RISK MANAGEMENT AND DECISION THEORY

A promising marriage between two wholly remarkable characters of mind-boggling lineage
Risk management and decision theory
Acknowledgements

It has been a rather educative blast, so to speak. I am proud to come to the zenith of my venture into the world of risk management and decision theory with this dissertation. Although this product is not my average type of product, as it is more theoretical and mathematically challenging than most other projects I have finished during my course, I found the process of concocting this dissertation a pleasure to the mind.

During the minor Enterprise Risk Management in the seventh semester, I took the opportunity to make myself acquainted with the marvels of the ever captivating field of decision theory through a series of lectures and a project. I am well pleased that I made the decision for decision theory as the topic of my dissertation.

First of all, a very well meant thank you to Arie de Wild who gave me the opportunity to write this dissertation and also helped me with my research. If it were not for this man of great intellect, I would have never gotten interested in decision theory in the first place. Also I would like to thank my supervisor for keeping me on track and, along with the second reader, for assessing my aptitude in the field of Business Economics.

To my loving other half, a great thank you for giving feedback on the language component of my dissertation and for putting up with my everlasting ramblings and inquiries on how words are properly spelt. To my parents, thank you for giving me the opportunity to study and always supporting me. Also to the rest of the people around me, I extend my sincere gratitude.
Table of contents

Executive summary ........................................................................................................... 5

Introduction ..................................................................................................................... 7

1 Theory .......................................................................................................................... 9

1.1 Risk management .................................................................................................... 9

1.1.1 Risk management process .................................................................................. 10

1.1.2 Risk matrix .......................................................................................................... 11

1.1.3 Risk responses ..................................................................................................... 13

1.1.4 Making risk management decisions .................................................................... 14

1.2 Decision theory ...................................................................................................... 15

1.2.1 Risk appetite and risk attitude .............................................................................. 15

1.2.2 Expected value .................................................................................................... 17

1.2.3 Expected utility .................................................................................................... 17

1.2.4 Loss aversion ....................................................................................................... 20

1.2.5 Prospect theory ................................................................................................. 22

1.3 Risk management’s and decision theory’s common ground .................................. 25

1.4 Decision influencing factors .................................................................................. 25

1.4.1 Demographic and socioeconomic factors ......................................................... 26

1.4.2 DOSPERT ........................................................................................................... 26

2 Experimental design .................................................................................................. 28

2.1 Desired information ............................................................................................... 29

2.2 Risk reduction ........................................................................................................ 30

2.2.1 Overview ............................................................................................................ 30

2.2.2 Costs of control and axis values ....................................................................... 32

2.2.3 Manipulations ..................................................................................................... 33

2.3 Indifferences ........................................................................................................... 35
2.4 Risk matrix ...........................................................................................................................................36
2.5 Demographic and socioeconomic factors ..........................................................................................36
2.6 DOSPERT ...............................................................................................................................................36
3 Analysis ....................................................................................................................................................37
4 Conclusion ................................................................................................................................................38
References ..................................................................................................................................................39
Appendix 1 – Example of a hypothetical participant ..............................................................................41
Executive summary

This dissertation will contribute to taking the application of decision theory in risk management out of its current rudimentary stage. Due to the recent popularity of risk management within organisations, risk management has evolved aplenty during the last decade. Decision theory has been around for a good while and could supply several useful tools for improving risk management’s decision making process. However, this amalgamate has only been suggested recently, so plenty of work to join the two is yet to be done. The aim of this dissertation is to provide a part of the pioneering research in the field of combining risk management and decision theory, by describing an experiment that brings the two together to implement a prescriptive new element in risk management.

With the help of relevant knowledge in the field of risk management and decision theory, a common ground was found, on which the experiment is based. This common ground includes the fact that both areas of expertise deal with uncertainties and prioritising them. Decision theory can act as counsel in the reaction to these uncertainties by calculating which course of action should be preferred, with the risk taking behaviour of the decision maker taken into account. This does not completely abolish the function of a risk manager within an organisation, as decision theory can only serve as a tool that makes a suggestion.

The experiment itself is designed to reflect risk management within an organisation. It works as an incentivised game in which the purpose is to reduce risks presented in a 5-by-5 risk matrix. Also, the objective is to stay within a specified constraint, which acts as a difficulty level and is burdened with a total impact based on a random draw of the residual risks. To reduce risks, the participants are endowed with an allowance which they can spend on moving risks around the cells of the risk matrix, which models an organisation’s budget that is available for managing risks. After a participant has finished this, the random draw is simulated. The impacts of the occurred risks are then totalled and compared with the imposed constraint. If the total impact does not surpass the constraint, the participant has passed the test and is rewarded a bonus. This buffer acts as the risk capacity of an organisation, which refers to the maximum potential
impact of a risk event that a firm could withstand and remain a going concern. The bonus system models the bonus acquired for achieving a goal within an organisation.

As the described experimental design brought forth in this dissertation is part of a parent research, it will be placed amid several other experimental tasks that assess the participants’ risk taking behaviour. Thus, next to the risk reduction part of the experiment, participants’ risk taking behaviour will be elicited in order to investigate the validity and predictability of the risk reducing task. This will also allow for the assessing of other risk related topics, such as the influence of age and gender on risk taking behaviour, which has been the topic of research in numerous studies.
Introduction

With an ever progressing world comes risk in all fields imaginable. To triumph over all of these risks would be tremendously hard, if not impossible. For several decades, risk management has evolved into a discipline that is applied by many organisations to overcome these ubiquitous risks.

Decision theory is concerned with calculating the consequences of uncertain decisions. This science has been present ever since Pascal came up with the idea of calculating expected value for uncertain decisions in the 17th century. Ever since, decision theory has evolved and is now used to describe decision making processes in various fields, such as economics, mathematics and psychology, on a higher level than just Pascal’s calculation of expected value.

As risk management is concerned with making decisions to manage uncertainties and their consequences and decision theory is concerned with evaluating choices people make, it would seem that these two disciplines share a common ground and are often used jointly. However, the only part of decision theory that is usually applied to risk management is calculating the expected value of a risk, whilst other aspects of decision theory are seldom used. This dissertation will contribute to the ongoing evolution of risk management by bringing risk management and decision theory together more closely and take the current application of decision theory in risk management out of its current rudimentary stage.

This dissertation is written within the confines of a parent research, which strives to “contribute to tightening the gap between the practice and promise of decision theory in the field of risk management” (De Wild, forthcoming). The research described in this dissertation is focussed on part of an experiment to gauge organisational risk appetite. A clear definition of an organisation’s risk appetite can be used as a guideline in the decision making process regarding risks. In the experimental part described in this dissertation, participants will be subjected to risks within a risk matrix and is given the opportunity to invest in reduction measures. The residual risks can subsequently be analysed and the participants’ risk appetite can be assessed.
The problem at hand is defined as “creating an experiment that allows for the assessment of risk appetite within a risk reduction context through application of the risk matrix”. The main research question is thus:

“How can risk appetite in the context of risk reduction be experimentally assessed through application of a risk matrix?”

To answer this question, several other questions can be posed, to come to the answer of the main research question:

What is the common ground of risk management and decision theory?
How can decision theory be used together with a risk matrix?
How can risk appetite be derived from a reduced risk matrix?

The parent research will provide a new perspective on risk appetite within organisations, which can assist risk management practitioners in determining the acceptable level of risk within an organisation and can thus further integrate decision theory in risk management. As merge has been suggested only recently, research can form the foundation of a valuable new eye-opening facet of risk management that provides insight in the risk taking behaviour of organisations. This dissertation provides part of the research necessary to achieve the intention of the parent research, by providing the basis for approaching risk appetite through application of a risk matrix.

