A BETTER UNDERSTANDING OF DECISION MAKING UNDER RISK

AN INTERDISCIPLINARY APPROACH

Zur Erlangung des akademischen Grades eines

Doktors der Wirtschaftswissenschaften

(Dr. rer. pol.)

von der Fakultät für Wirtschaftswissenschaften

Am Karlsruher Institut für Technologie (KIT)

genehmigte

DISSERTATION

von

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Tag der mündlichen Prüfung: 12.07.2016

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Karlsruhe, 2016

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Introduction

"When making a decision of minor importance, I have always found it advantageous to consider all the pros and cons. In vital matters, however, such as the choice of a mate or a profession, the decision should come from the unconscious, from somewhere within ourselves. In the important decisions of personal life, we should be governed, I think, by the deep inner needs of our nature."

(Sigmund Freud)

THE role of affect in decision making under risk has come into focus during the last decades. There are a lot of observed phenomena in subjects' decision behavior which might be explained by affective influence. Progress in technology allows for new methods to test for the affective influence in decision making under risk. However, economic literature still lacks a framework which structures the decision making process such that it can be analyzed where, why and how in each particular step of decision making, affect influences decision making and how these explanations of a cognitive-affective interplay lead to a better understanding of decision making under risk. Against this background, this thesis approaches the role of affect in decision making under risk on the basis of the concepts and findings of economics, psychology and neuroscience.

1.1 Motivation and Research Questions

The question of how subjects make, and how they should make judgments and decisions has occupied researchers for many centuries with different disciplines approaching the problem with characteristically different techniques (Sanfey et al. 2006). Economic research, over nearly three centuries, has fundamentally advanced our understanding of decision making under risk, yet in the middle of the last century the debate about rational decision makers has started. In economics, decision making under risk is usually modeled by a choice problem over a set of lotteries, where a lottery is defined as a distribution of probabilities over a set of prospective outcomes. Economic models assume that subjects have stable and well-defined preferences and make rational choices according to these preferences. Decision making is depicted as a matter of maximizing utility.[1] Soon after the publication of the Expected Utility Theory (EUT) by von Neumann and Morgenstern (1944), which is still seen as one of the most important models of decision making under risk, several researchers have proven that subjects hurt the EUT's axioms when actually making a decision under risk.[2] Trying to find purely rational explanations for these so-called anomalies in observed behavior fails. Kahneman and Tversky (1979) have approached these anomalies in their Prospect Theory (PT). They propose for example that subjects in fact weight probabilities non-linearly, that they show different risk attitudes towards gains and losses and that preferences may change due to a different framing. Thus, they address some psychological issues, however they don't specify these. Over the last years the field of behavioral economics, which has already been the subject of consideration within the "bounded rationality" by Simon (1955), has been replaced in the focus of research. As Loewenstein et al. (2008) state, behavioral economics,

[1] cf. Kreps (1990)
[2] c.f. Allais (1953)

amongst other questions of interest, considers the question of how utility depends on the prospective outcome. Other than classical economic models, which assume that the utility only depends on the prospective outcome itself, it is assumed that the utility also depends on emotions such as anticipated regret or disappointment.[3] Thaler (2000) predicts that Homo Economicus, as he has been described by economics over the last decades, will become more emotional, implying that economists will devote more attention to the study of emotions. He goes even further and states that "Homo Economicus will evolve into Homo Sapiens." (Thaler (2000), p. 140) Yet, we still lack the knowledge how decisions under risk are actually made. This implies why research in other disciplines comes into the focus of economic research on decision making under risk. Psychologist Sigmund Freud already noticed, back in 1900, that decisions to be made are different in their matters and thus are built upon different deliberations. When making a decision we consider the prospective outcomes - but very often we cannot tell for sure which prospective outcome is going to be realized. It lies in the nature of choosing, that the desirable prospective outcome of the one alternative goes along with the risk that the unwanted prospective outcome of the other alternative could be realized. That is, within decision making under risk, a subject has to weight *the pleasure of the desirable* prospective outcomes against *the pain of the undesirable* prospective outcomes in order to decide about the risk he is willing to take. But what about prospective outcomes that he really wants to achieve? Doesn't he tend to ignore all the other possibilities that could be realized even if they are not very unlikely? This leads to the idea that in fact affect guides human decision making and that there might be a difference in making a decision by head or by heart.

Research on the role of affect in decision making under risk addresses very interesting research questions which cannot be answered with standard economic theory. First of all, it needs to be elucidated what affect exactly is, especially as the counterpart of cognition, and how emotions, feelings and mood can be subsumed under the name of affect. In psychology and neuroscience there is a long history of emotion

[3] cf. Loomes and Sugden (1982), Loomes and Sugden (1986), Bell (1982), Bell (1985)

research, which reveals that for a long time, there was no consistent idea of what emotions actually are and how to define them.[4] Zajonc (1980) is a pioneer in discussing the role of affect in decision making. He discusses the possibility that affect and cognition are separate and partially independent systems and he argues that affective reactions to stimuli are very often the very first reactions which occur unconscious and fast. He states that all perceptions contain some affect.

> "We do not just see 'a house': We see a handsome house, an ugly house, or a pretentious house." (Zajonc 1980, p. 154)

It is important to further investigate where cognitive appraisal enters as a significant element of affective reactions. In the following years there has been plenty of research on the cognitive-affective interplay.[5] This research has been expanded by integrating the finding that affective reactions are accompanied by physiological reactions which are in fact measurable.[6] Bechara and Damasio (2005) integrated this emotion research and research from neuroscience to develop the Somatic Marker Hypothesis (SMH). Based on several lesion studies in the 1980's they investigated the question of how affective processing influences advantageous decision making. They subsume how these findings are generally applicable in economic decision making. They argue that

> "the development of what became known as the Expected Utility Theory was really based on the idea that people established their values for wealth on the basis of the pain and pleasure that it would give them. So utility was conceived as a balance of pleasure and pain. These notions of pleasure and pain were eliminated from notions of utility in subsequent economic models. The exclusion of current economic models of expected utility to the role of emotion in human decisions is therefore inconsistent with their foundations." (Bechara and Damasio 2005, p. 337)

[4] cf. Fehr and Russell (1984), Bechara and Damasio (2005)

[5] cf. Epstein (1994), Sloman (1996)

[6] cf. Ekman et al. (1983), Vianna et al. (2009), Rainville et al. (2006), for a review see Cacioppo et al. (2000)

RESEARCH QUESTION ≺1≻. *What is affect? How can affect be understood as the counterpart of cognition?*

Second, as it might in fact be a promising approach to take a closer look at the disciplines psychology and neuroscience, it has to be discussed which models exist and which concepts they provide to investigate the role of affect in decision making under risk. Parallel and in wide parts totally independent from research in economics, research in psychology as well as in neuroscience attend to the question of *how* human beings make decisions under risk. Psychological models consider the role of emotions, feelings and mood in the cognitive-affective interplay in decision making under risk whereas neuroscience provides the methods to gain insight in how the brain works while making decisions. In recent years the new research field of neuroeconomics arose as it became more and more obvious that economics, psychology and neuroscience can contribute to each other in order to develop a profound understanding of how subjects make decisions.

RESEARCH QUESTION ≺2≻. *Which are the appropriate models of economics, psychology and neuroscience with respect to further analysis of the cognitive-affective interplay in the decision making process? Based on these models:*

(a) Which are, from the economic perspective, the relevant components of decision making under risk?

(b) Which are the underlying concepts within economics, psychology and neuroscience suitable to analyze the cognitive-affective interplay?

Third, based on the discussion of the models in economics, psychology and neuroscience and the underlying concepts in each discipline, the central question within this thesis is how these disciplines can contribute to each other. Where does research in psychology and neuroscience offer explanations and approaches to extend economic literature? To answer this question a structure is needed which allows for a separate and thus systematic analysis of each economically relevant component of decision making under risk from the perspective of each discipline. This analysis makes it possible to specify those steps and elements which are processed affectively and cognitively.

RESEARCH QUESTION ≺3≻. *How can psychologic and neuroscientific research be integrated into economic theory in order to evaluate a decision on the basis of a cognitive-affective processing?*

Forth, after disassembling the decision making process, the question is how these results can be integrated into a framework to model human decision behavior under risk such that it allows to interpret the cognitive-affective interplay.

RESEARCH QUESTION ≺4≻. *How can affective decision making under risk be described and analyzed in a formal decision making framework?*

To answer these four central research questions, a strong interdisciplinary approach is needed, integrating research from economics, psychology and neuroscience. Integrating other disciplines might offer advances to the formulation of powerful economic models yet there are several challenges and problems to deal with. However, other than often claimed by traditional economists, integrating affect into a decision under risk doesn't always mean to give up the traditional approach of building models with utility maximizing subjects. Instead, this thesis provides an approach how to include affect in such utility maximizing models.

1.2 The Interdisciplinary Approach

This thesis uses an interdisciplinary approach. The idea that the discoveries of economics, psychology and neuroscience might contribute to each other in order to develop a better understanding of decision making has emerged several years ago under the name of neuroeconomics. Yet, the challenge is to identify how this contribution could possibly work.

Neuroeconomics is defined as an interdisciplinary field that seeks to explain the human decision making process. It studies how economic models and theories can shape our understanding of the brain, and how neuroscientific and psychological research can constrain and guide models of economics. It combines research methods from neuroscience, experimental and behavioral economics and cognitive and social psychology.[7] Neuroeconomic research addresses various fields of research within economics, such as social choice, intertemporal choice, game theory, auction theory and decision making under risk and uncertainty.[8] Yet, this thesis focuses on decision making under risk. With this focus, Figure 1.1 is introduced and depicts the possible contributions of psychology and neuroscience to approach affect in a formal decision making framework to be developed within this thesis.

Economic decision theory provides formal models and theories. Here, it is generally assumed that a subject bases his decision on a set of well-defined preferences and chooses in favor of the option with the highest expected utility. Hereby, affect is rather not taken into account (yet there is the emerging idea that affect cannot be ignored any longer). Psychology provides behavioral models and heuristics. It is suggested that every decision in fact depends on the content and context of a decision situation, as every different situation elicits different emotions which have an influence on the decision to be made. There seems to be evidence that a decision is based on cognition as well as affect and that each decision is processed within the interaction of a controlled, cognitive system and an automatic, affective system.[9] Neuroeconomic research addresses the question of how research on these behavioral models and heuristics can be integrated into economic models.

[7] Refer to Camerer et al. (2004), Park and Zak (2007) or Camerer et al. (2005), who provide an introduction into neuroeconomic research.

[8] cf. Camerer et al. (2004), Camerer et al. (2005), Rick and Loewenstein (2008)

[9] Refer to Section 2.1.2, where the idea that decision making might be processed by an experiential system as well as by a cognitive system is shortly introduced. Chapter 4 discusses how the psychological models deal with the cognitive-affective interplay within the decision making process.

Neuroscience provides neural systems and 'brain maps' as results of neuroscientific research of how the human brain works. This might improve the basic understanding of human decision making. As economic and psychological models are usually stylized and simplified they imply a useful environment to test for the impact of specific variables with neuroscientific methods. Neuroscientific research is a valuable factor in expanding the boundaries of economic models. It provides the methods and knowledge to explain how a decision is processed in the brain.[10] However, knowledge about how the brain works is still in its infants. The method of 'inverse inference' is used in neuroscience to draw conclusions from the activated brain regions during a decision task.[11] Thus, the more specific a decision task, the more concrete conclusions about the activation of a brain region can be made. That is, neuroscience doesn't only provide methods and brain maps but also uses results from economic and psychological research to expand knowledge about how the brain works.

There is a long history of experimental research within all three disciplines, yet based on very different conventions and rules. Especially in economics, there is a long tradition in correct experimenting in order to receive robust and replicable results. Thus, within neuroeconomic research it is necessary to integrate experimental neuroscience and psychology into experimental economics within a unified charta of conventions and rules to guarantee for robustness and replicability.

The goal of this thesis is to develop an Affective Decision Making Framework (ADMF) which integrates psychological and neuroscientific research into economic models of decision making under risk.

[10]Refer to Section 2.1.3, where the methodology of mapping the brain is shortly introduced. Chapter 4 discusses how the neuroscientific models deal with the cognitive-affective interplay within the decision making process.

[11]Refer to Section 2.1.3, where reverse inference is discussed.

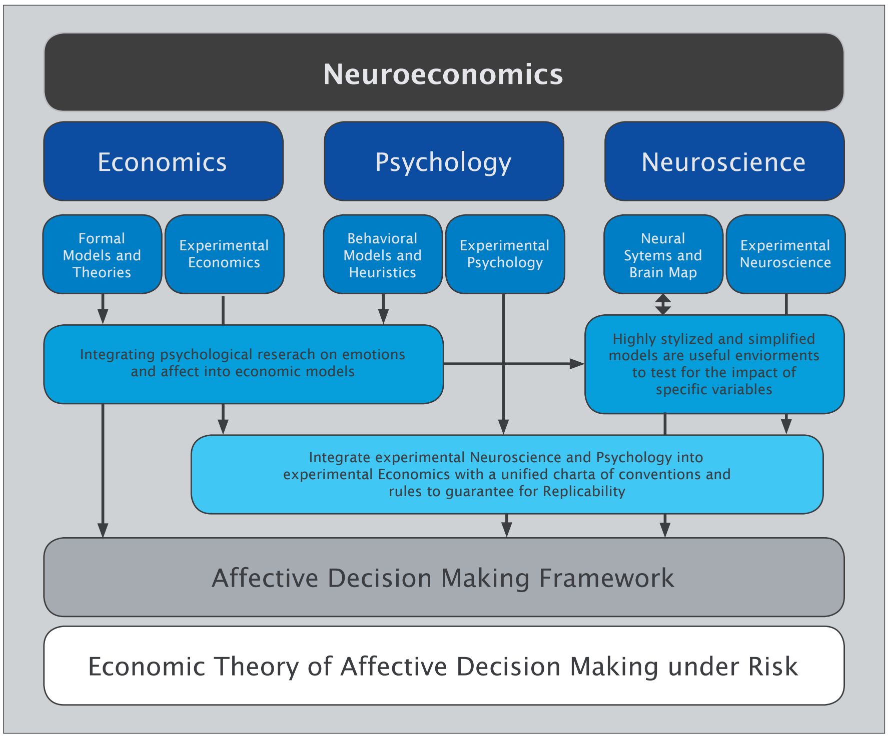

FIGURE 1.1: *Decision Making under Risk as an Interdisciplinary Approach*

1.3 Structure

The remainder is structured as follows. The thesis is composed of six chapters within three main parts. *Part I* consists of Chapter 1, Chapter 2 and Chapter 3 and serves as a preliminary and introduction for *Part II* in which the ADMF is developed. *Part III* concludes with a summary and a short outlook of future research.

