A C T A U N I V E R S I T A T I S L O D Z I E N S I S
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II. RESEARCH ON CONSUMER BEHAVIOUR

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DECISION TYPES, PERSONAL CHARACTERISTICS AND RISK AVERSION

1. Introduction

Since Daniel Bernoulli's conslusions of the St. Petersburg game results it is evident that individuals do not follow the principle of statistical expectation when deciding under risk. Two classes of models have been developed to describe and explain the outcomes of decisions under risk: "classical" decision models following the μ-σ- rule etc. and decision models based on the von Neumann-Morgenstern utility construct. Managerial decisions are mostly based on principles similiar to those of the μ-σ-rule, theoretical papers are based predominantly on the von Neumann-Morgenstern utility (vNMu) concept.

Two reasons are defavorable to any managerial use of the vNMu: first there is a lack of operational models of the vNMu and, second, there is no clear evidence on the risk aversion level in different risk situations.

In this paper we are aiming first to develop operational risk models based on the vNMu axioms, second, to parameterize them and, finally, to test hypotheses on the risk aversion rate levels depending on characteristics of the decision maker as well as the decision setting. Thus, we hope to develop a more operational as well as theory-based decision theory under risk.

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2. The vNMu Theory of Risk Aversion

2.1. Bernoulli's Principle and the vNMu Concept

According to theory individuals decide under risk not according to the mathematical expectation of the decision outcomes, but in compliance with the mathematical expectation of transformed decision outputs. The theory is well founded on sets of axiems [32,23,11,3]. The vNMu theory has been critizised [1,6,18] and - more recently - specified in details [5,4]. The following points are mostly accepted.

1. The vNMu is a composition of risk utility as well as income utility. It is assumed that the income utility function is concave for positive outcomes and convex for negative ones. Therefore, even if a decision maker is risk neutral his vNMu function should be convex.

2. Based on the uncontroversial complete order axion we define with X the random decision output, w as the welfare indicator, and L (X, p (x)) as the lottery with the outcomes X and the probability p (X):

$$\left.\begin{array}{l}\{\text{risk aversion}\} \leftrightarrow \{u(E(X + w)) > U(w) + u(L(X, p(X))\} \\ \{\text{risk proneness}\} \leftrightarrow \{u(E(X + w)) < u(w) + u(L(X, p(X))\}\end{array}\right\} \quad (1)$$

The level of risk aversion or risk proneness is depending not only on decision makers's characteristics but on the type of lottery, too.

2.2. Arrow Pratt Rate of Risk Aversion and Hypotheses on the Risk Aversion

For monotone increasing vNMu functions with existing second order differentials P r a t t [26] and A r r o w [2] defined the risk rate r x for any decision outcome x:

$$r(x) = - \frac{u''(x)}{u'(x)} \quad (2)$$

By convention:

$$\left.\begin{array}{l}\{r(x) > 0\} \leftrightarrow \text{risk aversion}\} \\ \{r(x) < 0\} \leftrightarrow \text{risk proneness}\}\end{array}\right\} \quad (3)$$

The risk aversion rate r(x) is not depending of the individual's state of welfare.

There are numerous hypotheses on the graphical form of the vNMu function [3,12,13] some of them are depicted in Fig. 1 and 2.

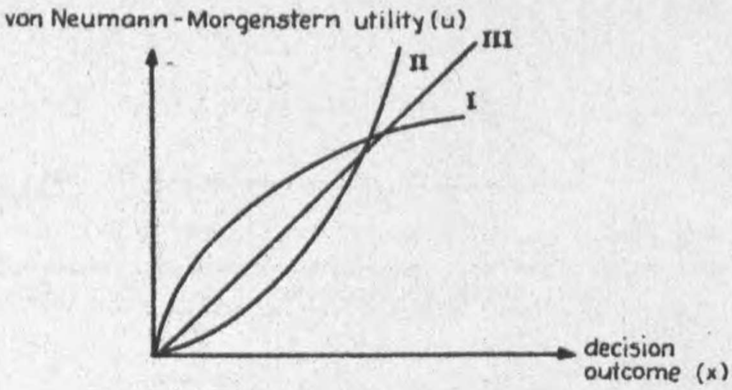

Fig. 1. Concave (I), convex (II) and linear (III) von Neumann-Morgenstern utility curve

