occur alone or can happen both during one period of time. For example, think of two different kinds of illness. Let pr_1 and pr_2 be the probability of sickness 1 and sickness 2 respectively. The four states of the model then are defined as follows:

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$$
\begin{aligned}
p_1 &= \left(1-pr_1(x_a,x_b)\right)\cdot\left(1-pr_2(x_a,x_b)\right)\\
p_2 &= pr_1(x_a,x_b)\cdot\left(1-pr_2(x_a,x_b)\right)\\
p_3 &= \left(1-pr_1(x_a,x_b)\right)\cdot pr_2(x_a,x_b)\\
p_4 &= pr_1(x_a,x_b)\cdot pr_2(x_a,x_b)
\end{aligned}
\quad . \tag{20}
$$

Differentiating these probabilities w.r.t. x_a and to x_b yields

$$
\begin{aligned}
\partial p_1/\partial x_i &= -\left(\partial pr_1/\partial x_i\right)\left(1-pr_2\right)-\left(\partial pr_2/\partial x_i\right)\left(1-pr_1\right)\\
\partial p_2/\partial x_i &= \quad -\left(\partial pr_2/\partial x_i\right)pr_1+\left(\partial pr_1/\partial x_i\right)\left(1-pr_2\right)\\
\partial p_3/\partial x_i &= \quad -\left(\partial pr_1/\partial x_i\right)pr_2+\left(\partial pr_2/\partial x_i\right)\left(1-pr_1\right)\\
\partial p_4/\partial x_i &= \qquad \left(\partial pr_1/\partial x_i\right)pr_2+\left(\partial pr_2/\partial x_i\right)pr
\end{aligned}
\tag{21}
$$

$$\text{for} \quad i=a,b\,.$$

To see if the out-of-pocket loss in case of sickness 1 in an optimal insurance contract should be the same as in case of sickness 2, $\partial p_j/\partial x_i$ and p_i for $j=2\ldots4$ and $i=a,b$ from (20) and (21) have to be plugged into (14). The resulting equations read:

$$
\lambda_P=\left(\begin{array}{c}
\dfrac{1+\lambda_a\dfrac{\left(-\left(\partial pr_2/\partial x_a\right)pr_1+\left(1-pr_2\right)\left(\partial pr_1/\partial x_a\right)\right)}{pr_1\cdot\left(1-pr_2\right)}}{1+\kappa}\\
+\dfrac{\lambda_b\dfrac{\left(-\left(\partial pr_2/\partial x_b\right)pr_1+\left(\partial pr_1/\partial x_b\right)\left(1-pr_2\right)\right)}{pr_1\cdot\left(1-pr_2\right)}}{1+\kappa}
\end{array}\right)\cdot U_2', \tag{22}
$$

$$
\lambda_P=\left(\begin{array}{c}
\dfrac{1+\lambda_a\dfrac{\left(-\left(\partial pr1/\partial x_a\right)pr_2+\left(\partial pr_2/\partial x_a\right)\left(1-pr_1\right)\right)}{\left(1-pr_1\right)\cdot pr_2}}{1+\kappa}\\
+\dfrac{\lambda_b\dfrac{\left(-\left(\partial pr_1/\partial x_b\right)pr_2+\left(\partial pr_2/\partial x_b\right)\left(1-pr_1\right)\right)}{\left(1-pr_1\right)\cdot pr_2}}{1+\kappa}
\end{array}\right)\cdot U_3' \tag{23}
$$

and

$$
\lambda_P=\left(\begin{array}{c}
\dfrac{1+\lambda_a\dfrac{\left(\left(\partial pr_1/\partial x_a\right)pr_2+\left(\partial pr_2/\partial x_a\right)pr_1\right)}{pr_1\cdot pr_2}}{1+\kappa}\\
+\dfrac{\lambda_b\dfrac{\left(\left(\partial pr_1/\partial x_b\right)pr_2+\left(\partial pr_2/\partial x_b\right)pr_1\right)}{pr_1\cdot pr_2}}{1+\kappa}
\end{array}\right)\cdot U_4' \tag{24}
$$

To see that a standard insurance contract cannot be optimal in this situation, it is sufficient to check if the values in the parentheses can be the same in (22), (23), and (24). However, equating the values in the parentheses of (22) with those of (24) and the values in the parentheses of (23) with those of (24) yields:

$$\frac{\lambda_a}{\lambda_b} = -\frac{\partial pr_2 / \partial x_b}{\partial pr_2 / \partial x_a} \text{ and} \tag{25}$$

$$\frac{\lambda_a}{\lambda_b} = -\frac{\partial pr_1 / \partial x_b}{\partial pr_1 / \partial x_a}. \tag{26}$$

Due to sign contradiction, neither of the two conditions, (25) and (26), can be met if both activities, a and b, are preventive activities reducing the probability of a sickness. It is therefore impossible to justify the same out-pocket-loss in all states, which unambiguously excludes the standard insurance contract from being the optimal insurance policy.