The chapters of Part I deal with the Research Questions 1 and 2. Chapter 2 addresses the interdisciplinary approach of this thesis. It deals with the formulation of possible interfaces between the disciplines economics, psychology and neuroscience. Chapter 2 points to the different approaches within each discipline and specifies the resulting challenges with respect to the interdisciplinary research in decision making under risk. This gives rise to the point that, by considering the role of affect in the sense of the Dual-Processing Theory, psychology and neuroscience can contribute to economic research in order to provide a better understanding of decision making under risk.

Chapter 3 provides a broad and structuring literature overview of the existing (and relevant within this thesis) models of decision making under risk in economics, psychology and neuroscience. On the basis of these models Chapter 3 selects and specifies the relevant components of decision making under risk as well as the underlying concepts which are appropriate to develop a formal framework. This discussion within Chapter 3 motivates the following structure for the further development of a formal framework. It should be analyzed separately how economics, psychology and neuroscience deal with the evaluation of prospective outcomes, the probability distribution and the subject's risk attitude.

Part II consists of Chapter 4 and Chapter 5. Chapter 4 addresses Research Question 3. Thus, the focus of Chapter 4 is on the analysis of the three central components of decision making under risk. The evaluation of the prospective outcomes, the probability distribution and the subject's risk attitude are discussed within nine sections, each from the perspective of economics, psychology and neuroscience. This analysis enables the identification and specification of those interfaces, where research in psychology and neuroscience can broaden economic models in their explanatory power. The discussion within the last section of Chapter 4 serves as a structured consolidation of the results in order to provide the basis for the formal approach developed in Chapter 5.

Chapter 5 deals with Research Question 4 and thus introduces the developed ADMF. The ADMF bases on the Dual-Processing-Theory. Thus, it is particularly developed with respect to the analysis of the interplay between the affective and cognitive evaluation of a decision under risk. First of all, Chapter 5 points to the requirements of the ADMF, based on the results of Chapter 4. Second, the ADMF is developed. Therefore, a comprehensive scheme of the decision making process is introduced. The decision making process is composed of four phases, whereof the first phase, the evaluation phase, is analyzed in detail in the following of Chapter

5. It turns out that, even though every phase is comparably important, the evaluation phase is most suitable to analyze the cognitive-affective interplay within decision making under risk. Further, the elements of the evaluation phase are introduced in order to develop a detailed processing scheme. This processing scheme is structured by the following correlations: The representation of a lottery triggers different emotions which change the subject's affective state. The affective state influences the subjective transformation of an objective lottery into a subjectively perceived lottery. Based on the overall affective state, either the affective processing or the cognitive processing of the computation of the lottery's overall value is active. Subsequently, Chapter 5 transfers this scheme to economic decision making under risk. It is shown, that each theory introduced in Chapter 3 can be integrated into the ADMF as a special case. The discussion of the economic theories reveals, that the ADMF is most closely related to the model of Reference Dependent Preferences by Köszegi and Rabin (2007), yet it extends the understanding of this model as the ADMF first gives rise to the question of how the specific properties of a utility function can be derived from the affectivity of a decision situation and second, how can a subject's content and context sensitivity, that is the impact of the reference dependent component of utility, be derived from the affectivity of a decision situation.

Part III concludes with Chapter 6 as a summary of this thesis. The chapter highlights the results in this thesis and the contributions to the existing literature, discusses the limitations and extensions of this thesis and concludes with some intentions for future research on decision making under risk.

Figure 1.2 depicts the structure of this thesis.

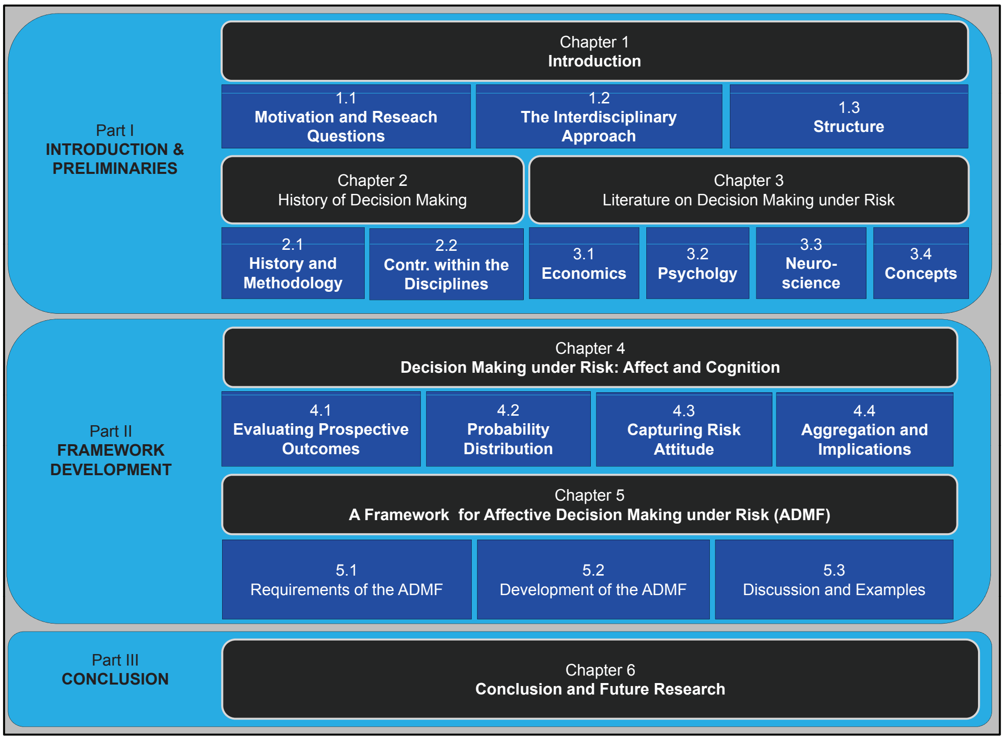

FIGURE 1.2: *Structure of this Thesis*

Chapter 2

History of Decision Making under Risk: An Interdisciplinary Approach

THIS chapter addresses the interdisciplinary approach of this thesis. It is intended as an introduction to the history of research and methodologies within economics, psychology and neuroscience to highlight the differences in language, approach, implementation and implication. It discusses how these disciplines deal with decision making within a very different background and using very different techniques. It further discusses that, besides these differences however, in the recent past it has become more and more obvious that research on these three disciplines can in fact contribute to each other by approaching the role of affect.

2.1 History and Methodology of Decision Research

2.1.1 Economics

Economic research on decision making under risk has a long history within a rather mathematical background. A decision under risk in the economic sense is a choice between two or more lotteries with each lottery carrying uncertainty about the realization of the prospective outcomes.[1] That is, choosing a lottery may result in either one prospective outcome or another. The probabilities with which these prospective outcomes may occur are known to the decider and may differ between the lotteries. Surely, there exist plenty of situations in which these probabilities are not exactly known, however, by considering decision making under risk economists only take those situations into account in which the probabilities are known. It was Frank Knight, who first introduced the differentiation between decisions under risk and decisions under uncertainty in his Phd in 1921.[2] Decisions under risk may also include situations in which only positive prospective outcomes are possible. That is, a decision under risk as economic models consider, does not necessarily involve an actual loss. The risk in such situations is, for example, to choose between a lottery which may result in a high prospective outcome with a small probability and a lottery which may result in a smaller prospective outcome with a high probability.[3] Thus, decision making under risk is closely related to probability theory. The idea of a theory of probabilities comes from the history of gambling and computing the different chances to win.[4] Thus, a probability specifies how likely it is that an event is going to happen. Blaise Pascal and Pierre de Fermat are seen as the "fathers" of probability theory. They developed an early understanding of expected value when discussing how to solve the problem of points posed by Chevalier de Méré.[5] Fermat first introduced the idea of equally likely chances to win by listing the prospective outcomes of the game in a table. This approach was generalized by Pascal (1665) with the help of a probability triangle. That is, the expected value is a simple method to evaluate a situation in which the realized prospective outcome is distributed by probabilities.

However, this concept is not applicable in situations in which the expected value

[1]Please refer to Section 3.1, where I discuss several economic models and theories and introduce how they deal with decision making under risk.

[2]cf. the reprint: Knight (2012)

[3]For examples of such lotteries see Kahneman and Tversky (1979).

[4]David (1962) provides a detailed overview of the history of gambling, probability and statistical ideas.

[5]The interested reader may be referred to David (1962), who presents extracts of the letters between Pascal and Fermat.

may be infinite. Daniel Bernoulli was the first to propose the concept of utility when solving the St Petersburg Paradox described by his cousin Nicolas Bernoulli (1738). The St Petersburg Paradox describes a situation in which a subject has to decide how much to pay for the participation in a gamble. In this gamble, a coin is tossed as long as head occurs. The gain of the subject depends on the number of coin tosses, that is, if head appears with the first toss the subject receives 1 Euro, if head also appears with the second toss 2 Euros, if head appears with the third toss 4 Euros and so on. That is, with every toss of the coin, while head appears, the amount which is paid, doubles. To be more precise, for the k^{th} toss of the coin, while head appears, the paid amount is $2^{(k-1)}$. If the subject decides to pay up to the expected value of this gamble, in order to participate, he would be prepared to pay any amount, as the expected value of this gamble is infinite. This seems not to be very rational as it is very likely to win a small amount and very unlikely to win a large amount. This led Bernoulli (1738) to the idea that

> "... the determination of the value of an item must not be based on its price, but rather on the utility it yields. [...] There is no doubt that a gain of one thousand ducats is more significant to the pauper than to a rich man though both gain the same amount" (Bernoulli 1738, p.24 of the english translation of 1954).

The concept of a subjective utility to evaluate a prospective outcome has been taken into account within most of the economic theories of decision making under risk. von Neumann and Morgenstern (1944) provide a very famous normative theory of decision under risk, the EUT. As the name of the EUT suggests, a subject's decision under risk is based on the comparison of the expected utilities of different lotteries.[6] Despite its continuous fame and wide acceptance as a normative theory, soon after the publication of the EUT, Allais (1953) presented several so-called anomalies in human behavior, which systematically hurt the underlying assumptions of the EUT. These

[6] Please refer to Section 3.1.1 for a discussion of EUT.

anomalies gave a first understanding that subjects might not decide as rationally as they are expected to. Kahneman and Tversky (1979) were the first to integrate some psychological factors to decision making under risk. With the PT they introduce a descriptive theory which, among others, takes the anomalies presented by Allais into account. The PT is still the most famous theory of decision making under risk.[7]

In economics, it is usual to experimentally test for the predictions of models and theories within laboratory experiments. Economic experiments are conducted for different reasons.[8] In many experiments, the experimenters expect to observe systematically occurring "mistakes" in a controlled environment which allows to interpret the observations in relation to the theory and to give feedback to theoretical literature. There are also experiments which study effects that have not yet been discussed in the existing literature. These experiments are often based on earlier experiments in order to isolate the cause of earlier observed systematically occurring mistakes by varying details of the former experiments. Accumulating these facts may allow to propose new theories which then can be tested again. Experiments are also conducted in mission to inform policy. These experiments investigate effects which occur when the market rules are changed. The experimental environment in such experiments is designed to simulate the environment which is in the focus of the political discussion.

2.1.2 Psychology

Psychologists consider emotions, feelings and mood to play an important role in the decision making process interacting with cognition.[9] This idea combines two strands of psychological research: emotion theories and cognitive psychology. Research on emotion theories intends to answer the question "What is an emotion?". Cognitive psychology investigates mental processes such as attention, language use, memory,

[7]Please refer to Section 3.1.2 for a discussion of PT.

[8]Kagel and Roth (1995) provide a very detailed book of the history and methodology of experimental economics.

[9]cf. Zajonc (1980), Schwarz and Clore (1983), Loewenstein et al. (2001), Slovic et al. (2007)

perception, problem solving, creativity and thinking.[10] To provide the basis to understand the models and theories introduced in Section 3.2 and further analyzed in Chapter 4, this section intends to introduce the history of the the basic elements of psychological research on decision making and the resulting challenges of research with respect to the following points:

- What is an emotion?
  - The lack of a unified definition
  - The lack of a clear classification of the terms affect, emotion, feeling and mood
- The idea of a Dual-Processing Theory

Understanding emotion theory from a psychological point of view reveals two intricacies. First, though psychologists have investigated emotions over centuries there is still no such one definition of emotion. Second, the term emotion is usually distinguished from feelings, mood, and affect, yet their use is often rather mixed and synonymous.

Concerning the question "What is an emotion?" Fehr and Russell (1984) state that:

> "Everyone knows what an emotion is, until asked to give a definition. Then, it seems, no one knows." (Fehr and Russell (1984), p. 464)

There is a huge spectrum of psychological literature discussing possible definitions of an emotion, depending on the particular context and from various perspectives.[11] In psychology, it is assumed that there exist several basic emotions out of which all other emotions are built. Ortony and Turner (1990) provide a selection of lists of basic emotions as discussed in the psychological literature. They question the existence of such basic emotions and rather suggest that instead of basic emotions there are other

[10] The interested reader may be referred to Gerrig and Zimbardo (2002).

[11] Paul R. Kleinginna and Kleinginna (1981) discuss 92 definitions and 9 sceptical statements from different sources in the literature of the emotion theories.

basic elements out of which different emotions are built. They suggest that these elements are rather components of cognitions, feeling states, and emotion responses.

In the nineteenth century, the scientists James (1884) and Lange and Kurella (1887) developed a completely new definition and explanation of the nature of emotions. The James-Lange-Theory refers to a hypothesis, which states that within subjects, as a response to certain stimuli, the autonomic nervous system creates physiological reactions like muscular tension, a rise in heart rate, perspiration, and dryness of the mouth. Emotions are expressed by feelings which come about as a result of these physiological changes, rather than being their cause. James (1884) explains his concept as:

> "My theory [...] is that the bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur is the emotion. Common sense says, we lose our fortune, are sorry and weep; we meet a bear, are frightened and run; we are insulted by a rival, are angry and strike. The hypothesis here to be defended says that this order of sequence is incorrect [...] and that the more rational statement is that we feel sorry because we cry, angry because we strike, afraid because we tremble [...] Without the bodily states following on the perception, the latter would be purely cognitive in form, pale, colorless, destitute of emotional warmth. We might then see the bear, and judge it best to run, receive the insult and deem it right to strike, but we should not actually feel afraid or angry." (James (1884), p. 190)

According to the James-Lange-Theory emotions are associated with distinct patterns of somato-visceral activity.[12] Table 2.1 provides an overview of several experiments that have been conducted to give evidence of the existence of distinct patterns of peripheral activity associated with basic emotions. Ekman et al. (1983) state that basic emotions are for example happiness, sadness, disgust, anger, surprise and fear.