In the first chapter a range of relevant theory regarding risk management and decision theory will be evaluated and common grounds shared by the two disciplines will be uncovered. In the second chapter the experimental method used to assess risk appetite through application of the risk matrix will be discussed. It will also swiftly go over other parts of the experiment employed in the parent research. In the third chapter a conclusion will be drawn to answer the questions posed in this introduction. In chapter four several recommendations will be made on how the results of the experiment designed in chapter three can be used for further research.
1 Theory

To create an experiment that uncovers risk appetite, it is necessary to first construct an appropriate theoretical framework to place it in. This chapter will first discuss risk management as it is applied in organisations, showing its goals, application and a popular risk management tool called the risk matrix. Paragraph two will discuss decision theory and how it can be applied to risk management. The presented theory in the first two paragraphs will only include theory that is relevant to this dissertation. The third paragraph will reflect on the previous two paragraphs and bring forth the common ground of risk management and decision theory. In the last paragraph passive traits influencing risk taking will be discussed.

1.1 Risk management

Risk is the possibility that an event will occur and adversely affect the achievement of objectives. Risk management is the process that attempts to manage the uncertainty that influences the achievement of objectives, with the goal of reaching the objectives and thus creating value for the organisation in which it is applied (COSO, 2004). In order to accomplish this goal, it is necessary to constantly apply risk management throughout all of the aspects of an entity.

Risk management attempts to identify risks and take appropriate action to diminish their impending effects on an organisation. As the process of risk management is rather abstract, several risk management standards, such as COSO, FERMA and CAS, have been developed. The guidelines offered by these standards are broadly applicable and make it possible to approach risks in a great variety of contexts, from financial portfolio risk to health care and from oil drilling to organising sports events.
1.1.1 Risk management process

As established in the previous paragraph, there are several risk management standards on offer. All of these have a similar approach to the management of risk. The approaches are different only in details and have the same general cyclic character, as described below and visualised in Figure 1.1.

Figure 1.1 The risk management process presented as a cycle (based on the designed by A. F. de Wild (Van der Waal, 2010)).

The general lay-out of the risk management process is as follows:

1. The first step is to clearly state the objective to be achieved. From the objective it is possible to derive what exactly is exposed to risk. The objective can involve a financial, customer, internal process or innovation perspective, also known as critical success factors as used in the balanced scorecard approach (Daniel, 1961; Van der Waal, 2010).

2. Based on what type of object is exposed to risk, it is possible to identify the events that form a threat to the objective. The result of the identification is a risk register, a list containing internal and external risks that form a threat to the object.

3. To be able to compare risks, the next step should be the assessment of the likelihood and impact of each of the identified events. This can be done in either
or both a qualitative or quantitative way. Assessment of impact is done in relevant quantities, in most cases this is done in monetary equivalents, but it is common to see impact expressed in other quantities, such as reputational damage and injuries.

4. Prioritisation of risks is done by comparing individual risks. This can be done in several ways. Frequently used methods of prioritisation are the expected value method, which ranks risks according to the product of a risk’s probability and impact, and plotting risks on a risk matrix, which offers a visual aid to compare risks. A more detailed description of risk matrices is supplied in paragraph 1.1.2.

5. When risks have gone through the prioritising step, an appropriate risk response is applied to deal with the risk. Possible risk responses include treat, transfer, terminate and tolerate. These responses to risk will be described in more detail in paragraph 1.1.3.

6. After selecting an appropriate risk response, the risk should be monitored to ensure it will not become a threat again. Depending on the severity of the residual risk, reassessment can be done on daily to an annual basis. This final step in the risk management process serves as a monitoring and feedback moment and closes the cycle of risk management.

1.1.2 Risk matrix

Risk matrices are widely used as a tool to visualise various types of risk. The use of risk matrices is promoted by several risk management standards (FERMA, 2002; COSO, 2004). A risk matrix is a rendering of a probability and a consequence axis in the form of a graph. The axes are divided in several categories, ranging from low to high. The resolution of this matrix depends on the amount of categories along the axes and is an arbitrary choice by the creator of the matrix. It is possible to give the axes both qualitative and quantitative labels. As a result the categories might not be linear in the case of quantitative labels. For quantitative labels a percentage is used for the probability axis and the consequence axis is usually expressed in monetary terms. Depending on the type of risks plotted in the risk matrix, another scale can be used, such as injuries or reputational damage. The two axes create a number of cells, each representing a range of probability and a range of consequence. To enhance the visibility of the risk matrix, colours or numbers are commonly used to indicate the
acceptability of each of the cells. Colours and numbers ranging from green or 1 (acceptable) to red or 5 (unacceptable) are most often used for this and can be arbitrarily applied to every cell. An example of a risk matrix is shown in Figure 1.2.

![Risk Matrix Example](image)

Figure 1.2 An example of a 5-by-5 qualitative risk matrix, with a numerical and colour scale indicating the acceptability of every cell, ranging from acceptable (1 and green) to unacceptable (5 and red).

Note that the risk matrix is not necessarily symmetric with respect to the diagonal. This can be explained by the fact that the range of every category can be arbitrarily chosen and that the last category of the consequence axis is where risks such as bankruptcy, death or irreparable damage are located. As these risks have an irrecoverable impact, they can practically never be grouped with any acceptable risks.

When identified risks are plotted in the risk matrix, they can be ranked for urgency as a result of prioritisation by the colour of the cell in which they are located. The acceptability index can also be used to roughly outline which control measures should be taken to manage risks (Glasgow Caledonian University, 2009). A red cell means that a risk is unacceptable and should be treated, transferred or terminated immediately. A risk located in an amber cell is momentarily acceptable, but should be considered for treatment or transferring shortly. Depending on the severity of the consequence, a risk located in an amber area could also be tolerated. Risks in a green cell can be tolerated or treated, depending on impact and probability.
Although the use of risk matrices is commonplace, the simple application of it comes with several disadvantages (Cox, 2008):

- Risk matrices are prone to poor resolution, as there can usually only be a rough indication of probability and consequence of risks;
- Due to the range used per category, a risk can be assigned a wholly erroneous level of probability or consequence;
- Risk reactions cannot be based on solely the probability and consequence categories and;
- Qualitative categorisation leads to subjective rating of risks.

Avoiding these limitations of risk matrices can be done by assigning a definite value to each category of the risk matrix whilst expressing risks in an objective quantitative measure, to prevent ambiguous interpretation of risks. Still, even a quantitative approach leaves room for errors due to the necessity of subjectively assigned likelihood and impact to risks unfamiliar to an organisation.

### 1.1.3 Risk responses

After assessing relevant risks, a proper response to each of the risks must be implemented. Possible responses are termination (avoidance), treatment (reduction), transfer (sharing) and toleration (acceptance) (COSO, 2004). In the list below, the risk responses are explained into further detail. First the response is named, followed by the COSO definition and an example:

- **Terminate**, completely shutting off all activities that cause the risk to exist. This happens when for example manufacturing a certain product is not viable for profit anymore. In this case a company can choose to stop manufacturing the product.
- **Treat**, reducing either or both the impact or probability of the risk directly. For example, the risk of fire can be treated by reducing either the impact or probability separately. To reduce the impact of the fire, a curative measure is taken, usually with no effect on the risk’s probability. This could be done by installing a sprinkler installation. On the other hand, a preventive measure can be taken to reduce the likelihood of a fire occurring. This is usually done by the use of materials impregnated with fire retardant agents, to avoid material from
bursting into flames. The preventive measure, in turn, does not always affect the risk’s impact directly.