For x > 0 (I) is supposed to be the most relevant curve when dealing with usual managerial decisions. (II) is said to be typical for all games of hazard, (III) should be applicable for repetitive decisions of minor importance. (I) to (III) describe a risk behavior which is constant as regards type of behavior as defined in [3] whereas (IV) and (V) are describing a risk behavior which is - depending on x - partly risk prone and partly risk averse. Normally the turning-point in (IV) is not theoretically determined, but supposed to be empirically found without considering the enormous specification, identification as well as validation problems arising from this method of turning point fixing. According to F i s h b u r n and K o c h e n b e r g e r [12] the turning point is the decision makers' individual target point (reference point). The vNMu function according to F r i e d m a n and S a v a g e [13] (V) has - to our knowledge - never been empirically tested; it is supposed to be a person-specific general function which is applicable for all decisions of an individual, in contrast the vNMu curves (I) to (IV) are decision type specific.

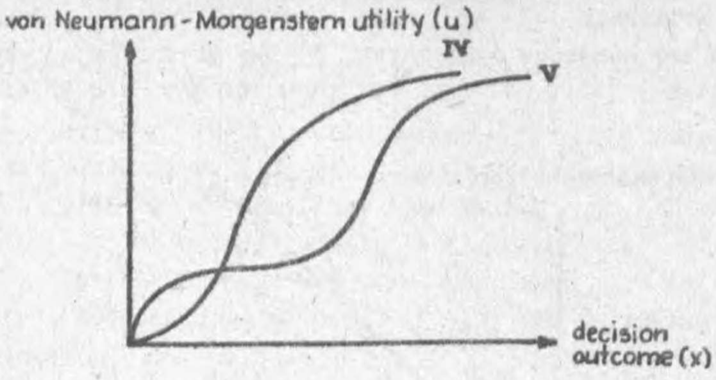

Fig. 2. Convex-concave von Neumann-Morgenstern utility curve (IV) and utility curve as to Friedman and Savage (V)

3. Specifying vNMu Functions

3.1. Basic Assumptions

The Bernoulli principle can be formulated as in (4):

$$u(X + w) = w + E \quad (u(X)) \tag{4}$$

Since X equal to a constant $(L = \{X,\ p(x) = 1.0;\ p(x') = 0\}$ is a special case of X as a random variable we conclude that the utility scores of the extreme outcomes of a lottery should be numerically identical to the utility scores of the extreme points of the relevant lottery. By a transformation as given in (5) this prerequisite is met:

$$\begin{aligned} &\max \{X/L\} \rightarrow 1.0 \quad \text{and} \quad u(\max\{X/L\}) \rightarrow 1.0 \\ &\min \{X/L\} \rightarrow 0 \quad \text{and} \quad u(\min\{X/L\}) \rightarrow 0 \end{aligned} \tag{5}$$

As a consequence the vNMu-functions have to be identified specifically for each maker and each decision type. We suppose that a decision maker may be comparatively risk averse if he has to take a very risky decision and comparatively risk prone or risk neutral if he has to take a decision with low risk.

3.2. Specifications of vNMu Functions

Within capital theory [32,7,16,25] generally concave vNMu curves are assumed. A mathematical model that is parsimonious and based on this theory is the following one.

$$u(x) = (a + bx)^{\frac{b-1}{b}} \qquad b \neq 0, \quad b \neq 1 \qquad (6)$$

$$\text{with } r(x) = \frac{1}{a + bx}$$

a,b > 0 in (6) indicates risk averse behavior. (6) standardized to $u(x_{min} \stackrel{!}{=} 0 =) \; 0$ and $u(x_{max} \stackrel{!}{=} 1.0) \stackrel{!}{=} 1.0$ gives (7):

$$\left.\begin{array}{l} u(x) = x^c \quad \text{with} \quad c = \frac{b-1}{b} \qquad c > 0 \\ \text{with } r(x) = \frac{1-c}{x} = \frac{1}{bx} \end{array}\right\} \qquad (7)$$

For $c < 1.0$ (7) shows a risk averse behavior and for $c > 1.0$ a risk prone behavior.