[12] Andreassi (2007) provides a very detailed book on human behavior and corresponding physiological responses.

TABLE 2.1: *Selected Literature on Psychophysiological Parameters*
(HR = heart rate, SC/SR = skin conductance/skin resistance, SP = skin potential)
(BP = blood pressure, ST = skin temperature, RF = respiration frequency, P = pulse, BF = blood flow, ECG = electrocardiography)

Author(s)	Published in	HR	SC/SR	SP	BP	ST	RF	P	BF	ECG
Vianna et al. (2009)	International Journal of Psychophysiology, Vol. 72		X							X
Rainville et al. (2006)	International Journal of Psychophysiology, Vol. 61		X				X			X
Christie and Friedman (2004)	International Journal of Psychophysiology, Vol. 51		X		X					X
Vernet-Maury et al. (1999)	Journal of the Autonomic Nervous System, Vol. 75	X	X	X		X	X		X	
Ekman et al. (1983)	Science, Vol. 221	X	X				X			
Averill (1969)	The Society of Psychophysiological Research, Vol. 5, No. 4	X	X		X	X	X	X		
Collet et al. (1997)	Journal of the Autonomic Nervous System, Vol. 62		X	X		X	X		X	
Levenson et al. (1990)	Psychophysiology, Vol. 27, No. 4	X	X			X				

The mentioned experiments investigate response patterns of the autonomic nervous system as a result to different stimuli, as, for example, voluntary facial expression, visual and olfactory stimuli or film clips (see Table 2.1). Response of the autonomic nervous system is expressed by different physiological reactions. These reactions are for example, as Andreassi (2007) describe them, changes in heart rate, skin conductance, skin temperature and respiration frequency. There is also a lot of criticism towards the evidence of distinct response patterns. Cacioppo et al. (2000) state, according to a meta-analysis of the studies investigating the physiological responses observed during basic emotions, that these studies only provide equivocal evidence. Rainville et al. (2006) propose two reasons for the limited result in finding distinctive physiological patterns regarding basic emotions. First, there is inadequate elicitation of the target emotion to be investigated. Second, there is incomplete physiological characterization of the following somatic states. As there is such a controversial discussion about the existence of distinct physiological patterns associated with basic emotions there clearly is the need of further investigation.

Additionally to this very controversial debate about observable physiological patterns of an emotion there is also another way of emotion classification. Loewenstein et al. (2008) propose a characterization of emotions according to the point of time when they are experienced. On the one hand, emotions can be expected to be experienced when a subject anticipates how it will feel when an event takes place. They are labeled as *anticipated or expected emotions*. On the other hand emotions can be experienced immediately when a stimulus occurs. Hence, they are labeled as *immediate emotions or also as anticipatory emotions*. Immediate emotions can further be distinguished by their reference to the considered situation. Immediate emotions can be integral or incidental to the situation.[13] With respect to integral emotions Rick and Loewenstein (2008) (p.138) denote that "they arise from thinking about the consequences of one's decision". That is, integral emotions are elicited by stimuli directly related to the decision. Incidental emotions "arise from dispositional or situational sources objectively unrelated to the task at hand" (Rick and Loewenstein (2008), p.138). That is, incidental emotions are also immediate but elicited by stimuli totally independent from the situation a subject is considering. However, incidental emotions may also influence behavior as a subject may not be aware that these emotions are incidental as discussed by Schwarz and Clore (1983).

Besides the problematic towards the definition of what an emotion actually is, there is also the problem that the terms emotion, feeling, mood and affect are often rather mixed up and synonymously used. With respect to this terminology, Scherer and Peper (2001) propose a classification of the so-called affective phenomena. An emotion is a rather short episode which refers to momentary responses to a single event.[14] According to Damasio (1994) the experience of an emotion results in a subjective feeling. The term feeling is very often used synonymously to the term emotion. Contrary to the short and intense episode of an emotion, Scherer and Peper (2001) consider

[13] cf. Schwarz and Clore (1983), Loewenstein et al. (2001), Rick and Loewenstein (2008)

[14] cf. Scherer and Peper (2001), Ortony and Turner (1990), Adam (2010), Loewenstein et al. (2001), Slovic et al. (2007)

mood to be of low intensity and longer duration.[15] Schwarz and Clore (1983) suggest a subject's mood mostly to be influenced by incidental emotions.

In this sense, affect is considered to be the umbrella term of all emotional concerns as the counterpart to cognitive concerns. Yet, there exist several other definitions of affect. Panksepp (1982) defines affect as the conscious experience of emotion and feeling. Slovic et al. (2007) define affect as the specific quality of goodness or badness experienced as a feeling which marks the positive or negative quality of a stimulus. All these affective phenomena (emotion, feeling and mood) influence a subject's affective state which refers to his ongoing affective processing.

In terms of this thesis, affect can best be described as the counterpart to cognition concerning the interplay of the head and the heart in human decision making. It dates back to Plato who proposed the idea of a tripartite structure of the soul: **emotional/affective, cognitive, conative** (see Figure 2.1).

The idea of a Dual-Processing-Theory of human decision making has emerged over the last century. It was Sigmund Freud (1900) who first considered the idea, that there might be more than just our conscious mind. He introduced the idea of an unconscious processing when he wrote his book about the interpretation of dreams. Research in psychology adopted this idea in research on decision making. It is assumed that affect and cognition interact when making a decision making. Zajonc (1980) was the first who addressed the idea that affective processing of a decision might actually be prior to cognitive processing. Epstein (1994) and Sloman (1996) both discuss the distinct characteristics of the affective and cognitive systems. Figure 2.2 and Figure 2.3 depict how the authors understand these differently processing systems.

These systems are referred to as System 1 (experiential system) and System 2 (cognitive system). In Section 3.2 it is discussed how psychological models and theories deal with affect based on the Dual-Processing Theory within a decision and in Chap-

[15]Mood is also referred to as background state by Bechara and Damasio (2005).
[16]Source: Scherer (1995)
[17]Source: Epstein (1994), Table 1 on page 711
[18]Source: Sloman (1996), Table 1 on page 7

Components of the soul	Glosses	Components of the state
Cognition	Thought, reason, will. Considered rational judgment - the „good“.	Ruling class. Philosophers, kings, statesmen, nobility. Interested in wisdom.
Emotion|Affect|Passion	„Thumos“, anger or spiri-tedhigher ideal emotions, resenting infringements by others and lower appetites.	Warrior class. Soldiers, policemen, auxiliaries, men of action. Interested in disticnition.
Conation|Motivation	Impulses, cravings, instincts, appetites. Multitude of clamant and conflicting appetites for particular gratifications.	Lower classes. Civilians, workers, peasantes, slaves. Interested in enjoyment and gratification.

FIGURE 2.1: *Plato's Tripartite Structure of the Soul*[16]

ter 4 it is analyzed how this can be integrated into economic decision making under risk.

In psychology research there is a long history of experimental testing.[19] Comparable to experimental economics, in psychological experiments it is investigated why subjects make mistakes with regard to a specific theory or model. According to Hertwig and Ortmann (2001) however, in psychology rather than in economics it is assumed that subjects decide according to simplified procedures such as heuristics instead of fully rational preference relations. These simplified mechanisms might be understood better if regarded through the lens of mistakes (Hertwig and Ortmann 2001). As well as in the field of economics the borders of experimental testing and thus supporting or neglecting theories and models are weakened by new method-

[19] There is a huge bandwidth of literature on experimental psychology grown within the last century, cf. Kantowitz et al. (2014), Woodworth and Schlosberg (1954), Osgood (1953), Underwood (1949).

Experiential System	Rational System
1. Holistic	1. Analytic
2. Affective: Pleasure-pain oriented (what feels good)	2. Logical: Reason oriented (what is sensible)
3. Associationistic connection	3. Logical connections
4. Behavior mediated by „vibes" from past experiences	4. Behavior mediated by conscious appraisal of events
5. Encodes reality in concrete images, metaphors, and narratives	5. Encodes reality in abstract symbols, words, and numbers
6. More rapid processing: Oriented toward immediate action	6. Slower processing: Oriented toward delayed action
7. Slower to change: Changes with repetitive or intense experience	7. Changes more rapidly: Changes with speed of thought
8. More crudely differentiated: Broad generalization gradient; stereotypical thinking	8. More highly differentiated
9. More crudely integrated: Dissociative, emotional complexes; context-specific processing	9. More highly integrated: Cross-context proccessing
10. Experienced passively and preconsciously: We are seized by our emotions	10. Experienced actively and consciously: We are in control of our thoughts
11. Self-evidently valid: „Experiencing is believing"	11. Requires justification via logic and evidence

FIGURE 2.2: *Comparison of the Experiential and Rational System*[17]

ologies arising from advances in technology. Most of these new methodologies can be found within neuroscientific research. A short introduction of the history and methodologies in neuroscientific research is provided in the next section.

2.1.3 Neuroscience

Research in neuroscience deals with the anatomy, physiology, biochemistry, and molecular biology of nerves and nervous tissue and especially with their relation to behavior and learning.[20] The focus in this thesis is on the cognitive-affective interplay within the decision making process. To provide the basis to understand the neuroscientific studies introduced in Section 3.3 and further analyzed in Chapter 4 this section intends to introduce the history of the basic elements of neuroscientific

[20] Source: http://www.merriam-webster.com/dictionary/neuroscience

Characteristic	Associative system	Rule-based system
Principles of operation	Similarity and contiguity	Symbol manipulation
Source of knowledge	Personal experience	Language, culture, and formal systems
Nature of representation Basic units	Concrete and generic concepts, images stereo-types, and feature sets	Concrete, generic, and abstract concepts; abstracted features; compositional symbols
Relations	(a) Associations	(a) Casual, logical, and hierarchical
	(b) Soft constraints	(b) Hard constraints
Nature of processing	(a) Reproductive but capable of similarit-based generalization	(a) Productive and systematic
	(b) Overall feature computation and constraint satisfation	(b) Abstraction of relevant features
	(c) Automatic	(c) Strategic
Illustrative cognitive functions	Intuition Fantasy Creativity Imagination Visual recognition Associative memory	Deliberation Explanation Formal analysis Verification Ascription of purpose Strategic memory

FIGURE 2.3: *Characterization of Two Forms of Reasoning*[18]

research on decision making. Considering decision making, neuroscientific research can be structured along the two following questions: What brain regions are involved in the decision making process? What can be inferred from these regions with respect to the cognitive-affective interplay?

The idea, that the mind of human beings is in the brain dates back to ancient Greece, where Hippocrates is said to be the first who considered that the brain is the leading part of intelligence.[21] It is assumed, that already in these early years autopsies were performed to gain information about how the brain works. A lot of the existing knowledge about the brain structure and its functionality was gained by experiments with animals and human lesion patients.

Early investigation on the role of affective and cognitive processing in human de-

[21] The interested reader may be referred to Finger (2001), Bear et al. (2007) or Panksepp (1982), who provide an interesting overview of the history of neuroscience.

cision making considered patients with lesions in different regions of the brain to compare their behavior with the behavior of healthy subjects or with their behavior before the lesion. One of the most famous studies in brain lesions is the case of Phineas Gage. In his book Descartes' Error, Damasio (1994) turns to the hypothesis, that rational decisions are rather not independent of emotions and feelings. He introduces the example of Phineas Gage whose case gained great attention in the 19th century. It was the first time to consider the relation between impaired rationality and specific brain lesions. Damasio states that when he decided to study the cognitive and neuronal mechanisms which underly human thinking and decision making on the one hand, he was rather forced into the study of emotion and feeling on the other hand as it was not possible to understand the one without integrating the other. He conducted similar studies (as the case Phineas Gage) with patients having different lesions. This made him draw conclusions of which part of the brain is responsible for decision making and how stimuli are processed in order to make decisions.

Damasio developed the SMH a neuroanatomical and cognitive framework for decision making and its influence by affect.[22] To test for the predictions and assumptions of the SMH Bechara et al. (1994) develop the so-called Iowa-Gambling task to investigate human decision making under uncertainty by comparing patients' with healthy subjects' behavior in conducting the Gambling-Task. Bechara et al. (1997, 1999) extend their investigation by measuring psychophysiological responses of the subjects to draw conclusions of affective processing in human decision making.[23]

Neuroscientific research provides the methods and techniques to draw a picture of the human brain and to determine the cognitive-affective interplay. There are different methods to investigate the role of affect in human decision making. The most common methods in neuroscience are Lesion Studies (LS), functional Magnetic Resonance Imaging (fMRI), Electroencephalography (EEG), Transcranial Magnetic Stimu-

[22]The SMH is introduced in detail in Section 3.3.1

[23]Refer to Section 2.1.2 where the discussion how to distinguish between different types of emotions based on different psychophysiological responses is shortly introduced.

TABLE 2.2: *Selected Literature on Investigating the Role of Affect in (Economic) Decision Making*

Author(s)	Published in	fMRI	LS	PPM
D'Acremont et al. (2009)	Neuroimage, Vol. 47	X		
Martino et al. (2009)	The Journal of Neuroscience, Vol.29, No.12	X		
Christakou et al. (2009)	The Journal of Neuroscience, Vol. 29, No. 35	X		
Krajbich et al. (2009)	The Journal of Neuroscience, Vol. 29, No. 7		X	
Bault et al. (2008)	Plos One, Vol. 3, No. 10			X
Xue et al. (2009)	Cerebral Cortex, Vol. 19	X		
Rao et al. (2008)	Neuroimage, Vol. 42	X		
Miu et al. (2008)	Biological Psychology, Vol. 77			X
Clark et al. (2008)	Brain, Vol. 131		X	
D'Argembeau et al. (2008)	Neuroimage, Vol. 40	X		
Tom et al. (2007)	Science, Vol. 315	X		
Berntson et al. (2007)	SCAN		X	
Weller et al. (2007)	Psychological Science, Vol. 18, No. 11		X	
Ben-Shakhar et al. (2007)	Journal of Economic Psychology, Vol. 28			X
Fellows (2006)	Brain, Vol. 129		X	
Van't Wout et al. (2006)	Exp Brain Res, Vol. 169			X
Huettel et al. (2006)	Neuron, Vol. 49	X		
Denburg et al. (2006)	International Journal of Psychophysiology, Vol. 61			X
Hsu et al. (2005)	Science, Vol. 310	X		
Oya et al. (2005)	PNAS, Vol. 102, No. 23		X	X
Shiv et al. (2005)	Cognitive Brain Research, Vol. 23		X	
Shiv et al. (2005)	Psychological Science, Vol. 16, No. 6		X	
Bechara and Damasio (2005)	Games and Economic Behavior, Vol. 52		X	X
Smith and Dickhaut (2005)	Games and Economic Behavior, Vol. 52			X
Leland and Grafman (2005)	Games and Economic Behavior, Vol. 52		X	
Houser et al. (2005)	Games and Economic Behavior, Vol. 52		X	
Crone et al. (2004)	Psychophysiology, Vol.41			X
Maia and McClelland (2004)	PNAS, Vol. 101, No. 45			X
Sanfey et al. (2003)	Science, Vol. 300	X		
Lo and Repin (2002)	Journal of Cognitive Neuroscience, Vol. 14, No. 3			X
Breiter et al. (2001)	Neuron, Vol. 30	X		
Bechara et al. (1999)	The Journal of Neuroscience, Vol.19, No. 13		X	X
Bechara et al. (1997)	Science, Vol. 275		X	X
Bechara et al. (1994)	Cognition, Vol. 50		X	

lation (TMS) and Psychophysiological Methods (PPM).[24] Some selected literature on investigating the role of affect in decision making is listed in Table 2.2.

