Demand for Insurance under Rank Dependent Expected Utility Model

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Abstract
This paper considers the demand for insurance under the non-expected utility theory. We apply the Rank Dependent Expected Utility model (RDEU) which involves, besides the standard utility function, a risk perception function.
In this context, insurance choices empirically observed, but impossible to validate with the Expected Utility model (EU), are explained:
i. When the insurance premium is actuarially fair, risk averse agents can choose a partial (or no) insurance;
ii. Instead, with loaded premium, agent can buy a full insurance contract.
In insurance context, agents behave not only according to their probability distribution but also according to their attitude towards risk.
Keywords: Insurance demand, Non-expected utility, Rank Dependent Expected Utility (RDEU), optimal coverage.

1. Introduction

Since the end of the 1970s, new models of choice under uncertainty have been developed which generalize the classic Expected Utility Theory (EU) of von Neumann-Morgensten (1944). Among these models, Rank Dependent Expected Utility (RDEU) theory, first proposed by Quiggin (1982), has been applied to a diverse range of topics, mainly concerning finance and insurance theory.

In this paper, we suggest an application of the RDEU theory to the demand for insurance and we examine some classical predictions.

Insurance not only contribute to a stable environment, but it also enhance companies of the importance of risk management, and influences their investment decisions.

The classical EU theory has been reproached from an experimental view point as well as for its restrictive lack of explanatory power.

The famous Allais paradox (Allais, 1953) involves experimental evidence that the observed behavior of the majority of decision makers are inconsistent with the EU predictions. Thus, EU was not an adequate characterization of individual risk preferences.

More reproaches of the EU concern its inadequacy of descriptive ability :

1. The utility function ***u*** characterizes both attitude towards risk and attitude towards wealth, so, under EU model, a decision maker with diminishing marginal utility (***u*** is concave) have to be a risk aversion agent.
2. A decision maker, that avoids risks, can choose the riskier situation, if he faces two risky situations. Theoretically, Weak Risk Aversion[1] not imply Strong Risk Aversion[2] . Under EU, these two averse risk notions are confused and characterized by the concavity of the utility function .
3. The probability of the same event can be perceived differently by different agents depending on subjective proprieties of each agent, and for the same agent, on the decision context.
4. The EU model cannot explain many economic behaviors. For instance, the behavior of complete insurance even though a loaded insurance premium is inconsistent with EU predictions.

The RDEU model (Quiggin, 1982, Yaari, 1987) has been built, in part, as an attempt to answer to some of these criticisms.

The purpose of this paper is to analyze the behavior of insurance under RDEU model and to illustrate the contribution of this model to the optimality of insurance policies.

A larger optimal insurance contracting is determined in the RDEU model than in the classical EU model. The introduction of rank dependent utility permit to enlighten some observed insurance behavior.

[1]Agent prefers to any random variable its expected value (Chew, Karni and Safra, 1987).
[2]Agent prefers any random variable to its Mean Preserving Spread (Chew, Karni and Safra, 1987).

First, risk-averse individual may buy a total coverage insurance contract even when the premium is actuarially unfair. Such behavior, in contradiction with EU theory, is explained by the introduction of a risk perception function in the decision-making process or in the value function of the individual.

The outline of the rest of paper is as follows. In the next section, we review the theory of RDEU maximization, and its different risk aversion notions. In section 3 we adopt this model for insurance demand. In section 4 we determine the maximal insurance premium. In section 5 we examine RDEU preference implications for optimal insurance demand.. Section 6 concludes.

2. Preference Representation under RDEU model

Consider a lottery : $L = (x_1, p_1;\ x_2, p_2;\ \ldots;\ x_n, p_n)$. Each $x_i \in \mathbb{R}^+$ is a monetary outcome, and $p_i \in [0,1]$ is its probability of occurrence. We assume that $\sum_{i=1}^{n} p = 1$. The outcomes (consequences) are ranked in an increasing order : $x_1 < x_2 < \ldots < x_n$.