Constant risk aversion is given assuming the following vNMu function:

$$u(x) = \begin{cases} -e^{-bx} & \text{for} \quad b \lessgtr 0 \\ x & \text{for} \quad b = 0 \end{cases} \qquad (8)$$

$$\text{with } r(X) = r = b$$

(8) standardized:

$$u(x) = \begin{cases} \frac{1}{1-e^{-b}} \; (1-e^{-bx}) & \text{for} \quad b \lessgtr 0 \\ x & \text{for} \quad b = 0 \end{cases}$$

$$\text{with } r(x) = r = b$$

(8) and (9) include any risk neutral and the maximal risk averse behavior (Wald rule) as special cases. The utility function (9) is well founded on axioms [4].

The vNMu functions given are theory-based, but they are only strictly concave or strictly convex. Concave and convex-concave vNMu functions can be estimated by the subsequent function with standardized ranges:

$$\left.\begin{array}{l} u(x) = (1 + b)\,\frac{x^a}{x^a + b} \qquad\qquad a, b > 0 \\ \text{with } r(x) = \frac{b(a-1) - x^a(a+1)}{(x^a + b)x} \\ \text{and } \{a \leqq 1\} \Longleftrightarrow \{\text{concave vNMu function}\} \\ \qquad \{a > 1\} \Longleftrightarrow \{\text{convex-concave vNMu function}\} \\ \text{turning point for } a > 1 \text{ and } a < \frac{b+1}{b-1} : \; x = \sqrt[a]{b\,\frac{a-1}{a+1}} \end{array}\right\} \qquad (10)$$

The risk rate in (10) is a complex function of two explicit parameters whereby one parameter is dominating. A much simpler utility function is the following one:

$$u(x) = e^b e^{-\frac{b}{x}} \qquad a,\ b > 0$$

$$\text{with } r(x) = \frac{2x - b}{x^2} \tag{11}$$

$$\text{and } \{b \geq 2\} \Longleftrightarrow \{\text{convex vNMu function}$$

$$\{b < 2\} \Longleftrightarrow \{\text{convex-concave vNMu function}$$

$$\text{truning point for } b < 2 : x = \frac{b}{2}$$

(10) and (11) are very flexible functions; they give the opportunity to parameterize all relevant vNMu functions (all but vNMu function as to Friedman and Savage).

3.3. Identification of vNMu Functions

F i s h b u r n and K o c h e n b e r g e r [12] have summarized the results on risk functions' parameterizations:

(a) Very often there are turning points in utility functions with the target point as a turning point [22,19]. Partly this target point is equivalent to the zero-point [30], partly the target point has a positive [15] or a negative outcome [14].

(b) The vNMu function is mostly convex below the target point and concave above the target point.

(c) The utility function is steeper below the target point as above the target point.

Fishburn and Kochenberger identified the following utility functions:

$$u(x) = ax \qquad a > 0 \qquad \text{with } r(x) = 0 \tag{12}$$

$$u(x) = ax^b \qquad a,b > 0 \qquad \text{with } r(x) = \frac{1 - b}{x} \tag{13}$$

$$u(x) = a(1 - e^{-bx}) \qquad a,b > 0 \qquad \text{with } r(x) = r = b \tag{14}$$

The utility functions have been estimated partwise (above and below the target points) by minimizing the sum of squared deviations. In total, thirty utility functions taken from five articles have been reviewed. The results as regards (a) to (c) in 3.3 are given in Tab. 1.

Table 1

Tests as regards the hypotheses (a) to (c) according to Fishburn and Kochenberger

Target point (frequency)				Shape of utility function (frequency)					
0	> 0	< 0	$\sum$	con-cav	con-vex	convex--concav	concav--convex	non given	$\sum$
23	3	4	30	3	5	13	7	2	30

Model with highest internal validity (frequency)										Function below the target point is steeper as above (frequency)	
below the target point					above the target point						
(13)	(14)	tied	non given	$\sum$	(13)	(14)	tied	non given	$\sum$	(12)	(14)
12	13	3	2	30	15	15	-	-	30	29	24

The results confirm the hypotheses (a) and (b). The conclusion [19] that individuals are risk prone below the target point and risk averse above the target point is however not a necessary one because the vNMu function is just a composition of the income utility function which is basically represented by a convex-concave curve of the risk utility function.

4. Hypotheses on the Shape of the vNMu Function for Different Lotteries and Different Individuals

There is an unanimity that individuals may show different rates of risk aversion; the one that the same individuals show different risk aversion rates for different lotteries cannot be excluded. We formulate the following hypotheses, therefore:

H_1: for $x > 0$: $r > 0$.

H_2: for $x < 0$: $r < 0$.

H_3: the greater the span of a lottery the greater $|r|$.