[24]The interested reader may be referred to Andreassi (2007), who provides a very detailed introduction of the common neuroscientific techniques.

However, research in neuroscience is more than just finding where things happen in the brain. By identifying the parts of the brain that are activated during different tasks, and especially by looking for overlap between diverse tasks, neuroscientists learn how the brain works. Camerer et al. (2005) argues that, to see which parts are more or less active during processes which are expected to be affective or cognitive allows for conclusions of the cognitive or affective nature of the different tasks in the decision making process and thus conclusions of the cognitive-affective interplay of the processes. This is a very common technique used within neuroscientific experiments labeled as the so called 'reverse inference'.

There are several limitations in neuroscientific studies. First, Poldrack (2006) discusses under what circumstances it might be possible to infer cognitive or affective processes from neuroimaging data and when results from applying this technique need to be treated cautiously. He states that confidence in reverse inference can be improved by increasing the selectivity of response in the brain region of interest or increase the prior probability of the process in question. Selectivity of response, i.e. how often the brain region of interest is active corresponding to different processes is not in the control of the researcher. Yet, there is a higher selectivity in smaller brain regions and considering the analysis of sets of brain regions might also provide a higher selectivity as a set of brain regions can be analyzed as a connected network active during a process. In other words selectivity means, if a brain region of interest is activated by a lot of processes it is harder to draw conclusions than if it is only activated by a few processes. The prior probability of the cognitive process to be investigated however depends on the task that is performed. Therefore, to improve the confidence of reverse inference it is highly necessary to conduct tasks which conduct a cognitive process with a very high probability.

Second, LS are generally limited to the small sample of subjects who meet the criteria of damage to a region of interest. fMRI studies also typically have small sample size due to financial and time constraints. Furthermore, as Levin et al. (2012) argue, the complexity and length of tasks that can be conducted in a scanner are limited.

Understanding how the brain deals with affect interacting with cognition and how this can be integrated into the economic theories of the decision making process is in the focus of this thesis.

2.2 Contribution within the three Disciplines

The elaboration within Section 2.1 inspired me to approach the role of affect in decision making under risk. As discussed, research on decision making in economics, psychology and neuroscience has started from very different perspectives. Yet, in the last years the idea has emerged that in fact there is a coherence between these disciplines, namely there is the upcoming assumption that within decision making, there must be a cognitive-affective interplay. The goal of this thesis is to identify *how* affect might possibly be integrated into the decision making process with respect to a better understanding of decision making under risk by developing the ADMF. Thus, integrating psychological and neuroscientific research into economics identifies the cognitive-affective interplay to draw a more complete picture of the human decision making process. The aim to integrate psychological and neuroscientific research and methodologies into economics yet reveals several challenges and problems. These challenges manifest in three dimensions.

- There is hardly a consensus of the relevant components of decision making under risk within the three disciplines.
- The terminology of the relevant concepts is rather different including a sometimes very different understanding within and between the disciplines.
- The methodologies applied within the different disciplines to test the theories and models follow rather different conventions.

The first point considers the challenge in this thesis to structure the theories and models of economics, psychology and neuroscience along the relevant components of decision making under risk. That is, it is important, although not easy, to identify the different parts and logical steps of the decision making process and to identify their interrelation with each other as in every discipline there exist different assumptions about how these tasks are processed when making a decision.

The terminology of the relevant concepts within the decision making process is not consistent within the disciplines. This makes it difficult to draw conclusions from the results of one discipline and transfer them to another. One important point here is the definition of risk. In economics, decision making under risk is defined as a very specific situation, where the probability of each prospective outcome is known. This is an important distinction to a situation in which the probabilities are unknown. In psychology and also in neuroscience however there are many theories, models and tests in which the definition of risk is different from that in economics.

Besides the differences in terminology, there are very different conventions of correct experimentation. In experimental economics there are four key aspects according to which good experimentation is classified as discussed in Hertwig and Ortmann (2001).

- script enactment
- repeated trials
- monetary incentives
- proscription against deception

Experimental economics and psychology on behavioral decision making have different conceptions of good experimentation. That is, in psychological experiments there is no constraint to provide the subjects with a detailed script, psychologists often do not repeat their trials, psychologists mostly pay their subjects a flat fee instead of paying according to the subjects' performance, and psychologists often deceive their subjects.[25] This implies why results from psychological studies are often not

[25] The subjects are for example fooled about the question the experimenter tries to answer in order to avoid socially desirable answers.

accepted by economists. Hertwig and Ortmann (2001) propose, that apart from the debate about the differences in methodologies on experimental research, there is a debate on a second level. Researchers in both disciplines are not at one in considering the implications of the evidence of irrationality (which is the evidence of most of the psychological studies about decision making). The different rules and conventions in experimental testing within each discipline hardly affect the development of the ADMF, yet they affect future experimental testing structured along the ADMF.

These challenges and problems impact the development of the ADMF. The following of this thesis discusses and analyzes the relevant models and theories in each discipline in order to identify the relevant components of decision making under risk and the underlying relevant concepts which are important to understand decision making from the perspective of each discipline. These components are analyzed within each discipline in Chapter 4 and merged to develop the ADMF in Chapter 5.

Chapter 3

Decision Making under Risk: A Literature Overview

THE last chapter discussed decision making under risk with respect to a possible contribution of psychology and neuroscience to economics by integrating the role of affect. It pointed out the different methodologies and the resulting challenges and problems and it has been inferred that, in order to determine the contribution of psychology and neuroscience in economic theories within the ADMF, the relevant components of decision making and the underlying concepts within all three discipline have to be identified firstly. Chapter 3 focuses on Research Question 2: "Which are the appropriate models of economics, psychology and neuroscience with respect to further analysis of the cognitive-affective interplay in the decision making process? Based on these models:

(a) Which are, from an economic perspective, the relevant components of decision making under risk?

(b) Which are the underlying concepts within economics, psychology and neuroscience suitable to analyze the cognitive-affective interplay?"

This chapter first discusses these models within each discipline and second concludes with a summary of the relevant components and underlying concepts which are analyzed in more detail within Chapter 4 in order to identify the cognitive-affective interplay in decision making under risk.

3.1 Economics

This section introduces several models and theories dealing with economic decision making under risk. I am aware of the fact that in economic literature there exists a wide variety of other models also considering decision making under risk. However, discussing them all would be far beyond the scope of this thesis. As all of the following models have EUT by von Neumann and Morgenstern (1944) as a common origin, it is necessary and useful to discuss its basic elements and assumptions. Further, as PT by Kahneman and Tversky (1979) is still deemed as the most commonly accepted theory of decision making under risk it is indispensable to discuss and analyze its basic elements in order to develop the ADMF. I further decided to discuss and analyze the model of Reference Dependent Preferences (RDP) by Köszegi and Rabin (2006), Regret Theories (RT) by Loomes and Sugden (1982) and Bell (1982) and Disappointment Theories (DT) by Bell (1985) and Loomes and Sugden (1986) as these theories are highly relevant in the economic literature and all of the theories somehow include the idea that utility is not only derived by the prospective outcome itself but that there are some emotions anticipated during decision making. The idea of including emotions into preference formation reveals the acceptance that affect might somehow influence decision making under risk. Economic theory usually models decision making under risk by a choice problem over a set of lotteries P, where a lottery is defined as a (known) probability distribution over a set of prospective outcomes C and a binary relation $\succeq$ in P. The here discussed theories have in common that they compute an overall utility U of each lottery in order to compare them to each other. The overall utility of Lottery X is given by its expected utility such that $U(X)$ is either $E(u(X))$, where u denotes the intrinsic utility, $E(v(X))$, where v denotes the reference dependent utility or $E(\mu(X))$, where μ denotes the modified utility.[1] X denotes a random variable corresponding to a lottery, expressed by the probability distribution p and the prospective outcomes x. For the sake of simplicity, I denote the random variable X, which is corresponding to a lottery, as Lottery X within the rest of this thesis. A lottery with n prospective outcomes is typically represented as $X : (x_1, p_1; x_2, p_2; ...; x_n, p_n)$. Then, within each of the following theories it is possible to say: Lottery $X \succ, \prec, \sim$ Lottery Y if $U(X) >, <, = U(Y)$.

3.1.1 Expected Utility Theory (EUT)

The standard approach for decision making under risk is EUT by von Neumann and Morgenstern (1944). As the name of the EUT suggests, a subject's decision under risk is based on the comparison of the expected utilities of different lotteries. That is, the subject decides in favor of the lottery which provides the highest expected utility. In case of discrete prospective outcomes, for example, the expected utility is given by the sum of the probability weighted utilities of the certain (riskless) prospective outcomes. To be more precise, if the subject faces a binary choice problem of accepting or declining a single lottery, it is assumed that a subject accepts the lottery if the utility, resulting from integrating the lottery with one's endowment, is higher than the utility of one's endowment alone. This means that the domain of the utility function is determined by the final endowment, rather than by gains and losses.

Given (P, $\succeq$) the EUT is based on four axioms:

[1]Please note that the terminology of 'modified utility' (μ, 'intrinsic utility' (u) and 'reference dependent utility' (v) is used for all theories with utility functions of this structure in the following of this thesis. I decided to go on with this terminology because it intuitively describes the meaning of each term. Other terminology would also be possible as e.g. choiceless utility, basic utility or consumption utility instead of intrinsic utility.

A1 *(Completeness)* For every Lottery X and $Y \in P$ either $X \succ Y$, $X \prec Y$ or $X \sim Y$ holds. Completeness assumes that a subject has well defined preferences to compare and evaluate two alternatives.

A2 *(Transitivity)* For every Lottery X, Y and $Z \in P$ with $X \succ Y$ and $Y \succ Z$ we must have $X \succ Z$. Transitivity assumes that, as a subject decides according to the completeness axiom, the subject also decides consistently.

A3 *(Independence)* Let X and Y be two lotteries with $X \succeq Y$, and let $t \in (0,1] \Rightarrow tX + (1-t)Z \succ tY + (1-t)Z$ for all Z. Independence assumes that the preference order of two lotteries mixed with a third one maintains the same preference order as when the two are mixed independently.

A4 *(Continuity)* Let X, Y and Z be lotteries with $X \succ Y \succ Z \Rightarrow \exists t \in (0,1)$ with $tX + (1-t)Z \sim Y$. Continuity assumes that when there are three lotteries (X, Y and Z) and the subject prefers X to Y and Y to Z, then there should be a possible combination of X and Z in which the subject is then indifferent between this mix and the Lottery Y.

For any rational subject satisfying the four axioms, there exists a function u assigning to each prospective outcome $x \in C$ a real number $u(x)$ such that $E(u(X))$ denotes the expected value of u.

Proposition 1 (Neumann/Morgenstern)**.** *Given* $(P, \succeq)$*, and let the axioms (A1 - A4) be satisfied, then there exist functions*

$$u : C \to \mathbb{R} \tag{3.1}$$

and

$$U : P \rightarrow \mathbb{R} \tag{3.2}$$

such that U with

$$U(X) = E(u(X)) = \sum_i u(x_i)p(x_i) \tag{3.3}$$

is a utility function, which represents $\succeq$ in P.

EUT implies that rational individuals maximize expected utility and takes into account that a subject is risk neutral, risk averse or risk seeking.[2]

EUT has dominated the analysis of decision making under risk over years and is generally accepted as a normative model. While a normative theory states how a subject should decide, a descriptive theory in fact predicts how a subject will decide. Both have in common the need for a rule of how to evaluate a lottery in order to choose the best option. That is, to evaluate a lottery and thus compare it to another lottery, a subject needs to evaluate the prospective outcomes as well as the probability distribution. The predictive quality of EUT as a descriptive model for decisions under risk has often been discussed and criticized, because it is often observed that subjects do not decide as predicted by EUT.

3.1.2 Prospect Theory (PT)

With the PT, Kahneman and Tversky (1979) propose an alternative account of decision making under risk. The core idea of PT is to offer a descriptive model which takes the observed phenomena in human decision making into account. Allais (1953) presents empirical examples, known as Allais Paradoxa, where systematic violations of the axioms of EUT are observed. The following experiments are illustrative exam-

[2]Please refer to Section 4.3.1, where the concept of risk attitude is discussed and analyzed in more detail.

ples of these phenomena:

TABLE 3.1: *Example lotteries of PT (Kahneman and Tversky 1979)*
(Number of participants is denoted by N and the percentage who chose each option is given in [])

Certainty Effect			
Problem 1:	X:(4.000, 0.8)	<	Y:(3.000, 1)
N = 95	[20]		[80]
Problem 2:	X':(4.000, 0.2)	>	Y':(3.000, 0.25)
N = 95	[65]		[35]
Reflection Effect			
Problem 3:	X'':(-4.000, 0.8)	>	Y'':(-3.000, 1)
N = 95	[92]		[8]
Isolation Effect			
Problem 4:	In the first step it is decided if a subject is rejected with a probability of 75% with a prospective outcome of 0 or with a probability of 25% the subject can can choose between the following lotteries.		
	X:(4.000, 0.8)	<	Y:(3.000, 1)
N = 141	[22]		[78]
Problem 5:	In the first step a subject is allocated with 1.000. In the second step he has to choose between the following lotteries:		
	X''':(1.000, 0.5)	<	Y''':(500, 1)
N = 70	[16]		[84]
Problem 6:	In the first step a subject is allocated with 2.000. In the second step he has to choose between the following lotteries:		
	X''''(-1.000, 0.5)	>	Y''''(-500, 1)
N = 68	[69]		[31]

The Certainty Effect refers to the phenomenon of certain outcomes being overweighted. This is shown in Problem 1 and 2. Most subjects prefer Lottery Y to Lottery X and Lottery X' to Lottery Y'. This shift of preferences is caused by adding a common ratio to Lottery X and Y, that is, Lottery X' can be expressed as $(X, 0.25)$ and Lottery Y' can be expressed as $(Y, 0.25)$. The preference relation of Problem 1 (assumed that u(0) = 0) implies that $\frac{u(3.000)}{u(4.000)} < \frac{4}{5}$ while the preference relation of Problem 2 implies the opposite. This shift of preferences violates the independency axiom of EUT. The Reflection Effect (Problem 1 and 3) refers to the phenomenon that preferences for lotteries change when the signs of these lotteries are inverted. Preferences for lotteries with positive prospective outcomes (gains) are inverted to the preferences for lotteries with negative prospective outcomes (losses). The Problems 5 and 6 refer to the Isolation Effect. That is, the phenomenon that preferences shift when, due to another framing of the decision problem, one of these components becomes more obvious. In Problem 5 and 6 the situations are identical with regard to the expected outcome. But the framing of the lotteries is different. Problem 5 can be interpreted as a chance to gain whereas Problem 6 can be interpreted as a chance to avoid a loss. This seems to show, that the basis for the valuation of ones utility is not the final state of endowment but the change of the endowment.