- **Transfer**, fully or partially reducing the impact or probability of the risk by a full transfer or sharing of a risk. The obvious example of this response is an insurance policy. When an organisation or person is not able to cover the impact of a risk, an insurer can be approached to cover the risk for a certain payment.

- **Tolerate**, leaving the risk as is without taking any action. This can be done when a risk is of negligible size and is considered an acceptable risk, either before or after the implementation of other risk responses, and cannot be further responded to. Otherwise, a risk of substantial size can be tolerated if the presence of the risk is vital for the existence and continuity of an organisation. Any risks that remain and are tolerated should be subjected to monitoring, for they should not evolve from a tolerated acceptable risk into an unacceptable risk.

An organisation can choose which response or combination thereof should be employed to counter a specific risk. To determine the best fitting response for a risk, the organisation should consider risk tolerance and the effects of the available responses on the organisation on a broad level. Also opportunities arising from both the bare risk as the response and a cost-benefit analysis should be taken into account.

### 1.1.4 Making risk management decisions

In the cycle of risk management, the step that creates value for an organisation is chiefly selecting the appropriate risk responses to counter risk. For financial risks this choice is often a case of optimisation, as the goal is to find a balance between the cost of the reaction to be applied and the residual risk after application. It is important to note that the decision maker’s attitude towards the impending risk has influence on the process of choosing the suitable reaction to deal with the risk. This leads to a person more lenient towards taking risk to sooner find a risk tolerable than a person more hesitant towards taking risk. Likewise, depending on the decision maker, a risk might be completely terminated, whereas someone else would find reduction preferable. To describe risk preferences, decision theory can be applied for a more mathematical approach to choices involving risks.
1.2 Decision theory

Decision theory is the part of probability theory that is concerned with calculating the consequences of uncertain decisions. This can be applied to state the objectivity of a choice and to optimise decisions. In this paragraph several aspects of decision theory will be discussed, being risk appetite, risk attitude, expected value, expected utility, loss aversion and prospect theory.

1.2.1 Risk appetite and risk attitude

A clear description of risk appetite allows for a consistent approach to handling risks within an organisation. The definition of risk appetite is the amount of risk, on a broad level, an entity is willing to accept in pursuit of value (COSO, 2004). Another term that is associated with this is risk attitude, which describes the tendency to risk averse, risk seeking or risk neutral behaviour. In other words, risk appetite relates to taking risks in a broad sense and risk attitude relates to making a risky decision. Risk attitude can be elicited from the upper echelon of an organisation and thus expressed in a quantitative manner by use of risk appetite, which reflects risk taking behaviour. This information can be formally published in a document such as a risk policy, which is an asset to an organisation by means of making it possible to handle risks in a reliable way.

An agent’s risk attitude can be elicited in a relatively straightforward way. When an agent is offered a choice between a risky and a safe option, the agent chooses and their preference is found. Depending on the choice the agent made, the sure option is made more or less attractive, after which the agent makes their choice again. This process can be repeated several times to iterate towards a point where both options are equally attractive and thus a point of indifference is reached. Such methods of eliciting risk attitude have been successfully used in experiments (Keeney & Raiffa, 1976; Pennings & Smidts, 2000). Example 1 illustrates this method. This example forms a crux for explaining several necessary concepts to calculate risk appetite throughout this dissertation.
Example 1

An agent has a choice between two options. If option 1 is preferred, the agent receives €50. The second option involves a gamble in which a coin is tossed and the agent has a free choice for heads or tails. A win results in €100, a loss in €0. The agent prefers option 1, after which the agent is offered the same gamble or a sure amount of €25. The agent now prefers the gamble, which leads to a sure amount of €37.50. This process is repeated several times, resulting in indifference, where the agent considers both options equally attractive.

The indifference between two options, one of which is a sure amount of \( x \), the other a gamble with probability \( p \) of gain \( g \) and complementary probability \( 1 - p \) of loss \( l \) can be denoted as

\[
(1: x) \sim (p: g; (1 - p): l). \tag{1.1}
\]

Note that the values for \( x \), \( g \) and \( l \) are not restricted to positive outcomes. Gain \( g \) expresses the consequence of the best possible outcome and loss \( l \) expresses the consequence of the worst outcome, which is not necessarily a loss. Using the abovementioned notation, the indifference elicited in Example 1 can be denoted as

\[
(1: x) \sim (0, 50: 100; (1 - p): 0), \tag{1.2}
\]

which shows that the agent is indifferent between the risky option of a coin toss for either €0 or €100 and acquiring a certain amount \( x \). In a risk management context, these two choices could be seen as a conflict between transferring a risk (the certain choice) and tolerating a risk (the risky choice).

Gambles such as described in Example 1 are used throughout this dissertation to model risks, so there are only two possible consequences when a risk is taken. Consequences of risks assessed in real life risk management are usually not the result of such a two-way gamble, but are instead continuously distributed and thus have a range of outcomes. A risk can be modelled by a likelihood function for impact, when a mean outcome and standard deviation are given. As describing a risk as a likelihood function...
of a consequence during an experiment would most likely not go down well with participants, not to mention the person analysing the results, risks are modelled as a two way gamble in decision theory.

To assess the agent's risk attitude with regards to the method employed in Example 1, the expected value of the two choices needs to be calculated. This is a fairly simple approach and will be described in the following paragraph.

1.2.2 Expected value

The two options in indifference (1.1) are equally attractive to the agent. However, calculating the expected value of the two choices, using the well known general definition of expected value,

\[
EV = \sum_{i=1}^{n} p_i x_i, \tag{1.3}
\]

where expected value \( EV \) is the sum of all products of an option with \( n \) possible outcomes with possibility \( p \) and consequence \( x \) for every possible outcome, it can be shown that the certain and uncertain choice should not be equally attractive, as an objective decision maker should be indifferent when the expected value of both options are identical. From this, the expected value can be used to assess the risk attitude of the agent. If \( EV_c \) is the expected value of the certain option to obtain amount \( x \) and \( EV_r \) is the expected value of the risky option that involves a gamble, then for \( EV_c > EV_r \) the agent is risk seeking, for \( EV_c < EV_r \) the agent is risk averse and for \( EV_c = EV_r \) the agent is risk neutral. By using the expected value to gauge an agent's indifference between the two options, it is not possible to explain why an indifference is obtained where \( EV_c \neq EV_r \). For an objective agent, this would not be true. To explain this phenomenon, another approach to indifferences is employed, namely expected utility.

1.2.3 Expected utility

In the world of economics, utility is used as a measurement of satisfaction. This can also be used in decision theory, as a means of expressing the satisfaction of a particular choice, as illustrated in Example 1. When indifference is reached, the satisfaction that the options carry is the same. To allow for easy comparison between different positive
amounts of money, a scale of 0 to 1 is used, where the highest possible amount of money $x_{\text{max}}$ in a given frame is denoted as $U(x_{\text{max}}) = 1$. A zero amount of money constitutes no change in utility, thus $U(0) = 0$. For values of $x$ between 0 and $x_{\text{max}}$, the utility is expressed as a value relative to $x_{\text{max}}$. This can also be applied to situations with exclusively negative outcomes and both positive and negative outcomes, which leads to negative utility. It is also possible to extend this framework to include possibilities of outcomes, which leads to the expected utility of an outcome.