Let us briefly recall the value function representing the preferences in the EU model in this model a consequence's rank is not important. For a lottery (decision) ***L*** , preferences can be represented by a functional such that:

$$U(L) = \sum_{i=1}^{n} p_i\, u(x_i) \qquad (1)$$

where $u : \mathbb{R}_+ \to \mathbb{R}$ is an utility function, strictly increasing and unique up to an affine positive transformation function. The value function ***U*** is linear in probabilities.

A decision maker, who behaves in accordance to the EU model, is completely characterized by this unique function ***u***. It has a double role of expressing attitude towards risk, concavity of ***u*** imply risk aversion, and attitude towards wealth, concavity of ***u*** imply also diminishing marginal utility of wealth. So, the EU preferences faces some paradoxes [Allais, 1953; Ellsberg, 1961].

The RDEU model, as a generalization of EU, has been developed, in part, to answer these paradoxes. The function that represents the preferences -the value function- of a decision maker, according to the axioms of the RDEU model (Quiggin, 1982; Yaari, 1987; Wakker, 1994; Chateauneuf and Wakker, 1999), is:

$$V(L) = u(x_1) + f\left(\sum_{i=2}^{n}[u(x_2) - u(x_1)]\right) + \cdots + f\left(\sum_{i=j+1}^{n}[u(x_{j+1}) - u(x_j)]\right) + \cdots$$
$$+ f(p_n)[u(x_n) - u(x_{n-1})] \qquad (2)$$

where ***u*** denotes a continuous, increasing and unique up to an affine positive transformation function and $f : [0,1] \to [0,1]$ an increasing and unique up to an affine transformation function, satisfying the normalization conditions $f(0) = 0$ and $f(1) = 1$.

The ***u*** function is interpreted as the satisfaction of the consequences and the function ***f*** is interpreted as a probability weighting function or a rank-dependant transformation of the objective probabilities.

The above expression may be interpreted as follows. The decision maker evaluates first the utility associated with the minimum result or worst outcome, $u(x_1)$, then adds the successive increases of utility weighted by the corresponding distorted probabilities.

The EU model is the particular case of the RDEU model where the function ***f*** is linear and then equal to the identity function. If ***f*** is different from the identity, the decision maker will not evaluate the same event with the same weight depending on whether the event is favourable or unfavourable.

A ***pessimistic*** (***optimistic***) agent under risk always ***underweight*** (***overweight***) the probability of the best result and overweight (underweight) the probability of the worse.

The different concepts of risk aversion, while equivalent in EU model, have different characterization in the RDEU model.

A RDEU decision maker has ***Strong Risk Aversion*** if and only if his probability transformation function ***f*** is convex and his utility function ***u*** is concave (Chew, Karni and Safra, 1987).This definition shows that strong risk aversion cannot be disentangled from diminishing marginal utility.

For ***Weak Risk Aversion***, we have only a necessary and sufficient condition that is $f(p) \leq p$, $\forall p \in [0,1]$ (Chateauneuf and Cohen, 1994). Therefore, a decision maker can have weak risk aversion without having a concave utility function ***u***.

3. Demand for insurance under RDEU

This section provides the application of RDEU preferences for the insurance demand.

An individual with initial wealth W_0 faces the risk of loss of amount x with objective probability p. He is a RDEU maximizing agent: he transforms the objectives probabilities according to a probability weighting function $f: [0,1] \to [0,1]$, continuous, increasing and unique satisfying $f(0) = 0$ and $f(1) = 1$.

The curvature of u is interpreted as reflecting optimism and/or pessimism with respect to probabilities:

- A RDEU individual with a function *f* such that $f(p) \le p, \forall p \in [0,1]$ is called a pessimist under risk : *f* is convex;
- A RDEU individual with a function *f* such that $f(p) \ge p, \forall p \in [0,1]$ is called a optimist under risk : *f* is concave.

