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On how access to an insurance market affects investments in safety measures, based on the expected utility theory

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Abstract

This paper focuses on how access to an insurance market should influence investments in safety measures in accordance with the ruling paradigm for decision-making under uncertainty—the expected utility theory. We show that access to an insurance market in most situations will influence investments in safety measures. For an expected utility maximizer, an overinvestment in safety measures is likely if access to an insurance market is ignored, while an underinvestment in safety measures is likely if insurance is purchased without paying attention to the possibility for reducing the probability and/or consequences of an accidental event by safety measures.

Keywords

- Insurance;
- Safety measures;
- Expected utility theory

1. Introduction

Principally, there are three alternative ways to treat risk in projects that affect safety. One can (1) take all the consequences when an accidental event occurs, (2) reduce the probability and/or the consequences of an accidental event by safety measures or (3) transfer the consequences of the occurrence to parties better able to carry them (i.e. buy insurance) [1] and [6].

When decisions are made with respect to resource use in safety measures and the insurance market in the risk analysis literature, it is common that the investments in safety measures are not affected by access to an insurance market [9]. As there is no theoretical justification of this practice, we will in this paper discuss whether or not access to an insurance market should influence the investments in safety measures. We use the expected utility theory as basis for our argumentation. The expected utility theory is the backbone for all economic thinking and states that the decision alternative with highest expected utility is the best alternative. We will not repeat the rationality of this principle, but it has validity under very reasonable conditions for logical and consistent behaviour; see for example [10].

We show that the investment in safety measures for an expected utility maximizer will normally be higher in situations where there is no access to an insurance market compared to a situation where such an access does exist. If access to an insurance market is not taken into consideration, this will normally lead to an overinvestment in safety measures for an expected utility maximizer. One could make an argument that is inverse too that an underinvestment in safety measures is very likely if we purchase insurance without paying attention to the fact that the probability and consequence of an accidental event can be reduced by safety measures.

Our work is closely related to the analysis of Ehrlich and Becker [6]. They also discuss the influence of insurance on safety measures with reference to the expected utility theory. Their main message to a large extent overlaps with our conclusions. However, the basis for their analysis is different from ours. In Ref. [6] all the consequences of an accidental event are transformed to one comparable unit (money). This is in strong contrast to much of the risk literature, where it is often regarded as problematic to compare the risk of fatalities with damages to property or even worse, increased consumption due to lower investments in risk reducing measures; see for example [2], [3], [4], [8], [9] and [12]. In our paper we introduce fatalities as a separate variable in the expected utility framework in addition to money. In this respect, our work expands the model of Ehrlich and Becker [6]. Thus, our model gives a basis for showing how non-economic variables interact with the economic variables and how an insurance market affects the investments in safety measures. This is of interest due to the fact that transformation of all attributes to one common comparable unit is avoided by many safety experts, and is also regarded as unethical by some [9].

The paper is organized as follows. In Section 2 an expected utility model is developed in order to show how an expected utility maximizer manages risk in situations first without and then with access to an insurance market. Then in Section 3 a short discussion about the value of a statistical life is given, seen in relation to the model developed in Section 2. Finally, in Section 4 special attention is given to the difference between optimal investments in safety measures for the two situations analysed in Section 2, before some conclusions are provided.

2. An economic model

In this section an economic model is developed to show how an expected utility maximizer manages risk in situations first without and then with access to an insurance market. In Section 3 special attention is given to the difference between optimal investments in safety measures for these two situations analysed in this section.

2.1. When access to an insurance market does not exist

Consider a firm that has preferences with respect to wealth y and a non-economic variable h. In the following, h is referred to as fatalities, but could in principle be all types of non-economic values such as injuries, environmental damages, etc. The preferences are represented by the utility function

$$U(y,h) \qquad (1)$$

We follow the standard in the literature and assume that the utility function is increasing and concave in y, which implies that the firm's marginal utility ($\partial U/\partial y$) diminishes as the wealth increases. The firm then considers the utility of an extra dollar of wealth to be higher when it is relatively poorer than the utility of an extra dollar when it is relatively richer. We also assume that the utility function is decreasing and convex in h. The firm then considers that the disutility of one extra fatality is reduced by the number of fatalities. This implies that the disutility for the first fatality is higher than the disutility of going from 100 to 101 fatalities. To make the model tractable, we make the standard simplifying assumption that there are only two states of the world, one where there is no accidents and one where there is one. The firm's wealth and number of fatalities are respectively y_1 and h_1 (h_1=0) if an accidental event does not occur. The wealth reduces to a level y_2 ($y_2<y_1$) and the number of fatalities increases to a level h_2 ($h_2>0$) if an accidental event occurs. The initial number of fatalities given an accidental event and the initial wealth are h_0 and y_0, respectively. The probability of an accidental event (being in state 2) is denoted *p*.