The expected utility of an outcome, with consequence $x$ and probability $p$, is calculated by multiplying the probability and the utility of the consequence, so that

$$EU(p, x) = p * U(x). \quad (1.4)$$

This definition of expected utility can be used to evaluate indifferences between a certain and a risky option. Taking indifference (1.1), by assuming the certain option is of the same expected utility as the two possible outcomes of the uncertain option, this results in

$$EU(1, x) = EU(p, g) + EU(1 - p, l). \quad (1.5)$$

If this is applied to Example 1, it can be shown that for indifference between a risky option with equally probable outcomes of € 0 or € 100 and a certain option involving an amount of money $x$, then

$$U(x) = 0.5. \quad (1.6)$$

This property of the gamble used in the example allows for simple plotting of indifference curves, using the outcome of the indifference. This is shown Figure 1.3 below.
Figure 1.3 The utility of gain $x$ for three agents with different risk attitudes.

Figure 1.3 shows the utility curve of three agents with different indifferences elicited using the method in Example 1. This illustrates the law of diminishing marginal utility for risk aversion, which implies that the first units gained, in this case the first few Euros, yield more pleasure than the last units gained (Wicksteed, 1910). In contrast, risk seeking behaviour implies the opposite. Risk neutrality implies a linear utility, where every Euro is valued equally.

In order to create the curve using a mathematical approach, a frequently used equation is the exponential equation

$$U(x) = 1 - e^{-\frac{x}{R}},$$

(1.7)

where utility is a function of amount of money $x$ and risk tolerance $R$. Risk tolerance is the range of acceptable variation an entity is willing to accept to achieve an objective (COSO, 2004) and is expressed as an amount of $x$, so that it represents the variation within a reference frame of $x$. This implies that risk tolerance $R$ should be in the same order of magnitude as amount $x$. Applying equation (1.7) to find the utility of a specific $x$ may not yield a result that fits in the aforementioned frame of utility for positive
consequences of \( x \), \( 0 \leq U(x) \leq 1 \). To allow for easy comparison between utilities within a particular frame, the acquired utility \( U(x) \) using equation (1.7) is divided by the utility of the highest possible consequence within the frame, \( U(x_{\text{max}}) \). This approach is valid for possible gains, as well as possible losses.

In the utility approach to risk aversion, applying equation (1.7), it implies that risk aversion is present for \( R > 0 \), risk seeking behaviour for \( R < 0 \) and risk neutrality for \( R = 0 \). Overall, people are inclined to establish a sure amount of wealth in gain scenarios, leading to risk aversion in the gains domain. Conversely, people tend to take a gamble to nullify a certain loss, leading to risk seeking behaviour in the losses domain (Kahneman & Tversky, 1979). Combining a gain and loss scenario within the same gamble is further explored in paragraph 1.2.4.

1.2.4 Loss aversion

As established in paragraph 1.2.3, people in general would rather take a decent sized certain gain than gamble for a potential large gain and in contrast are willing to take a gamble to avoid a certain loss. This leads to the aphorism "losses loom larger than gains", meaning that in the sense of utility, for most people the pleasure derived from obtaining some specific amount of money is less than the displeasure that is felt when that specific amount is lost. This has been experimentally confirmed (Kahneman & Tversky, 1979) and can be seen in the graph in Figure 1.4.
Figure 1.4 The value function graphically demonstrating loss aversion, expressed in bacon. The loss of a specific amount of bacon looms larger than the gain of the same amount of bacon.

Figure 1.4 presents the value function, which shows the characteristic curves in both the gains and losses domains, indicating risk averse behaviour for gains and risk seeking behaviour for gains. Additionally, the steeper inclination of the function in the losses domain illustrates how a loss looms larger than a gain. The apparent difficulty of a loss can be caused by the status quo bias (Samuelson & Zeckhauser, 1988; Novemsky & Kahneman, 2005) which indicates that most do not like giving up a good and require a sizeable compensation in order to give up a good.

In an experimental approach, loss aversion can be measured by giving a decision maker two options. The first option is the status quo choice, a certain option with no consequence, so that there is a 100% chance of acquiring € 0. The second choice is a mixed prospect, with a possible downside and upside consequence. By adjusting the second option, making it more or less attractive depending on the preferred choice, the agent iterates towards indifference, similar to the approach in Example 1. This leads to an indifference rather like indifference (1.1), but with $x = 0$, aling the agent to choose for a status quo option. This yields indifference

$$ (1: 0) \sim (p: g; (1 - p): l), \quad (1.8) $$
where a balance exists between the status quo and a mixed prospect, with probability \( p \) of incurring a gain \( g \) and a complementary probability of incurring loss \( l \). If the agent acts according to the expected value theorem, in case of equal probabilities of the positive and negative consequence occurring, then \( g = l \). However, if the agent shows signs of loss aversion, then \( g > l \), as the possible gain must overcompensate the possible loss.

The sunk cost effect can be explained with loss aversion (Knox & Inkster, 1968). Sunk costs are costs sustained in the past that cannot be recovered and thus are seen as a loss. What follows from this is the sunk cost fallacy, which describes that after a hefty investment in an on-going project that led to only a poor return, investments are kept being made in the hopes of a gain compensating for the loss, even though the best option on paper would be to pull out of the project. This is also colloquially called the Concorde fallacy, which refers to how the Concorde project should have been cancelled based on financial returns, whilst the British and French governments kept investing in the hope to turn the project into a profitable business.

Loss aversion is closely related to the endowment effect (Kahneman, Knetsch, & Thaler, 1990), which describes that people value an endowed good more than they would a good that is not endowed. Typically, to sell an endowed good, people demand more than they would sacrifice for the same good, if they were to purchase it. Studies have varying success producing loss aversion, indicating that a significant difference exists (Kahneman, Knetsch, & Thaler, 1990; Tversky & Kahneman, 1991) to little to no evidence of loss aversion or the endowment effect going on at all (Harinck, Van Dijk, Van Beest, & Mersmann, 2007; Ert & Erev, 2008). Also, the buying and selling price does not depend on actual physical endowment of the bought or sold item in question (Carmon & Ariely, 2000), which means loss aversion also occurs when a hypothetical prospect is at stake, which is good news for experiments dealing with loss aversion.

**1.2.5 Prospect theory**

In paragraph 1.2.3 it has been shown that the utility function for money is nonlinear and has a slight concave curve for people in general, which implies diminishing marginal utility. This phenomenon indicates that if an amount of money is expressed as its utility
equivalent, half the amount of money is not necessarily assigned half the utility equivalent of the double amount, so \( U(2x) = 2U(x) \) is not necessarily valid. To fall back on a risk context, this means that the consequence is interpreted subjectively and consequences of independent risks cannot be compared linearly. Peculiarly enough, this difficulty in comparing is not restricted to the monetary property of a risk, but is also present in the probability property of a risk, so if \( p \) is some probability and \( w(p) \) is its perceived probability then \( p = w(p) \) is not necessarily valid. Prospect theory explains this phenomenon and applies it to gambles.

Well-defined numerical probabilities should provide an agent with information to make an objective decision. However, the numerically expressed probabilities are interpreted subjectively and as a result the agent either exaggerates or undervalues said probability. Typically low probabilities are seen as higher than they really are, whilst high probabilities are seen as lower (Kahneman & Tversky, 1979). A graph illustrating this typical probability weighting is shown in Figure 1.5, where \( p \) is an objectively expressed probability and \( w(p) \) is the subjective probability an agent assigns to \( p \).