The optimal relative marginal utility between states 2 and 4 can be obtained by equating (22) and (24). Equating (23) and (24) reveals some more information about the relative marginal utility in states 3 and 4. Rearranging both equations yields

$$\frac{U_4'}{U_2'} = \frac{1 + \left(\frac{\partial pr_1 / \partial x_a}{pr_1} - \frac{\partial pr_2 / \partial x_a}{1 - pr_2} \right) \cdot \lambda_a + \left(\frac{\partial pr_1 / \partial x_b}{pr_1} - \frac{\partial pr_2 / \partial x_b}{1 - pr_2} \right) \cdot \lambda_b}{1 + \left(\frac{\partial pr_1 / \partial x_a}{pr_1} + \frac{\partial pr_2 / \partial x_a}{pr_2} \right) \cdot \lambda_a + \left(\frac{\partial pr_1 / \partial x_b}{pr_1} + \frac{\partial pr_2 / \partial x_b}{pr_2} \right) \cdot \lambda_b} > 1 \tag{27}$$

and

$$\frac{U_4'}{U_3'} = \frac{1 + \left(-\frac{\partial pr_1 / \partial x_a}{1 - pr_1} + \frac{\partial pr_2 / \partial x_a}{pr_2} \right) \cdot \lambda_a + \left(-\frac{\partial pr_1 / \partial x_b}{1 - pr_1} + \frac{\partial pr_2 / \partial x_b}{pr_2} \right) \cdot \lambda_b}{1 + \left(\frac{\partial pr_1 / \partial x_a}{pr_1} + \frac{\partial pr_2 / \partial x_a}{pr_2} \right) \cdot \lambda_a + \left(\frac{\partial pr_1 / \partial x_b}{pr_1} + \frac{\partial pr_2 / \partial x_b}{pr_2} \right) \cdot \lambda_b} > 1, \tag{28}$$

respectively. According to (14) both, the numerators and the denominators of (27) and (28), are positive in an interior solution. The nominators, however, also show positive terms in parentheses. Consequently, for an interior solution, the values of the fractions are greater than one and the insured's net wealth has to be lower in state 4 than in states 2 or 3.

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However, it will not generally be optimal to only add the insured's out-of-pocket losses they have to bear if they suffer loss 1 or loss 2 to yield to optimal out-of-pocket loss for the occurrence of both losses in the same period of time. Instead, the optimal out of pocket-losses in all three states of loss depend on the probabilities of loss 1 and loss 2 and the marginal effect of both prevention activities, x_a and x_b in equilibrium. An optimal umbrella policy would again have to prescribe a complex reimbursement schedule that is likely to be too complex for being written down in an insurance contract.

4. Practical consequences for the design of insurance contracts

Collecting the results of the model, it is possible to derive the following consequences for an appropriate design of umbrella policies under multiple moral hazard:

1. A pure deductible policy under multiple moral hazard is optimal only if the relative effect of one prevention activity on one loss is exactly compensated by a higher relative effect of another prevention activity on another loss (equation (16)).

2. As a special case of consequence 1, a pure deductible policy is sufficient if insured can only affect the probability of a loss, but not its amount (equation (18) combined with equation (15) or (16)).

3. A co-insurance policy can be justified if higher losses correlate with higher relative effects of prevention activities on their probabilities of occurrence (see section 3.1).

4. Generally, the optimal umbrella policy cannot be described as a deductible policy combined with some simple form of co-insurance. Instead, an optimal contract would call for complicated reimbursement schedules, depending of the relative effects of prevention activities in each state of loss (equation (15)).

The last consequence obviously limits the feasibility of umbrella policies under multiple moral hazard, giving rise to the idea that simple insurance contracts, prescribing a deductible and some simple (mostly linear) form of co-insurance, will continue to dominate in practice. They should be designed along the line sketched by consequences 1 to 3. Insured then have to optimize their portfolio of insurance contracts. Although for a number of reasons[5] each insurance contract covering one type of risk cannot be optimized independently of each other, the optimal portfolio of insurance policies does not necessarily have to be bought from one insurer only. Instead, insured can either create their optimal portfolio themselves or give this task to an independent financial intermediary. Thus, there is no practical case for an encompassing insurance contract because of multiple moral hazard. This is in sharp contrast to the idea of umbrella policies having the properties of the standard insurance contract as recommended on the basis of models that do not take into account informational asymmetries.

5. Conclusion

The literature on the optimal design of insurance policies started from settings where there is no moral hazard at all. Simple optimal insurance contracts in case of ex-ante moral hazard are derived for single losses only. Since this situation is unsatisfactory in the light of existing insurance contracts this paper investigates multiple losses and two self protection activities.

The model presented here provides some useful insights in what kind of insurance contracts may be advantageous under multiple moral hazard. The most important one is that the standard insurance contract, which is a policy offering full insurance above a deductible, is appropriate under certain conditions only, but not in general. Insurance schedules prescribing a simple form of co-insurance can only be justified if higher losses correlate in a simple way with higher relative effects of prevention activities on their probabilities of occurrence. This gives rise to the idea that some insurance contracts found in practice might be ill-designed.

[5] See Schlesinger and Doherty (1985).

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Furthermore, we provided an argument for the idea that not only simple umbrella-policies, providing a stop-loss insurance against a complete range of losses, are far from being optimal, but that all forms of encompassing contracts in practice are not as attractive for the insured as they may look at first sight. Multiple moral hazard alone does not provide any evidence why insured should buy their complete range of insurance protection in a single contract from one insurer only.

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