These phenomena hurt the axioms of EUT. PT has been developed to account for this behavior. PT differentiates between two phases in decision making: editing and evaluation. The purpose of the editing phase is to organize and reformulate given lotteries which results in a simpler or better known presentation of lotteries and to set a reference point which defines the domain of gains and losses. The reference point is usually assumed to be the status quo. The editing phase is separated into four steps:

- Coding: identification of gains and losses and determination of a reference point
- Combination of prospective outcomes of lotteries
- Segregation: isolation of riskless prospective outcomes
- Cancelation of those components which are identical considering the available lotteries (i. e. isolation effect)

In a further step, the edited lotteries are evaluated and the lottery with the highest overall utility is chosen. The overall utility of a Lottery X is expressed by $U(X)$ in terms of two scales, v and π . The first scale v assigns a real number $v(x)$ to each prospective outcome x, which reflects the reference dependent utility of the prospective outcome. As prospective outcomes are defined relative to the reference point, v measures the utility of deviations from that reference point (gains and losses). Within PT, the reference dependent utility function v is assumed to be concave in the domain of gains and convex in the domain of losses (see figure 3.1). That is, subjects are risk

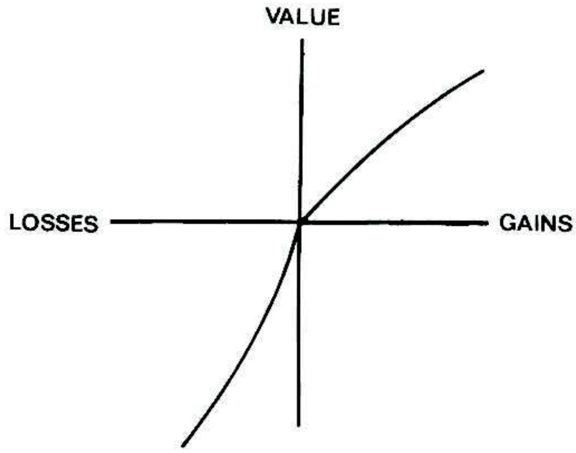

FIGURE 3.1: *A Hypothetical Value Function*[3]

averse in the domain of gains and risk seeking in the domain of losses.[4] v is steeper in the domain of losses, which means that losses loom larger than gains.[5] The second scale π associates a decision weight to each probability p, i.e. it reflects the impact of a probability to the overall utility of a lottery. π is an increasing function with $\pi(0) = 0$, $\pi(1) = 1$ and $\pi(p) \in [0,1]$. Within PT, the weighting function is assumed to reflect that typically small probabilities are overweighted and large probabilities are underweighted (see figure 3.2).[6] PT differentiates between strictly positive, strictly negative and regular lotteries[8]. For a regular lottery the overall utility of Lottery X is

[3]Source: Kahneman and Tversky (1979), Figure 3 on page 279

[4]Please refer to Section 4.3.1, where the concept of risk attitude is analyzed in more detail.

[5]The properties of v an its implications on the role of affect in decision making under risk are discussed in Chapter 4.

[6]The properties of the weighting function an its implications on the role of affect in decision making under risk are discussed in Chapter 4.

[7]Source: Kahneman and Tversky (1979), Figure 4 on page 283

[8]A lottery is given in form of: $(x_1, p_1; x_2, p_2)$. A lottery is strictly positive if $x_1, x_2 > 0$ and $p_1 + p_2 =$

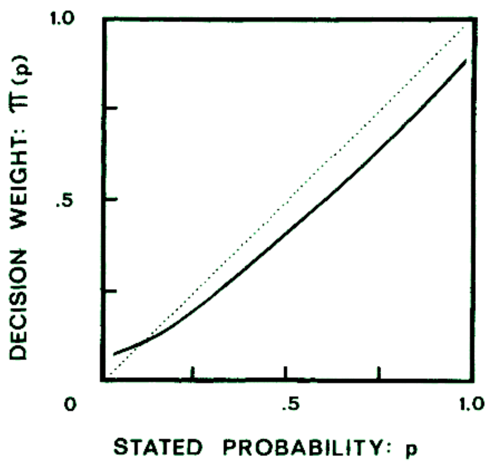

FIGURE 3.2: *A Hypothetical Weighting Function*[7]

given by

$$U(X) = \pi(p_1)v(x_1) + \pi(p_2)v(x_2). \tag{3.4}$$

with $v(0) = 0$, $\pi(1) = 1$ and $\pi(0) = 0$. This utility function generalizes EUT by relaxing the expectation principle.

For a strictly positive or negative lottery the overall utility of Lottery X is presented in a different way:

$$U(X) = v(x_2) + \pi(p_1)[v(x_1) - v(x_2)] \tag{3.5}$$

1, strictly negative if $x_1, x_2 < 0$ and $p_1 + p_2 = 1$. A lottery is regular if it is neither strictly positive or negative.

with $x_1, x_2 \in C$ and $x_1 > x_2$. The overall utility of such a lottery represents the utility of the riskless component plus the difference of utilities between the prospective outcomes multiplied with the weight of the more extreme prospective outcome.

With the PT, Kahneman and Tversky introduce the idea of a reference dependent evaluation of lotteries. Without doubt, this idea (among others) led to a better understanding of decision making under risk by improving the predictability of the economic models. The core idea of the prospect theory is to offer a descriptive model which takes the observed phenomena in decision making under risk into account. That is, PT includes more degrees of freedom. In general, this does not improve the quality of a model but in this case, the explanatory value and predictive quality of the model is considerably increased. However, PT shows some weak points. The three main points of criticism are first, that with more than two prospective outcomes, there is the possibility that First Order Stochastic Dominance may be violated.[9] That is, Lottery X might be preferred to Lottery Y even if the probability of receiving a prospective outcome x or greater is at least as high under Lottery Y as it is under Lottery X for all prospective outcomes x, and is greater for some prospective outcomes x. A revised version by Tversky and Kahneman (1992), called Cumulative Prospect Theory (CPT) overcame this problem by using a probability weighting function derived from Rank-Dependent Expected Utility Theory.[10] CPT can also be used for infinitely many or even continuous prospective outcomes (for example, if the prospective outcome can be any real number). CPT employs cumulative rather than separable decision weights. CPT applies to risky as well as uncertain lotteries with any number of prospective outcomes and it allows for different weighting functions for gains and losses. A subject evaluates the prospective outcomes of a lottery according to the reference dependent utility function v with the same properties described above. It is assumed that, given n observations, thereof k observations are negative:

[9]Please refer to Section 4.2.1, where the concept of Stochastic Dominance is analyzed in more detail.
[10]cf. Quiggin (1982) and Quiggin (1992)

$$(3.6) \qquad \pi_i = \begin{cases} \pi^-(p_1 + ... + p_i) - \pi^-(p_1 + ... + p_{i-1}) : i \leq k \\ \pi^+(p_i + ... + p_n) - \pi^+(p_{i+1} + ... + p_n) : i > k \end{cases}$$

with $\pi^+(.)$ and $\pi^-(.)$ being strictly increasing in the interval [0;1] and with $\pi^+(0) = \pi^-(0) = 0$ and $\pi^+(1) = \pi^-(1) = 1$. By meanings of CPT, the overall utility of Lottery X is represented by:

$$(3.7) \qquad U(X) = \sum_{i=1}^{n} \pi_i v(x_i)$$

Second, Kahneman and Tversky suppose the reference point to be static and third, they do not make any further assumptions about how the reference point actually is computed. That is, to apply PT or to conduct any experimental tests, there is a need for some exogenous assumptions about the reference point. For the sake of simplicity, most commonly it is assumed that the reference point is the status quo.

3.1.3 Regret Theory (RT)

With the RT, another alternative theory of rational choice under uncertainty has been proposed almost simultaneously by Loomes and Sugden (1982) and Bell (1982). RT extends the basic assumptions of EUT by an emotional component. That is, besides utility and probabilities, regret also influences a decision. Regret is an emotion which occurs when a subject learns that the prospective outcome would have been better if he had chosen the other lottery. The counterpart to regret is rejoice. Rejoice is an emotion which occurs when a subject learns that the prospective outcome would have been worse if he had chosen the other lottery. The intuitive idea of RT is that a subject compares the prospective outcomes of the chosen lottery to the prospective outcomes of the not chosen lottery. This implies that a subject knows about all prospective outcomes. In the sense of RT, a lottery can only be evaluated with respect to the not chosen lottery. That is, the overall utility of a lottery changes with the content and the context of the decision situation.

Loomes and Sugden (1982) approach the idea of integrating regret into decision making under risk by modeling choices under risk as actions. Each action is an n-tuple of prospective outcomes and associates, other than lotteries, prospective outcomes with particular states of the world. The *ith* prospective outcome of an action which realizes when the *jth* state of the world occurs is denoted as x_{ij}. There exist n states of the world. n is a finite number and each state of the world j occurs with a probability p_j, where $0 < p_j \leq 1$ and $p_1 + ... + p_n = 1$. Thus, prospective outcomes can be depicted in a complete action-state- matrix. However, for the sake of comparability with the other models, I interpret an action as a lottery such that the lotteries, between which a subject decides, have the same probability distribution p (representing the probabilities for the states of the world), yet over different prospective outcomes. That is, a subject prefers Lottery $X : (x_i, p_i)$ to Lottery $Y : (y_i, p_i)$ if

$$U(X|Y) = \sum_{i=1}^{n} p_i \mu(x_i|y_i) > U(Y|X) = \sum_{i=1}^{n} p_i \mu(y_i|x_i) \tag{3.8}$$

The main difference between the models of Bell and Loomes/Sugden is, that Bell only allows for the decision between two lotteries with two prospective outcomes each. That is, given $\mu(x_i|y_i)$, Lottery X is preferred to Lottery Y if

$$U(X|Y) = p\mu(x_1|y_1) + (1-p)\mu(x_2|y_2) > U(Y|X) = p\mu(y_1|x_1) + (1-p)\mu(y_2|x_2) \tag{3.9}$$

The models developed by Loomes and Sugden (1982) and Bell (1982) are very similar in its basic ideas, however approached from different assumptions. While Loomes and Sugden assume a specific functional form of μ to motivate the intuition of regret, Bell derives its specific form from several behavioral assumptions. However, they share the same properties. A subject has a modified utility function μ of the following structure:

$$\mu(x|y) = u(x) + v(u(x) - u(y)) \tag{3.10}$$

$\mu(\cdot)$ assigns a real number to every prospective outcome x with respect to the reference point y. μ comprises two components such that u is the intrinsic utility and v is the reference dependent utility, reflecting regret or rejoice. $u(x)$ assigns a real number to every prospective outcome x.[11] That is, $u(x_i)$ is as subject's intrinsic utility of prospective outcome x_i, i.e. the prospective outcome of Lottery X if the *ith* state of the world occurs. v is a regret-rejoice function which assigns a real number to every possible increment or decrement of the intrinsic utility. That is, if a subject prefers Lottery X to Lottery Y and the *ith* state of the world occurs, the prospective outcome x_i has been realized. If he had chosen Lottery Y, the prospective outcome y_i would have realized. A subject is thus neither able to assign a unique modified value to any prospective outcome x nor a unique overall value to Lottery X. Yet, a decision in the sense of RT is always context sensitive in the sense that the overall value changes with the lottery to which it is compared. In a situation where neither regret nor rejoice is anticipated, a subject is assumed to follow the predictions of EUT. The properties of the utility functions u and v and the following implications on the evaluation of a prospective outcome compared to the other economical theories are discussed in Section 4.1.1. Section 4.3.1 discusses how RT captures a subject's risk attitude.

3.1.4 Disappointment Theory (DT)

Loomes and Sugden (1986) and Bell (1985) both propose a DT. DT is similar to RT because it also extends the basic assumptions of EUT by an emotional component. That

[11] Note, that in order to highlight the influence of regret on a decision, u is mostly assumed to be linear. The implications derived from this assumption are discussed in more detail within Chapter 4.

is, besides utility and probabilities, disappointment also influences a decision. Disappointment is an emotion that occurs when expectations about a risky prospective outcome are higher than the actually realized prospective outcome. If for example a subject expects to receive a gratification of 1.000 Euros, yet he actually only receives 500 Euros, he might be disappointed. The counterpart to disappointment is elation. Elation is an emotion that occurs when expectations about a risky prospective outcome are lower than the actually realized prospective outcome. The higher the expectations the greater will be the disappointment. Yet, the main difference to RT is, that a subject might very often be disappointed when he learns about the realization of his decision. That is, a subject compares the realization of his decision to the alternative prospective outcome that might have been realized if another state of the world had occurred. Integrating disappointment into decision making under risk is approached by integrating a subject's expectations into decision making under risk.

The models introduced by Bell (1985) and Loomes and Sugden (1986) are different in their underlying assumptions. The main difference of Loomes and Sugden's model to the model introduced by Bell is, that they do not distinguish in the intensity of the sensation of disappointment and elation. Loomes and Sugden assume that the subject's degree of experienced disappointment or elation only depends on the difference between the intrinsic utility of *what is* ($u(x)$) and what he expected to have $\bar{x}$. This makes it possible to introduce a more general model. It is possible to represent the modified utility function with the same structure as within RT.

$$\mu(x|\bar{x}) = u(x) + v(u(x) - \bar{x}) \tag{3.11}$$

with u being the intrinsic utility and v) being the reference dependent utility, reflecting disappointment or elation.[12] The difference to RT is the reference point with

[12]Note, that in order to highlight the influence of disappointment on a decision, u is mostly assumed to be linear. The implications derived from this assumption are discussed in more detail within Chapter 4.

which the intrinsic utility is compared. It is assumed that the reference point is a subject's expectations of the lottery, that is its expected value $E(X)$ which is expressed by $\bar{x} = px_1 + (1-p)x_2$, where p is the probability of yielding the prospective outcome x_1 and $(1-p)$ is the probability of yielding the prospective outcome x_2. Assume that the prospective outcome x_1 has realized. The subject experiences disappointment or elation depending on $x_1 >,<,= \bar{x}$.