![Probability weighting of probability p](image)

Figure 1.5 An example of a typical probability weighting curve with overweighting for small probabilities and underweighting for high probabilities.
The probability weighting function as shown in Figure 1.5 applies to both gains and losses, which leads to optimism for potential gains with low probability and pessimism for gains with high probability. In the same way this leads to pessimism for losses with low probability and optimism for losses with high probability. Using this understanding of probability, it can be explained how a jackpot is an exciting prospect for a lottery ticket owner, even though it is very unlikely they will win the jackpot. This can also explain risks with consequences that are not expressed in monetary terms, such as bungee jumping and cricket. These activities are safe to enjoy, but involve risks with a fatal impact, but very low probability, yet these sports are not practiced as a pastime on a daily basis by many people, as they are considered dangerous.

Identical to expected utility, prospect theory is used to assign a preference value to gambles in order to rank the attractiveness of the complete prospect and not just the monetary outcome. To do this, the weighted probability is simply multiplied by the utility of the outcome, so that

\[ PT(p, x) = w(p) \cdot U(x), \]  

where \( PT(p, x) \) is the expected utility of a prospect with a weighted probability \( w(p) \) of probability \( p \) and utility \( U(x) \) of impact \( x \).

Probability weighting functions as a correction for the probability in the same way as utility functions as a correction for the impact of a risk. The elicitation of the probability weighting function is done in a similar way (Abdellaoui, 2000) as the elicitation of the utility function, as shown in paragraph 1.2.3. The probability weighting function itself can be described with equation

\[ w(p) = \frac{ap^\beta}{ap^\beta + (1-p)^\beta}, \]  

where \( \alpha \) influences the area of \( p \) near 100% and \( \beta \) influences the area of \( p \) near 0% (Lattimore, Baker, & Witte, 1992; Ostaszewski, Green, & Myerson, 1998; Wakker, 2008). In the case of \( \alpha = 1 \) and \( \beta = 1 \), the function is linear, so that \( p = w(p) \). Probability
weights assigned to probabilities for positive and negative outcomes do not necessarily have to be identical and are called respectively $w^+$ and $w^-$.  

### 1.3 Risk management’s and decision theory’s common ground

In paragraph 1.1 and 1.2, the cases of risk management and decision theory have been partially discussed. The knowledge of these areas of expertise now allows for an intersection of the two to find their common ground.

The most striking resemblance is that both risk management and decision theory would not exist without the presence of uncertainties. Moreover, there are several similarities when the risk management process is studied further. Risk management attempts to assess uncertainties and prioritise them, which decision theory is able to do for the latter. Risk management makes decisions to manage the uncertainties, whilst decision theory can prescribe what the correct course of action would be to deal with the uncertainty, if information on the risk taking behaviour of the decision maker is present.

Decision theory can be applied to prioritise risks in a similar fashion to the risk matrix. When sufficient information on the decision maker’s risk taking behaviour is available, the decision maker’s quantitative risk matrix can be predicted by calculating the utility of the cells in the risk matrix, each of which indicates a range of risks. The result can be used as an indication of priority, with risks in cells of the largest absolute utility having higher priority than risks with lower absolute utility.

### 1.4 Decision influencing factors

The decisions people make can be assessed by using the methods described in paragraph 1.2. These decisions are influenced by the personality and characteristics of the decision maker. This paragraph will discuss which traits influence risk taking behaviour and how risk taking behaviour expressed in nonfinancial areas can be used to assess risk taking behaviour in financial areas.
1.4.1 Demographic and socioeconomic factors

Influence on risk taking behaviour of demographic and socioeconomic factors such as age, sex and income status has been the subject in a number of researches. Research to these factors is mostly done by means of a questionnaire, although doubts have been raised over the reliability of this method. Questionnaires are said to do a poor job predicting actual investment behaviour (Bouchey, 2004) and to have only little correlation with reality (Yook & Everett, 2003). This creates an opportunity for a different approach to verify or falsify the outcomes of earlier research.

The consensus in efforts to research demographic and socioeconomic factors influencing risk taking decisions, appears to be that there is a positive correlation between being more risk seeking and the following (Bajtelsmit & Bernasek, 1996; Sung & Hanna, 1996; Grable, 2000):

- Being male;
- Being older;
- Being white;
- Being married;
- Being professionally employed with higher income;
- Having more education;
- Having more financial knowledge and;
- Having higher economic expectations.

1.4.2 DOSPERT

It is axiomatic that if one is prone to risky behaviour in one area, such as gambling, one is likely to show risky behaviour in other areas as well, such as sports and health. DOSPERT (Domain-Specific Risk-Taking) offers a psychometric scale that assesses risk perception in five content domains, including financial, health and safety, recreational, ethical and social decisions (Weber, Blais, & Betz, 2002; Blais & Weber, 2006). A person is to indicate the likelihood of engaging in a number of activities in one or any of the aforementioned domains, on a seven point scale, ranging from extremely unlikely to extremely likely. The points assigned to an activity are directly translated into a score and the sum of scores for all activities acts as an indication for the risk taking behaviour of said person.
The financial DOSPERT domain contains a risk taking sub domain, this element can be applied to research regarding risk taking behaviour. This domain contains opportunities with a risky financial context:

- Investing 10% of your annual income in a moderate growth mutual fund;
- Betting a day’s income at the horse races and;
- Investing 5% of your annual income in a very speculative stock.
2 Experimental design

The goal of the experiment is to test the theoretical framework, as described in chapter 1. This is done by comparing the data gathered from three tasks, covering a model of a risk reduction task in practice, an elicitation of indifferences as described in paragraph 1.2.1 and an assessment of a risk matrix. To test the underlying determining factors influencing the participants’ risk appetite, several manipulations will find place during the experiment.

The risk reduction task will show which risks are the most unacceptable ones in a practical scenario. To ensure a reaction that reflects a real situation, the reduction task involves real money and the goal for the participants is to maximise their earnings. In this task, several manipulations will be implemented, so the risk reduction can represent a number of different scenarios, all of which can be compared with one another. The reduction task as well as the manipulations will be described in the second paragraph.

In the second task the participants need to complete, risk attitude towards gains, losses and mixed gambles will be obtained. The results of this task will be used to calculate the participants’ risk aversion, probability weighting function and loss aversion, for gains as well as losses. The second task is described in paragraph three.

The third part of the experiment is the rating of acceptability of each of the risks involved in the first part of the experiment, which will be described in the fourth paragraph. The result is a risk matrix. In conjunction with data on risk taking behaviour, predictability of the risk matrix can be assessed.

In the final part of the experiment, the participants provide personal demographic, socioeconomic and DOSPERT information for further study. This is described in paragraph five and six.
2.1 Desired information

Following from the relevant theory in chapter 1, the actual experiment will consist of several separate parts, each investigating another aspect of decisions under risk. To achieve this, the experiment is divided in four distinct parts, being:

- Reduction of risks (paragraph 2.2);
- Finding indifferences(paragraph 2.3);
- Assessing a risk matrix (paragraph 2.4) and;
- Supplying relevant personal details(paragraph 2.5 and 2.6).

The reduction of risks will require participants to reduce a multitude of risks shown in the cells of a risk matrix. To do this, the participants are endowed with a finite amount of credits that can be spent on reducing risks along the probability or impact axis of the matrix, by moving risks from cell to cell. The participants are free to decide which risks should be reduced and which risks are left alone.

For the indifference part of the experiment the goal is to choose between two options to reveal the risk preference of each of the participants. Depending on the choice of the individual participants, one of the options will be made more or less attractive. By repeating this, the participant will iterate towards a point where the participant is considered indifferent between the options.