H_4: men are more risk prone than women.

H_5: the older the individual the bigger $|r|$.

H_6: the higher the education the lower $|r|$.

5. The Empirical Study

5.1 Data and Specified vNMu Functions

The empirical study is based on five lotteries. For each lottery several probability distributions have been used to estimate the utility scores (see Tab. 2).

Table 2

Lotteries used in the empirical study

Lottery	Outcomes of the lottery (x)		Probability distributions used for estimation purposes
A	0	+1 000	0.2/0.8; 0.4/0.6; 0.5/0.5; 0.6/0.4; 0.7/0.3; 0.8/0.2
B	+1 000	-1 000	
C	0	-1 000	
D	+ 500	- 500	
E	+2 000	-2 000	

The utility functions for parameterization have been selected on the basis of theoretical reasoning. Zero outcome has been chosen as the target point of the utility function. The functions, lotteries and data points underlying the parameterization are given in Tab. 3. (7), (9), (10) and (11) allow to estimate all discussed utility functions, especially those which have been analyzed by Fishburn and Kochenberger.

All utility functions have been estimated on the individuals' level whereby for some of the partwise estimation runs the residual degrees of freedoms are very low. The individuals have been selected by random, they are described by the subsequent sociodemographic variables (Tab. 4).

Data used to estimate the vNMu functions

Table 3

Utility function	Risk aversion	Lotteries	Data used standardization of outcomes x (x' transformed outcomes)	Probability distributions
$u(x) = x^c$ (7)	risk averse or risk prone	A - E	$x_{min} \overset{!}{=} 0$ $x_{max} \overset{!}{=} 1$	all
	risk averse or risk prone	B,D,E	$x = 10 \rightarrow x' = 0$ $x_{max} \overset{!}{=} 1$	0.2/0.8; 0.4/0.6
	risk averse or risk prone	B,D,E	$x_{min} \overset{!}{=} 0$ $x = 0 \rightarrow x' = 1$	0.6/0.4; 0.7/0.3; 0.8/0.2
	risk averse or risk prone	A - E	$x_{min} \overset{!}{=} 0$ $x_{max} \overset{!}{=} 1$	all
$u(x) = \frac{1}{1 - e^{-b}} (1-e^{-bx})$ (9)	risk averse or risk prone	B,D,E	$x = 0 \rightarrow x' = 0$ $x_{max} = 1$	0.2/0.8; 0.4/0.6
	risk averse or risk prone	B,D,E	$x_{min} \overset{!}{=} 0$ $x = 0 \rightarrow x' = 1$	0.6/0.4: 0.7/0.3; 0.8/0.2
$u(x) = (1 + b) \frac{x^a}{x^a + b}$ (10)	risk averse or risk prone-risk averse	A - E	$x_{min} \overset{!}{=} 0$ $x_{max} \overset{!}{=} 1$	all
$u(x) = e^b e^{\frac{-b}{x}}$ (11)	risk prone or risk prone-risk averse	A - E	$x_{min} \overset{!}{=} 0$ — $x_{max} \overset{!}{=} 1$	all

Table 4

Personal characteristics of the forty respondents included in the study and hypothesis on the characteristics' influence on risk aversion

Sociodemographic variables	Outcomes	Hypothesis: risk aversion...
Age	<30; 31-40; 41-50; 51-60; >60	increases with age
Sex	men, women	is higher for women than for men
Formal education	primary, seconadary, college, university level	decreases with formal education

5.2. The Results

Based on the forty respondents, interviews, the utility functions (7), (9), (10), and (11) have been estimated.

5.2.1. The Parameters of the Utility Functions

The results of the 1760 estimation runs (40 persons, 4 models, 5 lotteries with 1/3 data sets) are given in the subsequent table (Tab. 5) whereby a statistical and not an algebraic parameterization procedures have been used Currim/Sarin.

Table 5 gives the frequencies that specific models have the highest internal validity for the forty individuals selected; model (7) e.g. shows 15 times the highest internal validity. In contrast to models (7), (9) and (11) model (10) has two explicit parameters; a higher internal validity of (10) has to be expected, therefore. The internal validities of the model (10) against those of the models (7), (9) and (11) have been tested statistically. Taking into consideration the different numbers of explicit parameters the maximum internal validity frequencies which are given in brackets are the relevant ones.