A subject decides for the lottery with the highest overall utility given with:

$$U(X) = \sum_{i=1}^{n} p_i(u(x_i) + v(u(x_i) - \bar{x})) \tag{3.12}$$

Other than Loomes and Sugden, Bell introduces parameters $d,e \geq 0$, which constantly reflect the degree with which disappointment/elation affects a subject's decision. It can either be $d >,<= e$ such that a subject suffers more from disappointment that enjoying elation, vice versa or both emotions are experienced with an equal intensity. He then develops his model of DT in two steps. He first presents a limited model and then extends it to a more general model. In the limited model, lotteries are represented as $(x_1,p;x_2,1-p)$ with $x_1 \geq x_2$. That is, x_1 is at least as desirable as x_2 and p is the probability of winning. For the sake of a focused analysis on disappointment, Bell assumes constant marginal value for money such that $u(x) = x$. He thus implies two characteristics of v such that disappointment/elation within the reference dependent utility function can be expressed as:

$$v(x - \bar{x}) = \begin{cases} d(x - \bar{x}) \text{if } x < \bar{x} \\ e(x - \bar{x}) \text{if } x > \bar{x}. \end{cases} \tag{3.13}$$

A subject chooses the lottery with the highest overall utility. Thus, disappointment or elation reflect the proportion of the difference between what the subject expected and what he got. $\mu(x_1|\bar{x})$ and $\mu(x_2|\bar{x})$ are given with:

$$\mu(x_1|\bar{x}) = x_1 + e(x_1 - \bar{x}) \tag{3.14}$$

$$\mu(x_2|\bar{x}) = x_2 + d(x_2 - \bar{x}) \tag{3.15}$$

The overall utility of Lottery X is given with:

$$U(X) = p[x_1 + e(x_1 - \bar{x})] + 1 - p[x_2 + d(x_2 - \bar{x})] \tag{3.16}$$

A subject prefers Lottery X to Lottery Y if $U(X) > U(Y)$.

Thoughts about how expectations are formed and whether elation and disappointment depend directly on the involved probabilities led Bell (1985) to expand this simple model by further assumptions which allow to model disappointment and elation as a function of probability p. He implies that $L_0(x_1, p; x_2, 1-p)$ represent the state of owning an unresolved lottery $(x_1, p; x_2, 1-p)$, $L_1(x_1, p; x_2, 1-p)$ represents the state in which $L_0(x_1, p; x_2, 1-p)$ results in prospective outcome x_1 and $L_2(x_1, p; x_2, 1-p)$ represents the state in which $L_0(x_1, p; x_2, 1-p)$ results in x_2.[13] Bell derives that the situations $L_i(x_1, p; x_2, 1-p)$ $i = 0,1,2$ have certainty equivalents of $x_2 + (x_1 - x_2)\pi_i(p)$ for some functions $\pi_i(p)$ from introducing the following assumptions.

- Simple Orderings
- Sure-thing Indifference
- Monotonicity in the Probability of Winning

[13] Remember that always $x_1 > x_2$.

- Monotonicity in Value of Prizes
- Solvability
- Constant Marginal Value for Payoffs
- Risk Neutrality in the Absence of Disappointment

Thus, each Lottery X with the form $(x_1, p; x_2, 1-p)$ can be evaluated according to the certainty equivalents of the unresolved lottery, the winning and losing situation, which can be expressed by two modified utility functions μ with:

$$\mu_1(x_1|x_2) = x_1 + (x_1 - x_2)w(p) \tag{3.17}$$

$$\mu_2(x_2|x_1) = x_2 - (x_1 - x_2)l(1-p) \tag{3.18}$$

$$U(X) = CE(X) = x_2 + (x_1 - x_2)\pi(p) = p\mu_1(x_1|x_2) + (1-p)\mu_2(x_2|x_1) \tag{3.19}$$

π is an increasing, w and l are decreasing functions of probability p with $\pi(0) = w(1) = l(1) - \pi(1) = 0$ and $\pi(p) = p + pw(p) - (1-p)l(1-p)$. The function $w(p)$ can be understood as the value of the elation that comes with winning the lottery (1, p; 0, 1-p). The function $l(p)$ can be understood as the (positively valued) psychological cost of losing in the lottery $(1, 1-p; 0, p)$. A subject then prefers Lottery X to Lottery Y if $U(X) > U(Y)$ such that $CE(X) > CE(Y)$.

For a more detailed discussion of the assumptions made within each model, especially the assumptions made for the reference dependent utility function please refer to Chapter 4.

3.1.5 Reference Dependent Preferences (RDP)

Köszegi and Rabin (2006) develop a model of RDP which takes two main points of criticism about the PT into account: first, its assumption that the reference point is static and second, the lack of any further assumptions about how the reference point actually is computed. Motivated by research in psychology and behavioral economics, nowadays it is assumed that a subject somehow incorporates expectations about the future into the computation of his reference point. In other words, it is assumed that the reference point includes some stochastic elements. Köszegi and Rabin build their model on the essential intuitions in PT but extend and modify it to develop a more generally applicable theory. The model is based on the idea of a stochastic reference point which is determined by a subjects expectations about the future and it is computed endogenously by the economic environment within the decision making process.

Within this model, a subject‘s modified utility depends on comparisons of prospective outcomes x to relevant reference points r (expressed by the reference dependent utility function v) as well as on absolute components (expressed by the intrinsic utility function u). That is, Köszegi and Rabin incorporate basic assumptions of EUT and PT. The model is introduced step by step, beginning with the simple case where no uncertainty is involved.[14]

For a riskless prospective outcome $x \in C$ considered with respect to a riskless reference point $r \in C$, the modified utility $\mu : C \times C \rightarrow C$ is given by

$$\mu(x|r) = u(x) + v(x|r) \tag{3.20}$$

$u(x)$ is a subjects intrinsic utility that corresponds to the outcome-based utility classically studied in economics and $v(x|r)$ is the reference dependent utility, with similar

[14]For a better understanding I concentrate on the one dimensional version of this model and refer the interested reader to the original paper where the k-dimensional version of the model is discussed.

features as the value function in PT (see listing below).

The authors assume that

$$v(x|r) = v(u(x) - u(r)) \tag{3.21}$$

where v is a universal gain loss function which satisfies the following properties:

A0	*(Regularity)*	$v(0) = 0$, and v is twice differentiable on $\mathbb{R}_0$
A1	*(Preference Monotonicity)*	v is strictly increasing
A2	*(Small Stake Loss Aversion)*	$v'_+(0)$ and $\lambda := \frac{v'_-(0)}{v'_+(0)} > 1$
A3	*(Large Stake Loss Aversion)*	$x > x' \Rightarrow v(x) + v(-x) < v(x') + v(-x')$
A4	*(Diminishing Sensitivity)*	$v''(x) \leq 0$ for $x > 0$ and $v''(x) \geq 0$ for $x < 0$

Incorporating some uncertainty about the reference point, the model extends as follows. A riskless prospective outcome $x \in C$ is now evaluated according to an uncertain reference point $Y \in P$. That is, the reference point is expressed by a Lottery Y with distribution function G. That is, x is compared to possible reference points $r \in C$. A subject's overall utility is then given by the modified utility weighted by all reference points:

$$U(x|Y) = \int \mu(x|r) dG(r) \tag{3.22}$$

That is, a subject compares a prospective outcome x with what he, based on his expectations about the future, considers possible.

If the prospective outcome to be evaluated is also uncertain, i.e. if the subject compares a Lottery X with distribution function H with a reference Lottery Y with distribution function G the overall utility is given by

$$U(X|Y) = \int \int \mu(x|r)dG(r)dH(x) \tag{3.23}$$

That is, a subject evaluates each Lottery X according to its expected utility. The expected overall utility of each lottery is determined by the average of how it feels relative to each possible realization of the reference point Y. For example, if the reference lottery is a gamble between 0 Euro and 100 Euros, a prospective outcome of 50 Euros feels like a gain relative to 0 Euro, and like a loss relative to 100 Euros, and the overall sensation is a mixture of these two feelings.

The authors propose that evaluating a lottery, a subject assesses the reference dependent utility in each dimension (gains and losses) separately. This means that a subject not only cares about both intrinsic utility and reference dependent utility but there is also strong relationship between them.

Based on this model of RDP, Köszegi and Rabin propose two solution concepts which model how a subject chooses between two or more lotteries out of a choice set P. These concepts internalize the computation of the reference point within the decision making process. Both solution concepts require that expectations and choice of a subject have to be consistent. This means, that in a Unacclimating Personal Equilibrium (UPE), on the one hand the subject correctly predicts his own behavior regarding the choice of a lottery out of P and on the other hand he is not willing to deviate from this plan when he actually faces the choice between the lotteries out of P.

A Lottery $X \in P$ is a UPE if

$$U(X|X) \geq U(X'|X) \tag{3.24}$$

for all lotteries $X' \in P$. Maximizing his overall utility, a subject will consider his expectations as given. If a subject expects to choose X in his UPE, choosing X needs to actually maximize his overall utility among all others options, i.e. he is willing to go through with his plan. Obviously there might be more than one UPE regarding the choice between a set of lotteries. A lottery is a preferred personal equilibrium (PPE) if X is a UPE and

$$U(X|X) \geq U(X'|X') \tag{3.25}$$

for all UPE $X' \in P$.

A subject can evaluate all his UPE according to their overall utility, i.e. he can choose the one which brings the highest overall utility.

With respect to the analysis of the reference dependency of risk attitudes (refer to Section 4.3.1, where the concept of risk attitude is discussed in more detail), Köszegi and Rabin (2007) propose another solution concept, which is to be considered if there is a greater time span between choice and the realization of the prospective outcomes, as for example when buying an insurance. This longer time span enables the subject to adapt his expectations to the actual situation after the choice was made. A Lottery $X \in P$ is a choice-acclimating personal equilibrium (CPE) if

$$U(X|X) \geq U(X'|X') \tag{3.26}$$

for all lotteries $X' \in P$.

When a subject is going to choose $X \in P$, he anticipates that X will later serve as his reference point relative to which he will evaluate the prospective outcome. That is, the lotteries are compared to a reference lottery which is identical with the lottery under consideration. Observe, that within RDP (in CPE as well as in UPE and PPE) the reference point always equals the lottery actually chosen by the subject, such that the overall utility from choosing a sample Lottery X is always the same, independent of wether the subject bases his choice on UPE or CPE. The main difference in these solution concepts is what this overall utility is compared to. In UPE, the overall utility of choosing Lottery X is compared to the overall utility of not choosing Lottery X, given that the reference point is choosing Lottery X. That is, the reference point does not adjust to the deviation. In CPE, the overall utility of choosing Lottery X is compared to the overall utility of not choosing Lottery X, given that the reference point has changed to not choosing Lottery X. That is, the reference point does adjust to the deviation.

3.2 Psychology

In the field of psychology, there is a broad spectrum of literature and research considering the human decision making process. The main focus in this thesis is the cognitive-affective interplay within decision making and the two processing systems which are triggered according to the affectivity of a decision in the sense of the Dual-Processing Theory. It is assumed (as discussed in Section 2.1), that there exists an experiential system which processes affective decisions and an analytical system which processes cognitive decisions. This section introduces three psychological models which address the role of affect in the decision making process from a different perspective: the Affect Heuristic (AH), the Feelings as Information Theory (FaI) and the Risk as Feelings Theory (RaF).[15] The focus within the AH is on the question of how subjects rely on affect, expressed as mental images, while they make a decision. These mental images are directly elicited by the decision task itself. The authors don't make any assumptions about the contrary role of the analytical system, yet they are aware that there are two systems at stake. The main focus of FaI is on the idea that a subject's mood also influences a decision to be made. Schwarz and Clore (1983) address the circumstances under which even incidental emotional reactions may change a

[15] Please refer to Section 2.1.2, which shortly discusses the different possible definitions and characterizations of emotions and feelings. As the different definitions of emotions and feelings are sometimes rather confusing, the end of this chapter will point out the understanding of each concept which will be followed within the rest of this thesis. However, this literature review of the relevant theories follows the notations of the according authors.

subject's mood such that this may change his preferences. RaF is similar to the AH, unless it additionally focuses on the interplay between the experiential and the analytical system. Loewenstein et al. (2001) ask if the experiential system just informs the analytical system or if there is any stronger influence or guidance in the decision making process. Thus, discussing these three models comprises a wide range of research about the role of affect in the decision making process and it seems to be promising to further analyze these models with the focus on the development of the ADMF.

3.2.1 The Affect Heuristic (AH)

The AH is a theoretical framework, developed by Paul Slovic and his colleagues, that describes the importance of affect in guiding judgments and decisions.[16] Research during the last forty years considered the questions of how subjects perceive risk, loss, and benefit and how the provided information may influence decision making under risk.

As introduced in Section 2.1.2, affect is one component of within the Dual-Processing Theory. The authors consider affect as very important in the decision making process. According to Zajonc (1980), affect indicates an instinctual reaction to a stimulation which occurs before the typical cognitive processes. That is, affect in the AH is defined as the specific quality of goodness or badness experienced as a feeling. This feeling marks the positive or negative quality of a stimulus.

The term heuristic comes from the greek language and means "find" or "discover". A heuristic is based on techniques which refer to the experiences already made with similar situations for example decision making, solving a problem, or learning. The solution of a heuristic is not guaranteed to be optimal. Heuristics may be practical in use in situations where finding the optimal solution takes a very long time or costs are very high. That is, a heuristic can speed up the process of making a good decision by using mental shortcuts to ease the cognitive load of decision making.

[16] cf. Slovic et al. (2007), Finucane et al. (2000), Slovic et al. (2004), Slovic and Peters (2006)

The AH, as proposed by Paul Slovic and his colleagues, specifies how affect guides human judgement and decision making. Figure 3.3 depicts how the AH operates while a subject evaluates a decision. The upper part of Figure 3.3 depicts the affective and sometimes unconscious input, whereas the lower part of Figure 3.3 depicts the observable input of a decision situation. In the AH, it is assumed that representations of objects and events are tagged with affect, which means that there are mental images of these objects, marked by positive or negative feelings. These mental images might be based on experience in previous decisions or based on a comparison with similar situations.