Without insurance; the value function of a RDEU individual is :

$$V_0 = [1 - f(1-p)]u(W_0 - x) + f(1-p)u(W_0) \qquad (3)$$

Each agent can buy an insurance contract ***C = (P; I)***, which specifies a premium ***P*** and an indemnity $I(x) \ge 0$ for every possible loss x.

Two states of the nature are possible: state 1: "loss" with probability p and state 2 : "no-loss" with probability $1-p$.

The final wealth of individual in each state of nature are, respectively, $W_1 = W_0 - x - P + I$ and $W_2 = W_0 - P$:

- If $W_1 \le W_2$, partial insurance ($x \ge I$):

$$V(L) = [1 - f(1-p)]u(W_1) + f(1-p)u(W_2) \qquad (4)$$

• Si $W_1 \ge W_2$, over-insurance ($x \le I$):

$$V(L) = f(p)u(W_1) + [1 - f(p)]u(W_2) \qquad (5)$$

The rank dependant utility of binary risk L is:

$$V(L) = \begin{cases} [1 - f(1-p)]u(W_1) + f(1-p)u(W_2) & if\ x \ge I \\ f(p)u(W_1) + [1 - f(p)]u(W_2) & if\ x \le I \end{cases} \qquad (6)$$

4. Maximal premium and total coverage

If the agent chooses total insurance of his risk x, his rank dependant utility is evaluated as :

$$V_1 = u(W_0 - P) \qquad (7)$$

We note that the utility to contract an insurance policy is decreasing with the premium's amount :

$$\frac{dV_1}{dP} = -u'(W_0 - P) < 0 \qquad (8)$$

with ***u'*** the marginal utility of wealth.

An individual will buy full coverage if the corresponding premium is such that its utility is bigger than or equal to the non-insurance utility : $V_1 \ge V_0$.

For the maximal acceptable premium, the above inequality becomes an equality (it is assumed that if an individual is indifferent between obtaining and not obtaining insurance, he chooses to buy).

More explicitly, the condition for the maximal premium, P_{max}, is:

$$u(W_0 - P_{max}) = [1 - f(1-p)]u(W_0 - x) + f(1-p)u(W_0) \qquad (9)$$

Let's characterize some proprieties of P_{max}.

If the loss amount increases, individual accept to pay a higher maximal premium:

$$\frac{dP_{max}}{dx} = \frac{[1 - f(1-p)]u'(W_0 - x)}{u'(W_0 - P_{max})} > 0 \qquad (10)$$

since ***u(.)*** is strictly increasing.

When the loss probability p increases, the individual accept to pay a premium more important:

$$\frac{dP_{max}}{dp} = \frac{f'(1-p)[u(W_0) - u(W_0 - x)]}{u'(W_0 - P_{max})} > 0 \qquad (11)$$

since ***f (.)*** and ***u(.)*** are increasing functions.

It remains to examine the implications of a wealth increases on the insurance premium:

$$1-\frac{dP_{max}}{dW_0}=\frac{[1-f(1-p)]u'(W_0-x)+f(1-p)u'(W_0)}{u'(W_0-P_{max})} \quad (12)$$

The utility function u is increasing, thus, the sign of $\frac{dP_{max}}{dW_0}$ depends on:

$$U=u'(W_0-P_{max})-[1-f(1-p)]u'(W_0-x)+f(1-p)u'(W_0) \quad (13)$$

$$U=u'(W_0-P_{max})-u'(W_0-x)-f(1-p)[u'(W_0)-u'(W_0-x)] \quad (14)$$

From (10), we can deduce the value of $f(1-p)$:

$$f(1-p)=\frac{u(W_0-P_{max})-u(W_0-x)}{u(W_0)-u(W_0-x)} \quad (15)$$

Substituting in (14):

$$U=u'(W_0-P_{max})-u'(W_0-x)-[u(W_0-P_{max})-u(W_0-x)]\left[\frac{u'(W_0)-u'(W_0-x)}{u(W_0)-u(W_0-x)}\right] \quad (16)$$