The main results of the estimations can be summarized as subsequent: with the zero outcome as target point and positive outcomes, lotteries (A, B^+, D^+ and E^+) the utility function is significantly more often concave than convex (significant level: < 0.003%) with negative decision outcomes, lotteries (B^-, D, D^-

Table 5

Results of the parameterization runs for all four models and forty persons

Lottery	Data used for parameterization	Model with highest internal validity (frequency)					Person-specific minimal standared deviation	Shape of utility function (frequency)			
		(7)	(9)	(10)	(11)	$\sum$		concave	concave	concave-convex	$\sum$
A	all x-u-pairs	15 (18)	8 (16)	17 (6)	0 (0)	40	0.013-0.044	33 (37)	3 (3)	4 (0)	40
B	all x-u-pairs	0 (0)	0 (0)	1 (1)	39 (39)	40	0.013-0.107	0 (0)	0 (0)	40 (40)	40
	x-u-pairs below target	8	32	-	-	40	0.0004-0.105	0	40	-	40
	x-u-pairs above target	20	20	-	-	40	0.004-0.063	39	1	-	40
C	all x-u-pairs	8 (9)	4 (5)	4 (0)	24 (26)	40	0.022-0.104	0 (0)	12 (14)	28 (26)	40
D	all x-u-pairs	1 (1)	2 (5)	6 (1)	31 (33)	40	0.009-0.093	1 (2)	2 (4)	37 (33)	40
	x-u-pairs below target	10	30	-	-	40	0.000-0.077	1	39	-	40
	x-u-pairs above target	15	25	-	-	40	0.012-0.156	40	0	-	40
E	all x-u-pairs	0 (0)	0 (0)	1 (0)	39 (40)	40	0.021-0.094	0 (0)	0 (0)	40 (40)	40
	x-u-pairs below target	0	40	-	-	40	0.002-0.117	0	40	-	40
	x-u-pairs above target	16	24	-	-	40	0.003-0.066	40	0	-	40
$\sum$		93 (97)	185 (197)	29 (8)	133 (138)	440	-		-	-	440

and E^-) the utility function is significantly more often convex/ /convex-concave than concave (significant level: $< 10^{-9}$). The convex-concave utility functions are dominated by its convex part.

The results confirm the hypothesis described in chapter 3 of this paper.

5.2.2. The Analysis of the Utility Function Parameters

The hypotheses given in chapter 4 of this paper have been analyzed via ANOVA. The risk parameters in (7), (9) and (11) and the more important risk parameter in (10) have been classified as the dependent variable. The results are given in the subsequent Tables 6 to 9.

Table 6

ANOVA runs on the risk parameter estimates of model (7) with the lotteries A and C as a whole and the lotteries B, D and E divided in two parts

Independent variables	Sum of squares	Degrees of freedom	F-value	Level of significance
Lottery	2 882.395	7	22.64	< 0. 001
Age	63.183	4	0.87	0.45
Sex	31.330	1	1.72	0.30
Formal education	55.402	3	1.02	0.40
Residuals	5 530.240	304	-	-
Sum	8 562.550	319	-	-

Table 7

ANOVA runs on the risk parameter estimates of model (9) with the lotteries A and C as a whole and the lotteries B, D and E divided in two parts

Independent variables	Sum of squares	Degrees of freedom	F-value	Level of significance
Lottery	1 452.689	7	153.14	0.001
Age	30.471	4	5.62	0.001
Sex	14.587	1	10.76	0.002
Formal education	13.963	3	3.43	0.02
Residuals	411.964	304	-	-
Sum	1 923.674	319	-	-

Table 8

ANOVA runs on the risk parameter estimates of model (10) with the lotteries A to E as a whole

Independent variables	Sum of squares	Degrees of freedom	F-value	Level of signifi-cance
Lottery	26.245	4	53.29	< 0.001
Age	0.904	4	1.84	0.20
Sex	0.282	1	2.29	0.20
Formal education	0.416	3	1.13	0.40
Residuals	21.300	173	-	-
Sum	49.147	185	-	-

Table 9

ANOVA runs on the risk parameter estimates of model (11) with the lotteries A to E as a whole

Independent variables	Sum of squares	Degress of freedom	F-value	Level of signifi-cance
Lottery	23.168	4	101.78	< 0.001
Age	0.568	4	2.50	0.04
Sex	0.355	1	6.24	0.02
Formal education	0.467	3	2.74	0.05
Residuals	10.642	187	-	-
Sum	35.200	199	-	-

For all models the variable lottery is highly significant, where as the sociodemographic variables are only partly significant independent variables. ANOVA shows for model (9) - by far - the highest internal validity.