If a subject is confronted with a decision to be made, he consults an "object pool" containing all the positive and negative tags which are consciously or unconsciously associated with the representations. The basic research question which the authors try to answer within the AH is how perceived risk and perceived benefit are balanced against each other in order to announce: "How safe is safe enough?". It is assumed that information which is provided may influence the quality of a tag. The perception of risk and benefit is negatively correlated. That is, if information says benefit is high, this tags the problem positive and leads to a lower perception of risk and vice versa. If information says risk is high, this tags the problem negative and leads to a higher perception of risk and vice versa. Thus, these findings reveal different risk attitudes in different situations. The concept of risk attitude is discussed in more detail within Section 4.3.

To include the AH into the decision making process, as it will be discussed and analyzed in the following chapters, reveals challenges in two dimensions. First, the definition of risk used in the sense of the AH is not the same as it is commonly established in the economic conventions of decision making under risk as discussed in Section 3.1. Here, risk in the authors' definitions means the loss associated with an event which may occur with a certain probability. Thus, it is highly needed to set up a unified definition of the relevant concepts. Second, within their research considering subjects to use an AH while making decisions, Paul Slovic and his colleagues focus

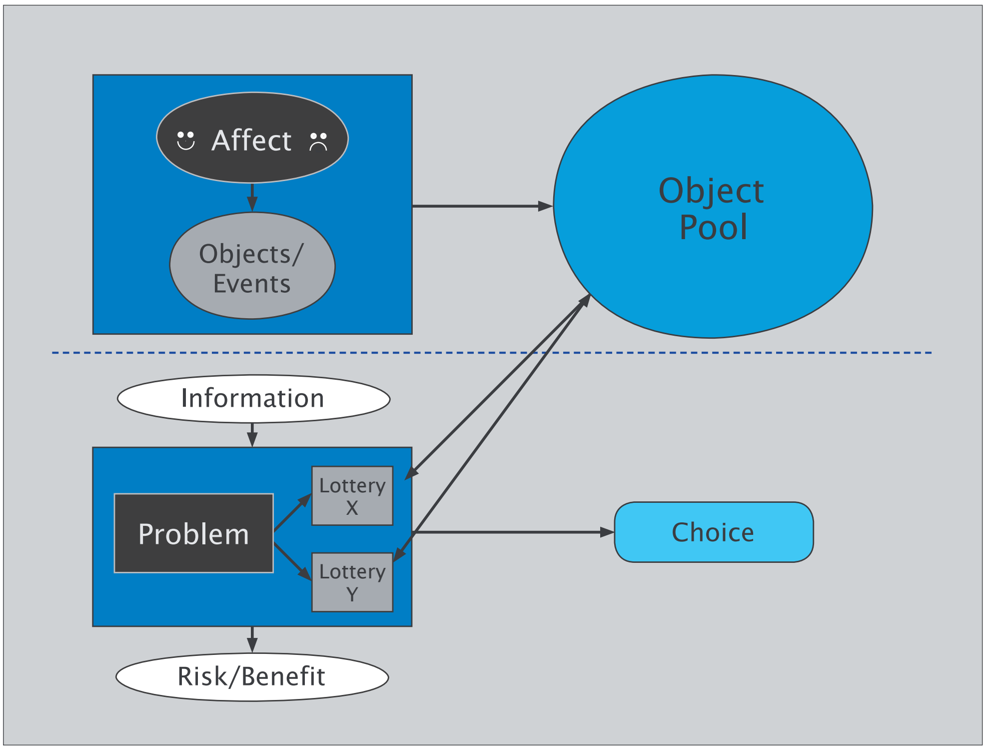

FIGURE 3.3: *The Affect Heuristic*

on the role of affect and rather relieve the discussion of its interplay with a cognitive processing of decision making. Yet, within the AH it is possible to "explain" several phenomena observed in economic decision making. The following chapter goes into more detail and analyzes how the findings coming from the AH can be integrated into the cognitive-affective interplay within the decision making process.

3.2.2 Feelings as Information (FaI)

FaI is also known as the Affect as Information Theory or Mood as Information Theory. It has been developed by Schwarz and Clore (1983) as a model to explain the role of affect in social judgment where the authors conducted two experiments in which happy and sad moods were induced to investigate the impact on a subject's general life satisfaction. The findings of this first study are applicable to more general feelings and judgments.

In the sense of FaI, Schwarz (2011) understands feelings as subjective experiences towards a judgment situation such as moods, emotions, metacognitive experiences, and bodily sensations, which occur mainly outside of consciousness. Within the framework of FaI it is assumed that subjects attend to these subjective experiences (feelings) as a source of information. That is, different feelings elicit different types of information and information processing.

This framework differentiates between incidental and integral feelings. Integral feelings are direct reactions towards a situation or problem. Incidental feelings are not directly elicited by the situation or problem to be judged but may also serve as informational input to guide the subject's judgement. Incidental feelings are for example elicited by sunny or rainy days which influence a subject's overall mood. Schwarz and Clore (1983) find that a subject judges his overall life satisfaction better on sunny days than on rainy days. Schwarz (2011) states that, incidental feelings that are due to an unrelated influence can lead a subject's judgement astray. Incidental and integral feelings provide information about goodness or badness of the current situation. Schwarz and Clore (1988) consider that, subjects integrate this unconscious evaluation by asking themselves "How do I feel about it?". How much a subject relies on the information provided by this unconscious evaluation depends on the source of these feelings. If a subject is aware that his good mood is due to the nice weather outside then the influence of these feelings on the judgement is mostly eliminated. On the other hand it is possible to prime subjects to trust their incidental feelings which leads to a greater influence on the judgement situation.

In FaI Schwarz and Clore (1996) assume, that depending on the value of the informational input different systems of processing are addressed. That is, if the unconsciously evaluated feelings signal a problematic environment, the processing is systematic, bottom up and with much attention to detail. If a benign environment is signalled, the processing is heuristic, top down and with the use of preexisting knowledge .

FaI has been developed in the context of social judgement rather than decision making under risk. But as it makes generally applicable assumptions on human judgement and problem solving it may also be applicable to the specific context of economic decisions in a risky environment. Whereas within the AH, as discussed in Section 3.2.1, the focus is on the role of affect which is directly related to the decision task, in FaI the authors focus on the question of how a positive or negative "background" mood might influence decision making. The main difference to the AH is, that a subject's background mood might be changed due to incidental events. The next chapter provides a discussion of how the findings of FaI might be integrated in the cognitive-affective interplay within the decision making process.

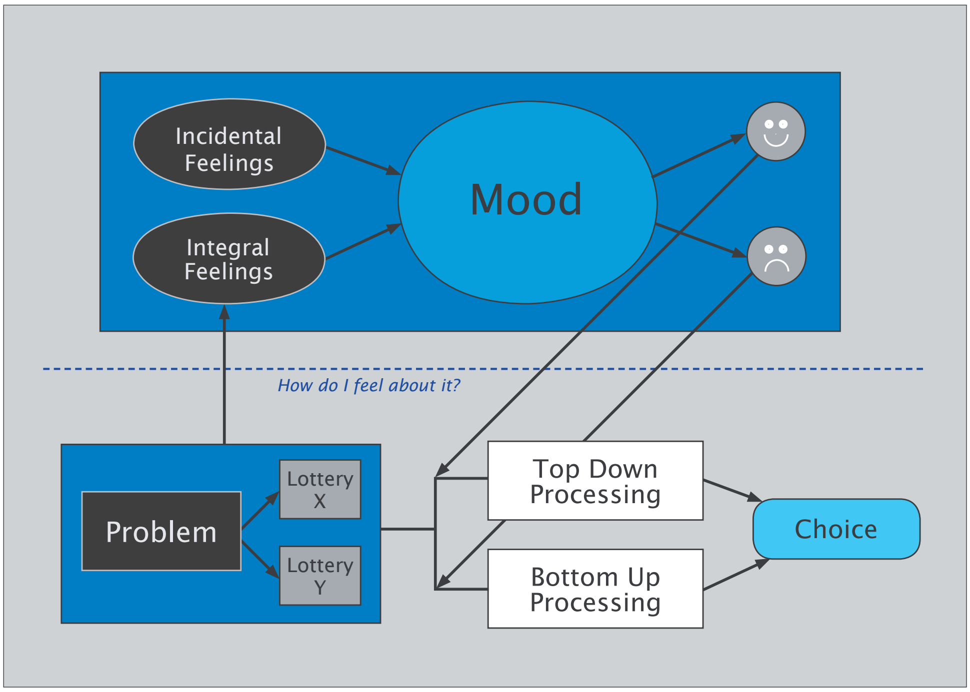

FIGURE 3.4: *Feelings as Information*

3.2.3 Risk as Feelings (RaF)

Loewenstein et al. (2001) propose RaF as an alternative model to the consequential perspective on decision making. The authors choose the term 'consequential' because in classic economic theory the lotteries of a decision problem are typically assessed by their possible consequences: the prospective outcomes. The model differs from the AH and FaI by highlighting the different role of expected and immediate emotions in the decision making process. On the one hand, expected emotions are expected to be experienced when the decision results in a positive or negative prospective outcome. That is, they are part of the cognitive analysis of the decision problem as they are part of the assessment of the prospective outcomes. These emotions are for example considered in the RT and DT.[17] On the other hand, there are immediate emotions or feelings, which are experienced when confronted with a decision problem. That is, immediate emotions are direct reactions to the input factors of a decision.[18] RaF proposes that, contrary to the AH and FaI, emotions do not only inform in the decision making process but immediate emotions also lead to different behavior than a pure cognitive evaluation would predict. That is, even if a subject is aware of the cognitively evaluated best strategy, feelings will lead to a different behavior. Within the framework of RaF these two strands of literature are brought together.

The main focus of the research by Loewenstein et al. (2001) is to investigate when and why such divergences in emotional and cognitive analysis of a decision problem occur and what can be learned in order to predict human behavior. As shown in Figure 3.5 RaF assumes that both cognitive evaluation and feelings guide behavior, which leads to a decision.

The authors propose that cognitive evaluation of a decision situation is on the one hand based on the desirability of a prospective outcome, which means emotions such

[17]Please refer to Section 3.1, where I discussed the relevant economic models and theories.

[18]Please refer to Section 2.1.2, which shortly discusses the different possible definitions and characterizations of emotions and feelings. As the different definitions of emotions and feelings are sometimes rather confusing, the end of this chapter will point out the understanding of each concept which are followed within the rest of this thesis.

[19]Source: Loewenstein et al. (2001), Figure 3 on page 270

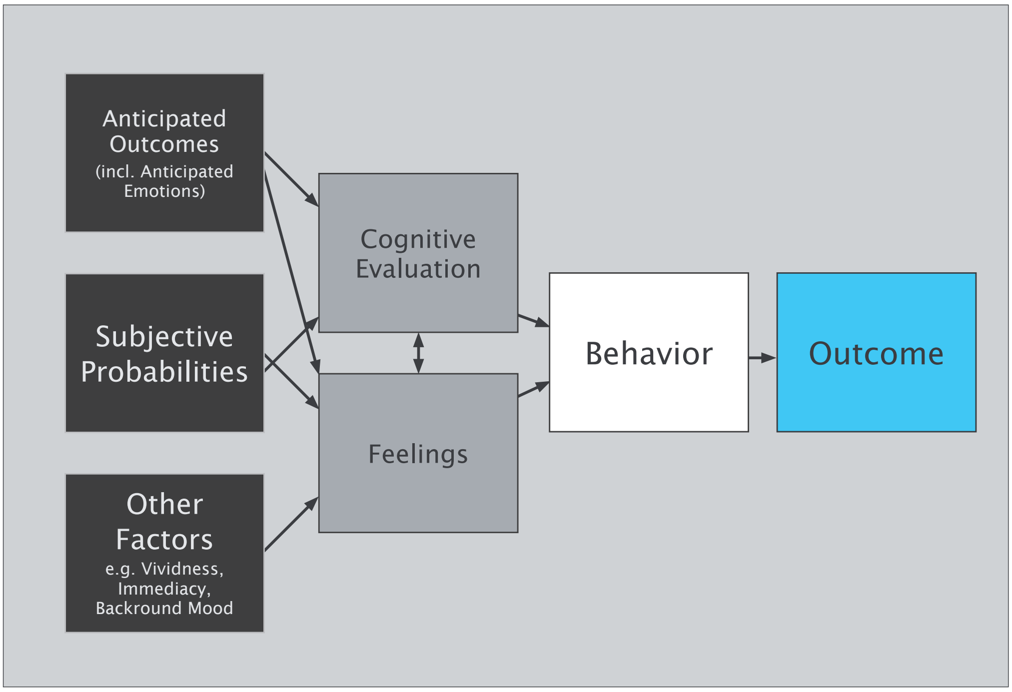

FIGURE 3.5: *Risk as Feelings*[19]

as regret, relief, and disappointment are included in the assessment of a prospective outcome. On the other hand the cognitive evaluation of a decision is based on subjective probabilities.

Parallel to the cognitive evaluation however, there is an emotional evaluation of the decision situation which results in immediate feelings towards the specific task. These feelings are influenced not only by the desirability of the prospective outcome and by subjective probabilities but also by other factors such as vividness and immediacy of the decision and also by the subject's mood. The authors propose that the different factors influencing emotional and cognitive evaluation lead to the observed discrepancy of behavior. Contrary to the AH and FaI, RaF focuses on both the affective and the cognitive processing of decision making. However, the authors don't make any further assumptions about how the interplay between these two systems might be modeled. They rather focus on the idea that the affective and cognitive processing might somehow work parallel. The following Chapter 4 analyzes how RaF deals with the evaluation of prospective outcomes, the given probability distribution and how a subject's risk attitude can be captured and thus how the findings of RaF can be integrated into modeling the cognitive-affective interplay.

3.3 Neuroscience

In neuroscience, there is an emerging field of research considering neural systems involved in economic decisions under risk. Contrary to research in psychology where the above described frameworks are proposed and widely accepted as an environment for testable variables considering the decision making process, in neuroscience there is only one model that provides an overall environment of the decision making process which is widely accepted, the SMH. Thus, neuroscientific research is still at its beginning in providing a framework of the neural basis of economic decision making under risk. There are however numeral experimental studies which investigate specific tasks and identify the role of the different brain regions in the economic decision making process. There is a strong need to bring these experimental results together and provide a universal language which allows the definition of an overall framework of the neural system of economic decisions under risk. This section first introduces the SMH and second gives an overview of other existing neuroscientific frameworks, experimental studies and reviews considering decision making under risk and, with the focus on Research Question 2, identifies the relevant underlying concepts that are important for further analysis of the neuroscientific input into the decision making process.