Differentiating U with respect to $\boldsymbol{P_{max}}$:

$$\frac{dU}{dP_{max}}=-u''(W_0-P_{max})+u'(W_0-P_{max})\left[\frac{u'(W_0)-u'(W_0-x)}{u(W_0)-u(W_0-x)}\right] \quad (17)$$

$$\frac{dU}{dP_{max}}=u'(W_0-P_{max})\left[\frac{-u''(W_0-P_{max})}{u'(W_0-P_{max})}+\frac{u'(W_0-x)-u'(W_0)}{u(W_0)-u(W_0-x)}\right] \quad (18)$$

This equation is, at least one time, equal to zero on $]0,x[$ (the theorem of Rolle on differentiable functions): $\frac{dU}{dP_{max}}=0$; we deduce then :

$$\frac{-u''(W_0-P_{max})}{u'(W_0-P_{max})}=-\frac{u'(W_0-x)-u'(W_0)}{u(W_0-x)-u(W_0)} \quad (19)$$

We distinguish two cases :

1. If ***u(.)*** is concave, so $u''<0$ ***u*** is increasing, and ***u'*** is decreasing so that: $u'(W_0-x)>u'(W_0)$ et $(\frac{u''}{u'})$ is diminishing with wealth which imply that $\frac{dU}{dP_{max}}=0$ is a maximum for ***U*** and take negative values on $]0,x[$: $U<0\Rightarrow\frac{dU}{dP_{max}}\leq 0$: the maximal acceptable premium is decreasing with individual's wealth ;

2. If ***u(.)*** is convex, so $u''>0$ ***u*** so that: $u'(W_0-x)<u'(W_0)$ et $(\frac{u''}{u'})$ is increasing with wealth which imply that $\frac{dU}{dP_{max}}=0$ is a minimum for ***U*** and take positive values on $[0,x]$: $U>0\Rightarrow\frac{dU}{dP_{max}}>0$: the maximal acceptable premium is diminishing with wealth.

Therefore, an individual with concave utility diminishes the maximal premium that he accepts to pay if his initial wealth increases. On the contrary, an individual with convex utility function will accept to pay a more important premium if his initial wealth increases.

The former behaves as if he has means to supporting the loss while the latter take advantage of being richer to contract a more expensive insurance policy. These results are identical to those of the EU model[1].

However, a fundamental difference has to be specified between the two models: the EU model predicts that a risk averse agent (***u*** concave) accepts to pay a maximal premium superior to the expected loss(***x***) :

[1] The probability transformation function has no implications on the effects of individual wealth on maximal acceptable premium.

$P_{max} > E(x) = px.$

Under RDEU, this behavior is not directly involved by the utility function shape :

$$pu(W_0 - x) + (1-p)u(W_0) > [1 - f(1-p)]u(W_0 - x) + f\,(1-p)u(W_0) \qquad (20)$$

Which imply that $u(W_0 - xp) > u(W_0 - P_{max})$ from (11): If $P_{max} > xp$, so:

$$f\,(1-p) < \frac{u(W_0 - px) - u(W_0 - x)}{u(W_0) - u(W_0 - x)} \qquad (21)$$

This inequality becomes dependant on the forms of ***u*** and ***f*** :