By assessing a risk matrix, participants’ personal risk matrices will be revealed. This is done by making the participants indicate to what degree a cell within the risk matrix is acceptable.

The final part of the experiment will provide demographic, socioeconomic and DOSPERT data by the participants.
2.2 Risk reductionction

The first part of the experiment consists of reducing a number of risks plotted in a risk matrix. In this paragraph the general overview of the risk reduction part of the experiment will be given, as well as the cost of reducing single risks in this matrix. The desired manipulations and their implementation will also be clarified.

2.2.1 Overview

For the first task, the participants are expected to reduce a number of risks, expressed as a probability $p$ of negative consequence $x$, without further context. In total 25 risks will be presented to the participants, as defined by a 5-by-5 risk matrix, with 5 categories for both probability and consequence. This should give the outcome a reasonable resolution, whilst keeping the experiment understandable to the participants. Each cell in this matrix contains a unique risk that can be reduced by the participants. A risk $R(p,x)$ is defined as an event with probability $p$ and consequence $x$, illustrated in Figure 2.1.

![Risk Matrix](image)

Figure 2.1 A risk matrix with risk $R(5,5)$. The values of $p$ and $x$ refer to the respective categories the risk is located in.

When a participant is presented an unacceptable risk $R(p,x)$, the participant can pay a certain amount for control measures to reduce the risk in either or both the probability or consequence domain. The remainder of the risk after application of the control measures is now residual risk $R'(p',x')$, as illustrated in Figure 2.2.
To simplify the described action and allow for easy analysis, risks can only be reduced on a step by step basis, meaning that they can be moved freely to any cell with lower or equal probability and impact. This limits the participants to move the risk to a number of predefined possibilities for probability and consequence of residual risk.

The participants are free to choose which risks are reduced and to what extent. When the participants have finished reducing risks, an optimum has been reached, where the total payment for control measures and the residual risks are in optimal condition, within imposed constraints.

The first part of the experiment will be carried out in an organisational setting where a certain amount of risks are present that can be reduced, as described above. To invest in risk reducing measures, the participant is provided with an initial endowment that can be used for this purpose. A second amount of money is available to the participant and will function as a financial buffer, to absorb losses from risks that do occur after simulation. This buffer is not accessible to the participant and will only function as a constraint for allowed losses. When the participant has finished investing in control measures and does not want to make more investments, a random draw is simulated for all 25 risks, based on the probability and losses of the remaining risks. The total losses are deducted from the financial buffer and the result is compared with the financial goal that was set for the participant before the implementation of control measures. The rewarded total earnings of the participant are based on the level of completion of their
objectives. If a participant has managed to keep their buffer above a certain threshold, they will be rewarded more than when the buffer is below the threshold.

When this task has been finished and the participant is content with the reductions made and does not want to reduce any more risks, the result is an optimised residual risk matrix, where an optimum has been achieved. The resulting residual risk matrix shows the participant’s best situation for given risks, initial endowment, costs of control and goal.

2.2.2 Costs of control and axis values

The probability axis of the risk matrix is divided into five categories, ranging from 10% to 90%, with a 20% interval between each of the categories. The impact axis is fitted with five categories, ranging in value from €1 to €9, with a €2 interval between each category. These values correspond to the order of magnitude of the financial endowments used in an experimental environment where real money is at stake. The linear increase in both probability and impact makes the risk matrix more understandable to the participants and will thus contribute to a swift and reliable result.

For costs of reduction the assumption is made that moving a risk in a specific direction does not influence the costs of the next move. This does not exclude the possibility to employ different costs for preventive and curative measures. The assumption of constant costs makes the reduction task easier to comprehend for the participant, as well as for the person analysing the outcome.
2.2.3 Manipulations

Risk reducing behaviour can be analysed in order to find out which factors influence the decision maker. To allow for this, several factors will be induced by manipulating the participants. Manipulated factors are:

- Height of the initial endowment (two possible manipulations);
- Difficulty of the objective (two possible manipulations);
- Cost of control (four possible manipulations);

The total amount of manipulation groups in this experiment is 16. In the following paragraphs it will be discussed how the manipulated factors will be implemented in the experiment.

2.2.3.1 Height of the initial endowment

The initial endowment models the resources within an organisation that can be used for reducing risks. Within the experiment this endowment serves as an allowance to reduce risks and is thus meant to be fully committed to risk reduction. A higher allowance makes it easier for participants to reduce risks, whereas a lower amount forces participants to make a conscious decision as to which risks are deemed more acceptable than others. A possible additional manipulation would be to allow the participant to add the remainder of the allowance to the buffer described in the next paragraph.

It is suggested to endow the participants with an allowance for 10 moves in a scenario with a low initial endowment and where both preventive and curative costs are 1 unit. This allows the participants to reduce a sufficient amount of risks to generate a residual risk matrix with enough resolution to compare with the result of the other experimental tasks. To evaluate the effects of a higher endowment on the residual risk matrix, it is suggested to give the participants an allowance for between 15 and 20 moves in the same scenario. This will supply enough difference between a high and low initial endowment and can serve as a check for the effects.
2.2.3.2 Difficulty of the objective

The participants will be split into two groups with different difficulties of objective to achieve. Both groups will strive to reach the same goal, to keep expenses due to risks within either a low or high buffer level. The buffer models the risk capacity of an organisation, which refers to the maximum potential impact of a risk event that a firm could withstand and remain a going concern (COSO, 2009). The impact on the buffer of the remaining risks is modelled by a random draw of risks, based on their residual probability and impact.

The height of the buffer should be based on the expected value of the most profitable residual risk matrix for each of the manipulation groups, with the possibility of adding an amount of the initial endowment to the buffer. Furthermore, the difficulty to stay within the allowed buffer height should be first expressed in terms of a desired pass/fail ratio of participants. Also the available resources for this part of the experiment need to be clearly defined, as well as the amount of participants. When these figures are on hand, an actual numerical value can be assigned to both of the buffer heights.

2.2.3.3 Cost of control

In order to compare the effects of costs of control on risk appetite, the participants will be divided in four groups, each with predetermined high or low costs of control for preventive and curative measures, as described in paragraph 1.1.3. Table 2.1 shows which height of costs is assigned to each of the group.

Table 2.1 The costs of control throughout the different manipulations, where L indicates a low cost and H indicates a relative high cost.

<table>
<thead>
<tr>
<th>Costs of control</th>
<th>Group</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Preventive</td>
<td>1</td>
<td>L</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Curative</td>
<td>1</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
</tbody>
</table>

The ratio of L:H should be great enough to supply a significant difference between the two. However, it should also not be too great, as this would make one control measure
too expensive, leading to a low usage of the expensive control measure, which leads to too large a difference to actually make a sensible analysis.

The low cost should be a good deal for the first few reductions of high priority risks. If the impact scale is linearly divided from € 1 to € 9 with a € 2 interval and the probability scale is also linearly divided from 10% to 90% with 20% intervals, this means that, from an expected value point of view, a € 1 would be a good investment for the reduction of a high priority risk. Yet, also from an expected utility point of view, the reduction of lower priority risks, located in the first categories of the two axes, should not be potential candidates for reduction.

From the same expected value approach, used to find an appropriate low cost of control, a limit could be derived for high costs. Taking the first step of the first reduction, which should be moving risk (90%, €9) one cell, it follows that this move causes a reduction of € 1,80 in expected value. In fact, every next move causes a reduction of € 0,20 expected value less. With this knowledge, it becomes possible to deduct a range of values in which the high cost of control should be placed. This ranged is advised to lie between € 1,25 and € 1,40, to satisfy the desired ratio between low and high costs, whilst still making it attractive to invest in both low and high cost control measures.