The numerical values of different models risk parameter are given in Tab. 10.

When operationalizing the risk of a decision via the span of outcomes these data confirm in five of six cases hypothesis c as given in chapter 3.3 of this paper. For model (9) the findings can be summarized as follows:

Table 10

Average risk parameters for different lotteries and models

Model parameter	Average risk coefficient for lottery										
	A	B	B^+	B^-	C	D	D^+	D^-	E	E^+	E^-
(7)/(b)	2.63	-	2.90	-2.61	-2.92	-	3.11	-2.74	-	3.29	-3.66
(9)/(b)	2.38	-	2.23	-2.55	-0.88	-	1.59	-1.72	-	2.46	-3.51
(10)/(a)	-0.47	-0.07	-	-	0.66	-0.06	-	-	-0.12	-	-
(11)/(b)	-0.42	-0.09	-	-	0.62	0.05	-	-	-0.05	-	-

Table 11

Average risk parameters for different risky decisions

Lottery/part of lottery	Risk level (= span of outcomes of the lottery)		Average risk coefficient
D^+	0	500	1.59
A, B^+	0	1 000	2.30
E^+	0	2 000	/2.38; 2.23/
D^-	-500	0	2.46 -1.72
B^-, C	-1 000	0	-1.72
E^-	-2 000	0	/2.55; -0.88/ -3.51

From Tab. 11 we conclude that the higher the risk is the higher is the average absolute value of the risk parameter. This hypothesis is basically confirmed, just one minor restriction comparing the lotteries D^- and B^-, C emerges. For the range of positive outcomes the findings are intuitively appealing, however for the range of negative outcomes it is hard to explain them.

6. Conclusions

Based on experimental interviewing von Neumann-Morgenstern utility functions have been estimated. Furthermore, variations of the risk parameters have been explained by variables describing the individual decision makers as well as the decision settings.

For decision settings with purely positive outcomes decision making can be described very effectively by a concave utility function, for decision . settings with purely negative outcomes by a convex utility function. The utility function which seems to be the most relevant one is a utility function with a constant risk aversion rate (9).

This model's parameter may be explained by external variables very efficiently, too. It turned out that older, female and less educated indiviudals are more risk averse than younger, male and more educated individuals. Furthermore, the more risky a decision is - risk operationalized by the span of outcomes - the higher are the risk aversion rate in the positive outcomes area and the risk promeness rate in the negative outcomes area. We are advocating that this phenomenon is not due to risk behavior but due to income utility judgements which are always mixed in empirical studies.

The study has been based on somehow artifical lotteries, it would be worthwhile to duplicate the study with more realistic decision settings and taking into account professional variables (e.g. finance managers risk averse, marketing managers ←→ risk prone).

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RODZAJE DECYZJI
CECHY DECYDENTA I NIECHĘĆ DO PODEJMOWANIA RYZYKA

W sytuacji rozpatrywania jednorodnych alternatyw decyzyjnych pojęcie użyteczności stosowane przez von Neumann-Morgensterna jest właściwą konstrukcją, służącą wyjaśnianiu oraz przewidywaniu efektów indywidualnych decyzji. Na podstawie kształtu funkcji użyteczności oraz wskaźnika niechęci do podejmowania ryzyka, zależnego od cech decydenta oraz rodzaju decyzji, można sformułować szereg hipotez.

W badaniu eksperymentalnym respondenci zostali poddani wielokrotnie działaniu przypadku (loteria). Opierając się na działaniu przypadku (loterii) oraz przy uwzględnieniu specyficznych cech respondenta oszacowano statystycznie właściwą mu funkcję użyteczno-

ści. Przetestowano również hipotezy dotyczące niechęci do podejmowania ryzyka sformułowane dla różnych grup społeczno-demograficznych oraz dla różnych typów loterii.

Zgodnie z założeniami teoretycznymi funkcja użyteczności jest częściowo wklęsła a częściowo wypukła, co jak się przyjmuje jest konsekwencją funkcji użyteczności dochodów. Okazuje się iż zarówno typ loterii, jak i niektóre zmienne społeczno-demograficzne wyjaśniają dobrze wahania wskaźnika niechęci do podejmowania ryzyka.