1. **If *u* is concave** then $u(W_0 - px) > pu(W_0 - x) + (1-p)u(W_0)$, and so $f\,(1-p) < \frac{u(W_0 - px) - u(W_0 - x)}{u(W_0) - u(W_0 - x)}$:
   - If the individual is ***pessimistic*** (*f* is convex), ***f (1 − p) < (1 − p)***, then the inequality (21) is always verified : $P_{max} > E(x) = px$;
   - If individual is ***optimistic*** (*f* is concave), $f\,(1-p) > (1-p)$, then the inequality (21) is not often verified : $P_{max} > E(x) = px$ is valid for some cases.
2. **If *u* is convex** then $u(W_0 - px) < pu(W_0 - x) + (1-p)u(W_0)$, and so $f\,(1-p) > \frac{u(W_0 - px) - u(W_0 - x)}{u(W_0) - u(W_0 - x)}$:
   - if the individual is ***pessimistic*** ($f'' > 0$), $f\,(1-p) < (1-p)$, then the inequality (21) is verified in some cases ;
   - if individual is ***optimistic*** (*f* is concave), $f\,(1-p) > (1-p)$, then the inequality (21) is never verified : $P_{max} < E(x) = px$.
3. **If *u* is linear** so that $u(W_0 - px) = pu(W_0 - x) + (1-p)u(W_0)$, and $f\,(1-p) > \frac{u(W_0 - px) - u(W_0 - x)}{u(W_0) - u(W_0 - x)}$
   - if the individual is pessimistic ($f'' > 0$), $f\,(1-p) < (1-p)$, then the inequality (21) is always verified : $P_{max} > E(x) = px$,
   - if individual is optimistic (f est concave $f'' < 0$), $f\,(1-p) > (1-p)$, then the inequality (21) is not verified : $P_{max} < E(x) = px$.

The different results and configurations are summarized in the following proposition.

Proposition 1 :

*An agent with RDEU preferences, characterized by a probability transformation function **f (.)** et an utility function **u(.)**, is ready to pay a maximal premium for full insurance superior to the expected loss if and only if:*

*1. **u** is concave ($u'' \leq 0$) and **f** is convex ($f'' > 0$);*

*2. in some cases, if **u** and **f** are both concave ($u'' < 0$ and $f'' < 0$) , or convex ($u'' > 0$ and $f'' > 0$)..*

5. Optimal insurance coverage under RDEU

In this section, we consider that the insurance premium is proportional to the insurance coverage : $P = \alpha I$ where $\alpha \in [0,1]$ is the premium per unit of coverage ($\alpha = (1+\lambda)p$) where λ is the loading factor.

We assume that the individual is pessimistic (has strong risk aversion) and, then, his utility function is concave and has convex risk perception function ***f*** : $f\,(p) < p$.

The optimal coverage is determined by maximizing the rank dependant utility function : $\max_\alpha V(X)$.

$$V(X) = \begin{cases} [1 - f\,(1-p)]u(W_1) + f\,(1-p)u(W_2) & if\ x \geq I \\ (\,f\,(p)u(W_1) + [1 - f\,(p)]u(W_2\,) & if\ x \leq I \end{cases} \qquad (22)$$

Where wealth in state of nature 1 " ***loss***" is $W_1 = W_0 - x + (1 - \alpha)I$ and for the state 2 "***no loss***" is $W_2 = W_0 - \alpha I$.

Differentiating the equation (22) with respect to I, :

$$\frac{dV(X)}{dI} = \begin{cases} (1 - \alpha)[1 - f(1 - p)]u'(W_1) - \alpha f(1 - p)u'(W_2) & if\ x \geq I \\ (1 - \alpha)f(p)u'(W_1) - \alpha[1 - f(p)]u'(W_2) & if\ x \leq I \end{cases} \quad (23)$$

The full insurance ($x = I$) resolves this problem if:

$$\left.\frac{dV(X)}{dI}\right|_{I=x} = \begin{cases} [1 - \alpha - f(1 - p)]u'(W_0 - \alpha x) \geq 0 & for\ x > I \\ [f(p) - \alpha]u'(W_0 - \alpha x) \leq 0 & for\ x < I \end{cases} \quad (24)$$

$u'(.) > 0$ since ***u*** is strictly increasing, thus the full coverage is optimal for :

$$[1 - \alpha - f(1 - p)] \geq 0 \ \ and\ \ [f(p) - \alpha] \leq 0 \quad (25)$$

Thus :

$$[f(p)] \leq \alpha \leq [1 - f(1 - p)] \quad (26)$$

Under RDEU, for any unitary premium a between $f(p)$ and $[1 - f(1 - p)]$, the total insurance is optimal : $I = x$. The EU model, contrary to RDEU, predicts that an actuarially fair premium is a necessary condition to the optimality of full insurance.