### 2.3 Indifferences

The second task will elicit the risk attitude of the participants in a gain, loss and mixed prospect scenario. The result of this task will be compared with the results of the first task and will prove whether or not the participant’s risk taking behaviour during the reduction task can be predicted when knowledge on the participants risk aversion, loss aversion and probability weighting is available. During the second task the participant will iterate towards a point of indifference, akin to the method used in Example 1.

The results of the three scenarios allow for the uncovering of the participant’s risk aversion, probability weighting function and loss aversion. In a win scenario, the participant will be subjected to a choice between a certain gain and a gamble, with a possibility of a larger gain or nothing. In the loss scenario another two choices are presented, involving a certain loss and a possibility of a larger loss or nothing. By
analysing the results of these two scenarios, the utility function and the probability weighting function for gains as well as losses for the participants will be found. The mixed prospects scenario will present the participant with a slightly more difficult choice that is modelled as an investment choice. The participant will have a choice between two options. The first option involves a gamble with a possibility of a gain as well as a loss and the other option is a certain outcome of zero. Using the results of the mixed prospects scenario, the loss aversion of the participant is found.

2.4 Risk matrix

To find out the acceptability of the risks involved in the reduction task, the participant is to fill out a risk matrix, rating every risk’s acceptability. This is done by using a five point scale, for each of the 25 risks of the 5-by-5 matrix as used in the reduction task. The product of this task can be compared with the results of the reduction task, to assess the predictability of the participant’s risk reducing behaviour. It is to be expected that the most unacceptable risks as defined in this part, are reduced first in the risk reduction task.

2.5 Demographic and socioeconomic factors

To allow for further investigation of the role of personality and socioeconomic background, some additional information about the participant is required. Data of interest are the participant’s sex, age, marital status, income, education, financial knowledge and economic expectations (Grable, 2000). To analyse the factors that affect risk taking according to literature, a relationship is attempted to be found by linking the acquired personal information to the participant’s risk taking behaviour.

2.6 DOSPERT

Examination of the DOSPERT scale can be done by adding a number of questions as proposed in DOSPERT studies (Weber, Blais, & Betz, 2002; Blais & Weber, 2006), which relate to financial risk taking.
3 Analysis

The experiment will generate data which can be used to analyse the participant’s risk
taking behaviour. This chapter will discuss how the data can be analysed and compared.
This chapter is accompanied by an example analysis of a hypothetical outcome of one
participant, included in appendix 1, which is suggested to read alongside this chapter
for increasing comprehensibility of the process.

Predictions on the risk reducing behaviour can be made by using the risk matrix that is
formed in part three of the experiment. Obviously the most unacceptable risks in this
matrix are to be reduced first. This enables the analysis of the consistency in choices the
participant makes.

The second part of the experiment entails the elicitation of indifferences. The
participants’ risk aversion and probability weighting for both gains and losses can be
calculated with the results of indifferences for gains and losses. The information
retrieved from this part of the experiment can be used to make calculations of expected
value, expected utility and expected utility according to prospect theory to predict
participants’ behaviour. With these predictions, it is possible to construct a suggested
risk matrix, based on the indifferences. The suggested risk matrix provides a
prioritisation of risks and can be compared with the outcome of the risk matrix task.
The prioritisation can be compared with the outcome of the reduction task to see if the
participants make a logical choice and reduce the most undesired risk first.
Furthermore, the suggested risk matrix can predict the shape of the residual risk matrix,
after completion of the task.

Lastly it is possible to statistically analyse the effect of the demographic and
socioeconomic details of the participants, as well as the answers to the DOSPERT
questions. The results of this analysis show which factors have the greatest influence on
the experimental results and can be used to predict a participant’s behaviour towards
risk. Also analysis will show if DOSPERT is a satisfactory measure of the participants’
risk attitude. A large amount of participants also allows for comparing the results of
combined manipulations.
4 Conclusion

The common ground of risk management and decision theory can be found in the primary issue where both attempt to deal with, which is uncertainties. Furthermore, risk management assesses these uncertainties and manages them, which includes prioritising of and responses to risks. When information on the decision maker’s risk taking behaviour is available, decision theory can prioritise risks and prescribe how to react to them numerically. This prioritisation can be done by applying the calculations for various theories such as expected value, expected utility and prospect theory on the cells of the risk matrix. To gather an adequate amount of information to make these mathematical approaches, indifferences for gains, losses and mixed prospects need to be sought and evaluated.

This dissertation presents a method of assessing risk appetite by applying a risk matrix. This method involves a risk reduction task, where one risk is present in every cell of a 5-by-5 risk matrix. Reduction, though not complete transfer, of these risks is done on a cell by cell basis, with invariable costs per move. The experiment is incentivised to reflect a real organisation that manages a portfolio of risks. A realistic situation is realised by introducing:

- An endowment which serves as a budget to reduce risks;
- A financial buffer which can absorb impacts to a specific threshold and imposes a goal to reach and;
- A reward system, which pays out an amount of money based on if and to what level the goal has been reached.

The residual risk matrix presents a measure of risk appetite for specific available resources, difficulty of objective and costs of control.

It shows that risk management forms a husk, in which risks are acknowledged, assessed and dealt with on mostly a qualitative basis. By expanding risk management with decision theory, it is possible to suggest a course of action to deal with risks on a quantitative basis. Establishing part of the basis for this expansion of risk management can be done with the presented experiment.
References


Bouchey, P. (2004, July 1). Questionnaire quest: New research shows that standard questionnaires designed to reveal investors’ risk tolerance levels are often flawed or misleading. *Financial Planning*.


Appendix 1 – Example of a hypothetical participant

After a participant has finished all of the experimental tasks, calculations and observations can be made. This example will discuss a hypothetical outcome for one participant.

First, let us take a look at the risk matrix that was the result of task where the participant has to indicate how acceptable the negative risks in each of the cells of the risk matrix are. The result is the risk matrix displayed in Figure 0.1.

![Risk Matrix](image)

In this risk matrix acceptability is indicated on a 5 point scale, with 1 for an acceptable risk and 5 for an unacceptable risk. This risk matrix indicates that a high probability is less acceptable than a high impact. One could say that risks with near certain impact are not preferred, which indicates risk seeking behaviour for losses, just as one would expect from the theory in paragraph 1.2.3.

---

1 This risk matrix is the result of a previous experiment, where participants were to indicate the acceptability of risks in each of the cells of a risk matrix in a similar setting. The presented risk matrix is a median of 73 risk matrices.
Now let us take a look at the result of the risk reduction task as displayed in Figure 0.2.

This risk residual risk matrix is the result of a reduction task where every step costs € 1, the total resources available was € 20, so in total, all risks were moved 20 cells. The numbers in the risk matrix signifies the amount of risks located in each of the cells. As with the risk matrix with indicated acceptability, the reduced risks were typically of higher probability which, again, shows risk seeking behaviour for losses. If a closer look is taken at the risks that were reduced, one can see that all of the risks indicated with a 5 on the acceptability scale have been reduced. Also, the remaining risks that were reduced all score a 4 on the acceptability scale. This leads to the conclusion that the participant has reduced risks consistently with their acceptability.