Suppose that the firm may invest *r* (the effort) in self-protection that affects the consequences in the case of an accidental event. We assume that the cost of effort *r*, *c*(*r*) is an increasing and convex function; $\partial c/\partial r>0$ and $\partial^2 c/\partial r^2<0$. This means that the cost increases by an increased effort by the firm, but gradually the increased effort in self-protection contributes to an increased cost by the firm, for example caused by new production technology, etc.

The magnitude of the reduction in losses in wealth (*l*) and the number of fatalities (*v*) depends on the investments in *r*. As a simplifying assumption we say that the reduction in losses in wealth and the reduction in the number of fatalities of the investments in self-protection are deterministic. We assume that the reduction in losses in wealth when an accident occurs due to the investment in *r*, *l*(*r*), is increasing and convex; $\partial l/\partial r<0$ and $\partial^2 l/\partial r^2<0$. The same assumptions are also given to *v*(*r*), which means that $\partial v/\partial r<0$ and $\partial^2 v/\partial r^2<0$. From these assumptions one can see that the firm's marginal utility from self-protection diminishes as the investments in self-protection increase. One can, for example, say that the utility of the first dollar spent on self-protection is higher than the utility of the last dollar spent on self-protection.

Under these assumptions, the firm's problem is to choose *r* to maximize

$$EU=(1-p)U(y_1,h_1)+pU(y_2,h_2) \quad (2)$$

where

$$y_1=y_0-c(r); \quad y_2=y_0-c(r)-l(r) \quad (3)$$

and

$$h_1=0; \quad h_2=h_0-v(r) \quad (4)$$

The derivative of the expected utility with respect to *r* is

$$\partial EU/\partial r=(1-p)U_{1y}(-c_r)+pU_{2y}(-c_r-l_r)+pU_{2h}(-v_r)$$
$$=-pU_{2h}v_r-pU_{2y}l_r-[pU_{2y}+(1-p)U_{1y}]c_r=0 \quad (5)$$

where U_{iy} denotes partial derivatives of U_y with respect to *i*, l_r is the derivative of *l* with respect to *r*, and c_r the derivative of *c* with respect to *r*.

The condition (5) means that the optimal level of self-protection is at the point where the marginal utility cost of decrease in the firm's wealth due to the cost of self-protection, $[pU_{2y}+(1-p)U_{1y}]c_r$, is equal to the marginal utility of the self-protection, $pU_{2h}v_r+pU_{2y}l_r$. This means that the firm's optimal investment in self-protection is at the point where the utility of the last dollar spent on self-protection is equal to the utility of the reduction in losses caused by the last dollar spent on self-protection. The marginal utility consists of two parts: (I) the marginal utility from an increase in the firm's wealth through reduction in losses, $pU_{2y}l_r$, and

(II) the marginal utility from a decrease in the number of fatalities in the bad state, $pU_{2h}v_r$. Hence, even though the firm's wealth is not being reduced by fatalities, it will influence the firm's decisions as long as the firm cares about avoiding accidents. If this term is removed from the problem, that is the firm does not take into account the fatalities that the accidental event can cause, the firm will underinvest in risk-reducing measures. This seems to support the notion that analysis focusing only on economic factors will lead to underinvestment in safety measures, and it will if the effect of these variables are not taken into account. However, in the economic literature non-economical variables are usually not removed from the decision problem even if wealth is the only attribute included, as non-economic variables are transformed to one comparable unit, money [13]. In such cases, the difference in the safety investment will be determined by the weight given to these variables in different approaches to determining the level of safety investments.

Note that as long as a reduction of the consequences of an accidental event is costly, there will always be negative consequences for the firm if an accidental event occurs. The cost of reducing the consequences of an accidental event (or the probability) will usually increase to infinite when the consequences approach zero.

2.2. When access to an insurance market exists

Until now we have ignored the fact that for some risks the firm has an alternative method to handle risk for investment by transferring risk to parties that are better able to carry the consequences. Such mechanisms include insurance, use of derivatives and government protection. For simplicity, we will here refer to all such mechanisms as insurance as they all work in a similar manner.