Substituting $\alpha = (1 + \lambda)p$, (26) becomes:

$$\left[\frac{f(p) - p}{p}\right] \leq \lambda \leq [1 - p - f(1 - p)] \quad (27)$$

For a pessimistic individual ($f(p) < p$), the full coverage can be optimal for $\lambda \geq 0$.

The partial insurance ($x > I$) is optimal (interior optimum) if:

$$V'(X) = (1 - \alpha)[1 - f(1 - p)]u'(W_1) - \alpha f(1 - p)u'(W_2) = 0 \quad (28)$$

and $V''(X) = (1 - \alpha)^2[1 - f(1 - p)]u''(W_1) + \alpha^2 f(1 - p)u''(W_2) < 0$

The second condition is fulfilled when the utility function is concave ($u'' < 0$).

The first order condition gives :

$$\left.\frac{dV(X)}{dI}\right|_{I=x} = [1 - \alpha - f(1 - p)]u'(W_0 - \alpha x) < 0 \quad (29)$$

Consequently, the partial insurance is optimal if the utility function is concave and the premium per coverage unit verifies:

$$\alpha > [1 - f(1 - p)] \quad (30)$$

Replacing α with his value:

$$\lambda > \left[\frac{1 - p - f(1 - p)}{p}\right] \quad (31)$$

The second order condition is not verified for a convex or linear utility function, therefore, the individual choose to not insure his risk.

Note that partial insurance is always optimal for optimistic agent : $p < f(p)$.

The same analysis allows us to conclude that the over-insurance $(x < I)$ is optimal in the case of concave utility function and optimistic individual : $\alpha < f(p)$. Pessimistic individuals do not choose over-insurance.

The optimal levels of insurance, in RDEU model, are summarized in the following proposition.

Proposition 2 :

Under RDEU, a pessimistic agent, chooses:

1. *The full insurance ($I^* = x$), if $\alpha \in [f(p), (1 - f(1 - p))]$;*
2. *Partial insurance ($I^* < x$), if $\alpha > [1 - f(1 - p)]$ and his utility function u is concave;*
3. *Over-insurance ($I^* > x$) if $\alpha < f(p)$ and for concave utility function ;*
4. *Non-insurance, if $\alpha > [1 - f(1 - p)]$ or $\alpha < f(p)$ and for **u** convex or linear.*

This proposition states that the full insurance coverage is optimal on an interval of premium and not, as in EU preferences, for a unique equitable premium. Therefore, we deduce that both parties of the insurance contract evaluate their equitable premium according to their individual risk perception.

The optimal level of coverage is not validated only for unique premium value but for an interval of premiums. The extent of this interval depends on the risk perception function f So, the full insurance is strictly preferred to any partial level of cover for a range of premium above the actuarially fair rate.

6.Conclusion

The preference representation under the RDEU model makes insurance decision depending on the probability deformation function that becomes the parameter characterizing the individual attitude toward risk.

Therefore, we can generalize the optimality of full insurance to an interval of premium (or loading factor) and only to a unique value of actuarially fair premium as in EU model. The extent of this premium depends on the individual risk perception.

The latter is also fundamental for determining the maximal premium that agent accept to pay for full insurance: a pessimistic individual with convex utility function or an optimistic with concave can pay a premium less than their expected loss in contradiction with the classical-EU predictions.

In our paper, the demand for insurance is studied under the assumption that both parties of the insurance contract know exactly the true probability distribution. This assumption cannot be feasible in reality where the probability of risks can be estimated in an imprecise manner. The introduction of such uncertainty can enlighten us about the insurance decisions and explain some observed insurance behavior unexplainable with the models of decision making in risk.

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