Once the indifferences have been completed, it is relatively straightforward to calculate the various parameters necessary to describe the participant’s risk taking behaviour with nonlinear regression using statistics software such as SPSS. Without further palaver, let us assume that the following parameters have been found:

\[ R = € -2.5 \]
\[ \alpha = 1.3 \]
\[ \beta = 0.6 \]

---

2 This residual risk matrix is the result of several trials by several students with experience in the risk management area. An actual pilot to test this experimental part has not been set out, yet the preliminary trials indicate that participants typically follow the pattern that shapes the presented residual risk matrix.
Note that risk tolerance $R$ is valid for the reference value used in the indifference elicitation, which should be in the same order of magnitude. Let us assume that this is a fairly low reference value, such as € 10, which is the reference value used in the risk reduction task. As the reference values are in the same order of magnitude, the value for $R$ can be used to evaluate the result of the risk reduction task. The parameters can be plugged straight into the equations for utility and probability weighting, as presented in paragraph 1.2.3 and 1.2.5. This results in the graphs as shown in Figure 0.3. Note that the utility and probability weighting are valid for losses with a reference value of $x = € 10$.

Figure 0.3 The utility and probability weighting functions for a hypothetical participant, as elicited using indifferences.

Note that the utility curve presented in Figure 0.3 indicates risk seeking for losses and that the probability weighting function in indicates pessimism for losses with a small probability and optimism for losses with a high probability. The obtained parameters can be applied on every cell of the risk matrix, as probabilities and impacts are known. When this is done for expected value, expected utility and prospect theory, this yields a
specific value per cell, either an expected value or expected utility. Based on the value per cell, the cells are ranked, which indicates the order of prioritisation, 1 to 25 indicates a high to low priority. The result is the 3 matrices displayed in Figure 0.4.

<table>
<thead>
<tr>
<th>Probability in %</th>
<th>90</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>0.90</td>
<td>0.70</td>
<td>0.50</td>
<td>0.30</td>
<td>0.10</td>
</tr>
<tr>
<td>70</td>
<td>2.70</td>
<td>2.10</td>
<td>1.50</td>
<td>0.90</td>
<td>0.30</td>
</tr>
<tr>
<td>50</td>
<td>4.50</td>
<td>3.50</td>
<td>2.50</td>
<td>2.10</td>
<td>0.50</td>
</tr>
<tr>
<td>30</td>
<td>6.30</td>
<td>5.00</td>
<td>5.00</td>
<td>2.70</td>
<td>0.50</td>
</tr>
<tr>
<td>10</td>
<td>8.10</td>
<td>6.00</td>
<td>7.00</td>
<td>0.70</td>
<td>0.90</td>
</tr>
<tr>
<td>Ranking</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact in Euros</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Probability in %</th>
<th>90</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>0.30</td>
<td>0.23</td>
<td>0.16</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>70</td>
<td>0.63</td>
<td>0.49</td>
<td>0.35</td>
<td>0.21</td>
<td>0.07</td>
</tr>
<tr>
<td>50</td>
<td>0.78</td>
<td>0.61</td>
<td>0.43</td>
<td>0.26</td>
<td>0.09</td>
</tr>
<tr>
<td>30</td>
<td>0.85</td>
<td>0.66</td>
<td>0.47</td>
<td>0.28</td>
<td>0.09</td>
</tr>
<tr>
<td>10</td>
<td>0.88</td>
<td>0.68</td>
<td>0.49</td>
<td>0.29</td>
<td>0.10</td>
</tr>
<tr>
<td>Ranking</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

| Impact in Euros |

<table>
<thead>
<tr>
<th>Probability in %</th>
<th>90</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>0.27</td>
<td>0.23</td>
<td>0.19</td>
<td>0.14</td>
<td>0.09</td>
</tr>
<tr>
<td>70</td>
<td>0.58</td>
<td>0.48</td>
<td>0.39</td>
<td>0.31</td>
<td>0.18</td>
</tr>
<tr>
<td>50</td>
<td>0.72</td>
<td>0.59</td>
<td>0.49</td>
<td>0.38</td>
<td>0.22</td>
</tr>
<tr>
<td>30</td>
<td>0.78</td>
<td>0.64</td>
<td>0.53</td>
<td>0.41</td>
<td>0.24</td>
</tr>
<tr>
<td>10</td>
<td>0.81</td>
<td>0.67</td>
<td>0.55</td>
<td>0.43</td>
<td>0.25</td>
</tr>
<tr>
<td>Ranking</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

| Impact in Euros |

<table>
<thead>
<tr>
<th>Probability in %</th>
<th>90</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>0.16</td>
<td>0.21</td>
<td>0.26</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>70</td>
<td>0.21</td>
<td>0.14</td>
<td>0.26</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>50</td>
<td>0.11</td>
<td>0.11</td>
<td>0.26</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>30</td>
<td>0.14</td>
<td>0.14</td>
<td>0.26</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>10</td>
<td>0.16</td>
<td>0.16</td>
<td>0.26</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>Ranking</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

| Impact in Euros |

<table>
<thead>
<tr>
<th>Probability in %</th>
<th>90</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>13</td>
<td>17</td>
<td>19</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>70</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>50</td>
<td>3</td>
<td>7</td>
<td>11</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Ranking</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

| Impact in Euros |

Three theories applied to the risk matrix, along with prioritisation by rank.

Figure 0.4 Three theories applied to the risk matrix, along with prioritisation by rank.
A logical consequence of the priority ranking system is that the cells indicated with the first ranks are seen as the most unacceptable ones and should consequently be reduced first. Therefore, this suggested prioritisation can be used to analyse the reduced risk matrix by simply going over the reduced risks and checking if the suggested prioritised risks are actually reduced first.

If one of the three presented decision theories would hold, it should predict which risks are reduced first. As the residual risk matrix presents nine cells without any risk present, the matrices presented above should rank the cells with no present risk 1 to 9. After careful examination of these matrices, it becomes clear that both expected value and prospect theory correctly identify the nine risks with highest priority.

After the ranking step, it is possible to construct a predicted risk matrix in which every cell is given an acceptability index, according to the rank of each cell. The amount of 1s, 2s, 3s, 4s and 5s assigned to each of the calculated matrices should be the same as used in the matrix completed in the acceptability part, to allow a fair comparison of the matrices. The obtained parameters can be applied on the risks in the cells of the risk matrix using the several decision theories. This leads to the prediction of risk matrices as presented in Figure 0.5, based on the results of the indifference part of the experiment.
Figure 0.5 The predicted risk matrices that follow from the three applied theories.

Note the symmetry of the expected value matrix, following from its calculation that is independent on risk taking behaviour. Both matrices following from expected utility and prospect theory indicate risk seeking behaviour. Comparing the predicted risk matrices and the resulting risk matrix from the acceptability task can possibly be done by simply counting the differences of acceptability per cell in every predicted risk matrix, with regards to the result of the acceptability task. For example, if a specific risk is indicated by the participant as 3, whilst according to prospect theory this should be 4, then one error is made.

Comparison of the acceptability task’s result and the predicted risk matrices according to expected value, expected utility and prospect theory yield an amount of inconsistencies of respectively 6, 2 and 8. This would lead to the conclusion that out of
the presented decision theories, expected utility is most consistent with the participant’s indication of acceptability of risks, followed by expected value and prospect theory.

The conclusion of this example is that the theory that predicts the risk matrix most accurately is prospect theory. Both expected value and prospect theory correctly identify the highest priority risks, in accordance with the residual risk matrix. Also, the participant behaves according to their risk matrix during the risk reducing task.

Further available information that could be analysed is data on the participant’s demographic and socioeconomic characteristics, DOSPERT results and used manipulations. This data can only be statistically analysed when a sufficient amount of participants have completed the experiment.