Access to an insurance market gives the firm the opportunity to transfer the economic consequences of an accidental event to others by compensation, the insurance premium, s. The firm's wealth will then in the good state be reduced by s, while the wealth in the bad state will increase with the insurance payment, g. The wealth in the bad state increases when the insurance payment increases, which means that the insurance payment is an increasing function of s, $\partial g/\partial s>0$.

Assuming that the insurance market is fair and there is no administration cost, the insurance premium is equal to the expected loss [5]. Say, for example, that the total loss is 100 if an accidental event occurs and that the probability of an accidental event is 0.1. Then the insurance premium is 10. If the firm pays 5 for insurance, then the payment in case of an accidental event will be just half of the total loss (50). The relation between the insurance premium and payment is in other words constant. The relation between the insurance premium and the insurance payment is usually set in such a way that the expected cost is unaffected [5]. Thus, the insurance payment is both an increasing and linear function in s; $\partial g/\partial s>0$ and $\partial^2 g/\partial s^2=0$.

The firm's problem is then to choose r (the effort in self-protection) and s to maximize

$$EU=(1-p)U(y_1,h_1)+pU(y_2,h_2) \quad (6)$$

Where

$$y_1=y_0-c(r)-s; \qquad y_2=y_0-c(r)-l(r)+g(s) \quad (7)$$

And

$$h_1=0; \; h_2=h_0-v(r) \tag{8}$$

Note that h_2 is a function of the investment in self-protection only, and not of the investment in the insurance market. Insurance cannot give a reduction in health in the case of an accidental event, but can only give an economic compensation for such losses.

The first-order conditions for an interior solution are

$$\partial EU/\partial r=(1-p)U_{1y}(-c_r)+pU_{2y}(-c_r-l_r)+pU_{2h}(-v_r)= -pU_{2h}v_r-pU_{2y}l_r-[pU_{2y}+(1-p)U_{1y}]c_r=0 \tag{9}$$

$$\partial EU/\partial s=pU_{2y}g_s-(1-p)U_{1y}=0 \tag{10}$$

Condition (9) is equal to condition (5). Condition (10) says that the optimal level of insurance is at the point where the marginal utility from an increase in the firm's wealth through insurance expenditures in the case of an accidental event, $pU_{2y}g_s$, is equal to the marginal utility cost of a decrease in the firm's wealth due to the insurance premium, $(1-p)U_{1y}$. The firm's optimal investment in insurance is in non-economic terms at the point where the utility of the last dollar spent on insurance is equal to the utility of the reduction in losses caused by the last dollar spent on insurance. From both (9) and (10) we see that a rational agent facing the risk of an accident normally will handle that risk by combining investments in insurance, investments in safety measures and to carry the costs of an accident if it happens, such as the marginal utility of the different actions are the same.

Till now attention has been given to how the investments in safety measures are influenced by access to an insurance market. We may also easily reconstruct our problem to cover a situation which is the opposite: how the investments in the insurance market are influenced by the possibility of reducing risk by safety measures. The model (and the first order conditions) for the problem is not presented because of the strong relation to the economic model already presented. The conclusion is that an underinvestment in safety measures is very likely if we purchase insurance without paying attention to the fact that the probability and consequences of an accidental event can be reduced by safety measures.

3. The value of a statistical life

So far we have posed the model in accordance with the principles of many researchers in the safety literature in that there is no explicit trade-off between wealth and fatalities. However, as we have noted, when a term representing fatalities is included in the model, it will influence the magnitude of the investment in safety measures (including insurance). Most economists will regard this trade-off as being present independently of whether it is explicitly made, as the decisions made in each case will reveal how many resources one is willing to invest, and thereby the value of a statistical life (VSL) [13] and [7].

That any decision with respect to investments in safety measures also implies a value of a statistical life is most easily seen by reformulating the first-order condition in Eq. (5) as

$$v_r = \frac{pU_{2y}lr - [pU_{2y} + (1-p)U_{1y}]c_r}{pU_{2h}} \tag{11}$$

Here the change in the number of fatalities due to an increase in the investment in safety measures is expressed as a function of other terms that are values. By integrating, one can then find the VSL given the other choices that have been made. Moreover, if one is willing to use this value, the solution of the model will be identical to that of Ehrlich and Becker [6]. Hence, the main consequence of not giving a VSL in the analysis is that one allows the disutility associated with fatalities to differ between analysis, possibly leading to more resources being spent on reducing some types of accidents than other types.

4. Discussion and conclusion

In economic models of safety investment, there is always a trade-off between the cost of the investment in safety measures when an accidental event does not occur, and the benefits in the form of lower probability of an accidental event or reduced consequences [6]. This trade-off is commonly simplified by representing all consequences with a common unit, money. We extend this model by allowing factors without a monetary value to influence the decision problem. In general, such factors, like the number of fatalities, will increase a firm's investments in safety measures. We also show that access to an insurance market gives an extra option with respect to how risk should be treated.

With no access to an insurance market the firm will invest in the safety measure up to the point where the marginal utility of the safety investment is equal to the marginal utility of taking all the consequences if/when an accidental event occurs. In non-economical jargon one may say that the firm will invest in self-protection up to the point where the effect of the last dollar spent on self-protection is equal to the reduction in losses caused by the last dollar spent on self-protection. If the firm's risk preferences are neutral, the incentives to invest in the safety measure will be unaffected by access to an insurance market. The reason is that a firm with risk neutral preferences is indifferent between a certain cost (income) and an uncertain cost (income) with the same expected value [5]. Thus, an expected utility maximizer cannot increase the utility by an investment in an insurance market, as the insurance premium is (approximately) equal to the expected costs.

With risk averse preferences there will be a trade-off between how much to invest in the safety measure and how much to insure. A risk averse firm with access to an insurance market will invest in the safety measure up to the point where the marginal utility of the safety measure is equal to the marginal utility of the insurance. With no access to an insurance market (or with risk neutral preferences) the firm will invest in the safety measure up to the point where the marginal utility of the safety measure is equal to the marginal utility of taking all the consequences if/when an accidental event occurs. From this we see that the decision criterion for the firm changes if there is access to an insurance market.

A simple example is used to explain what this difference in decision criterion means for the investments in safety measures. Consider a building having a value of one million dollars. The probability of a fire resulting in a total loss is 10^{-4} for a period of one year. This gives an expected loss of 100. To reduce the risk the house owner can invest in probability reducing measures. Assume that there are two potential probability measures available: one measure that reduces the probability of a fire resulting in a total loss to 10^{-5} at a cost of 50 dollars, and one that reduces the probability to 10^{-6} at a cost of 1000 dollars. To keep the example simple we assume that the house owner cannot invest in both probability reducing measures. Based on the preferences, the house owner wants to invest in the safety measure that reduces the probability to 10^{-6} at a cost of 1000 dollars. Now, assume that access to an insurance market exists. The insurance premium is then 100 as the insurance premium is equal to the expected loss. That means that the house owner can be fully insured for 100 dollars a year. Certainly, an investment of 1000 dollars for reducing the probability of a fire resulting in a total loss to 10^{-6} is not appropriate if access to an insurance market exists. Access to an insurance market does not necessarily mean that there will be no investments in safety measures. Returning to our example, we see that the house owner can invest 50 dollars in order to reduce the probability to 10^{-5}. The expected cost is then 10 dollars if this probability reducing measure is implemented. The house owner can then be fully compensated in case of a fire if he invests 60 dollars a year (50 dollars in the probability reducing measure and 10 dollars in insurance). The cheapest way for the house owner to treat the risk is then to spend money on both the probability reducing measure and insurance. We may say that spending 50 dollars in the probability reducing measure gives a higher utility than spending these dollars on insurance. From this point it is more fruitful to spend money on insurance than on further probability reducing measures. If the different measures also lead to changed expectation with respect to personal injuries or loss of lives due to the fire, this will influence investments in safety measures relatively to insurance.

The exact trade-off between self-protection and insurance will depend on their relative costs. In Ref. [11], a comparative static analysis was used to examine the effects of the investments in self-protection and insurance of an increase in the insurance cost. These authors have shown through the comparative analysis that market insurance and self-protection are strategic substitutes in the sense that an increase in the insurance cost reduces the demand for market insurance and increases the demand for self-protection, which has become relatively cheaper. The fact that insurance cannot give a reduction in losses related to lives and environmental issues, does not have any influence on the conclusion. Similarly, an increase in the cost of self-protection reduces the demand for self-protection while the demand for insurance will increase.

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