3.3.1 The Somatic Marker Hypothesis (SMH)

What the common economic models of decision making under risk, as discussed in Section 3.1, do not explain is: Why do subjects evaluate gains unlike losses, for example: Why are subjects risk averse facing gains and risk seeking facing losses? Why do states of optimism lead to different choices than states of pessimism? Why, when the market is crashing everyone rushes to sell, and when it is growing, everyone rushes to buy? These questions are, to a certain extent, addressed by the psychological models introduced in Section 3.2. The SMH assimilates the idea introduced by psychological literature, that besides the cognitive processing of a decision, there might also be an affective processing of a decision.

Within the SMH, it is suggested that prior to every cognitive processing there is an unconscious evaluation of prospective outcomes by somatic markers, which strengthens the deliberations by Zajonc (1980) that affective processing in fact is prior to cognitive processing.[20] The unconscious preparing by the body may help to identify which alternatives are advantageous and which are not. In other words, prior to every decision there is an unconscious evaluation of different alternatives. The evaluation results in physiological reactions, like for example changes in HR or SR. This means, the body enters different somatic states when confronted with different decision situations. These somatic states are reactions to the anticipation of different prospective outcomes and guide the subject to advantageous decisions. The SMH provides a systems-level neuroanatomical and cognitive framework for decision making and shows how it is influenced by emotions. The key idea of this hypothesis is that decision making is a process influenced by marker signals, which express themselves in emotions and feelings (Bechara and Damasio 2005). According to the authors, an emotion is defined as follows:

> "An emotion is defined as a collection of changes in body and brain states triggered by a dedicated brain system that responds to specific contents

[20]Please refer to Section 2.1.2 where the idea of a Dual-Processing Theory is briefly introduced.

> of ones perceptions, actual or recalled, relative to a particular object or event." (Bechara and Damasio (2005), p. 339)

The trigger that elicits an emotion is "an emotionally-competent stimulus". The subject responds to this stimulus. This response results in a specific somatic state, which is expressed by physiological reactions. These reactions are for example, as described in Section 2.1.3, changes in HR, SC or respiration. A stimulus can be a primary or secondary inducer. Primary inducers result in immediate emotions while secondary inducers result in anticipated emotions. Primary inducers are innate or learned stimuli that cause pleasurable or aversive somatic states. Primary inducers automatically trigger a somatic response, as for example a snake automatically induces fear. Secondary inducers are generated by remembering an emotional event, i.e. thoughts and memories of the primary inducer, which then elicits a somatic state. Examples of secondary inducers are for example the memory of encountering a snake or the memory of losing a large sum of money. The imagination of being attacked by a bear, winning an award, or losing a large sum of money, are also examples of secondary inducers.

The authors suggest that the Amygdala is a critical substrate in the neural system for triggering somatic states from primary inducers, whereas the Ventromedial Prefrontal Cortex (VMPFC) is a critical substrate for triggering somatic states from secondary inducers.

The somatic reactions that drive a subject's decisions can be positive or negative somatic reactions, whereas positive somatic reactions serve as a *start-signal* for a decision and negative somatic reactions serve as a *warning-signal* against a decision.

The SMH is a commonly accepted model of neural systems of decision making. However, as it doesn't focus specifically on decision under risk, there is a wide variety of future research questions which can be investigated and discussed.

3.3.2 Neural Systems of Decision Making

Besides the SMH, there exist several other frameworks and theories which take the neural systems of decision making into account. However, none of them provides such a comprehensive study as the SMH. These frameworks and models are rather mostly more focused on specific tasks within the decision making process which is naturally not less important to develop a better understanding of decision making. Studies of neuroscience with different methods such as fMRI and LS investigate how the brain works and which parts of the brain are active during the different tasks of the decision making process.[21] In neuroscience as well as in psychology, there is the upcoming interest of research how the brain includes affective and cognitive processing. There are brain regions and systems that are suggested to be appropriate for cognitive processes and others are suggested to be appropriate for affective processes. By scanning the activation of these brain regions during a decision task it is inferred how these regions might be involved in the decision task.

Table 3.2 provides an overview of literature relevant in this thesis. Within these studies, the computational and neural basis of the decision making process is investigated by combining the methods from the behavioral decision making literature such as risky decision making tasks. The results and findings are extremely limited to the underlying decision task that has been conducted during the experiment.[22]

Gold and Shadlen (2007) discuss the decision making process by considering how it is implemented in the brain. Figure 3.6 depicts the elements of the decision making process. The left side of the picture represents elements "in the world" and the right side represents elements of the decision "in the brain". The black-rimmed elements represent context. The red-rimmed elements form a decision. The blue-rimmed elements evaluate and possibly update the decision making process. They focus on very simple sensory motor tasks such as wether to put ones hand up or down. However,

[21]Please refer to Section 2.1.3, where the history and methodology of research in neuroscience is discussed.

[22]Refer to Section 2.1.3, where the limitations of neuroscientific methods are shortly discussed.

they state understanding how such simple tasks are processed in the brain provides the basis to understand more complex tasks.

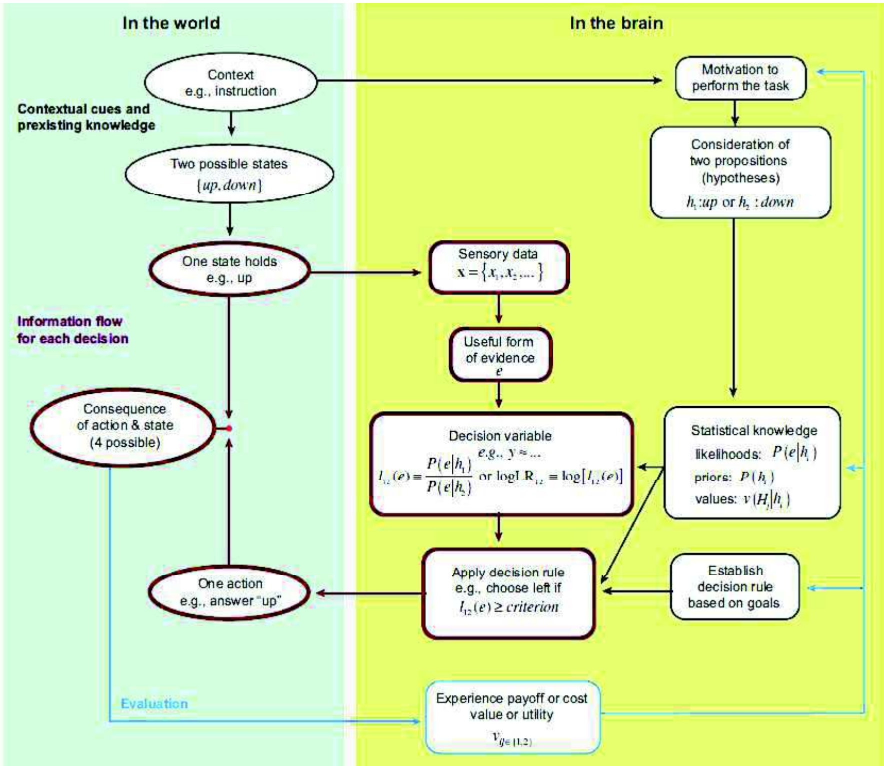

FIGURE 3.6: *The Neural Basis of Decision Making*[23]

Rangel et al. (2008) present a framework which focuses on the decision making process to be divided into five steps. Figure 3.7 depicts the five steps of the value-based decision making process. The first step focuses on the representation of the decision which includes the set of the feasible actions. The authors assume that these feasible actions are evaluated differently according to which internal or external state the subject is in. An internal state is for example the state of hunger, an external state may consider the environment, i.e. how far is the next restaurants away.[25] In the

[23]Source: Gold and Shadlen (2007), Figure 1 on page 537

[24]Source: Rangel et al. (2008), Figure 1 on page 546

[25]These assumptions underline psychological research in a way, that an internal state might be put on one level with the idea of an affective state.

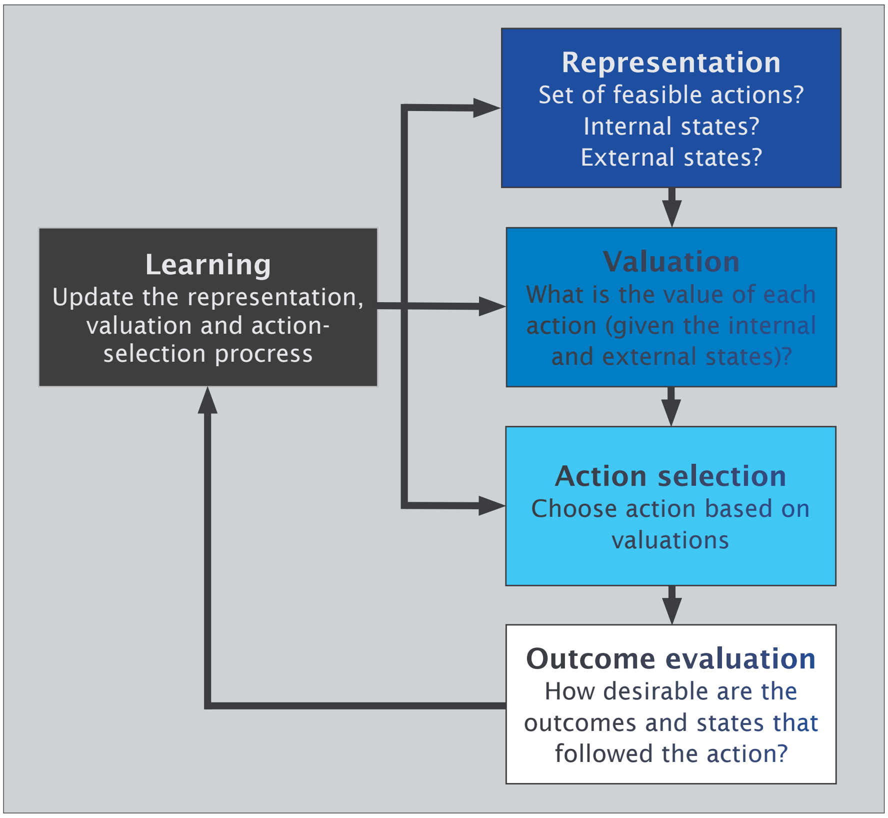

FIGURE 3.7: *The Neurobiology of Value-Based Decision Making*[24]

second step the subject has to identify the value of each action and in the third step the action with the highest value is chosen. In the forth step the prospective outcome is evaluated according to how desirable it is. The representation, valuation and action selection processes are updated according to what is learned in the fifth step in order to improve the quality of future decisions.

Mohr et al. (2010) investigate the neural processing of risk. Figure 3.8 depicts a potential mechanism of risky decision making. As the authors understand it, a risky stimulus is for example a gamble, or a choice menu with different financial investments. This stimulus is initially evaluated on an emotionally level. The Anterior Insula (aINS) is suggested to estimate how possible it is that the risky stimulus results in an unwanted prospective outcome. The thalamus is suggested to reflect other important aspects of prospective outcomes, e.g. their variability. Mohr et al. (2010) suggest that after an initial emotional processing, there is a cognitive processing mediated by the Dorsomedial Prefrontal Cortex (DMPFC). Emotional as well as cognitive processing inform the actual decision process in the Dorsolateral Prefrontal Cortex (DLPFC) and the Parietal Cortex where actually the choice is made.

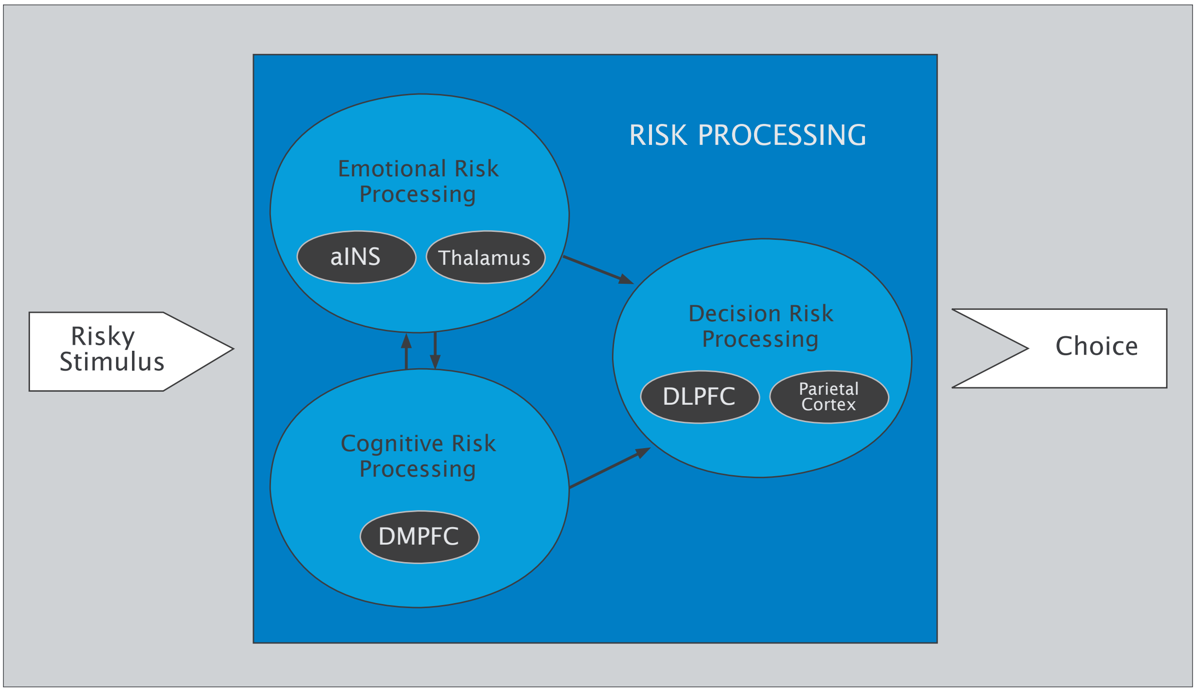

FIGURE 3.8: *A Potential Mechanism of Risky Decision Making*[26]

Levin et al. (2012) conduct a meta study to investigate the question of distinct neural systems processing gains and losses. Figure 3.9 depicts a neural model of decision making under uncertainty. The authors suggest that uncertainty of a decision situation serves as a stimulus which is characterized as a primary inducer. Primary inducers are processed by the Amygdala, which then triggers the VMPFC. The VMPFC is suggested to process uncertainty more deliberately on a cognitive level. It is, however, suggested that decisions which involve potential losses (which primarily

[26]Source: Mohr et al. (2010), Figure 4 on page 6617

induce a danger), trigger a redundant neural system in the Insula (anterior, posterior, and both) and the adjacent Primary Somatosensory Cortices (SI) and Secondary Somatosensory Cortices (SII), which are independent of the Amygdala. This is suggested to be a back up system which guarantees for the fast processing of potential danger in case of a lesion in one of these brain regions.

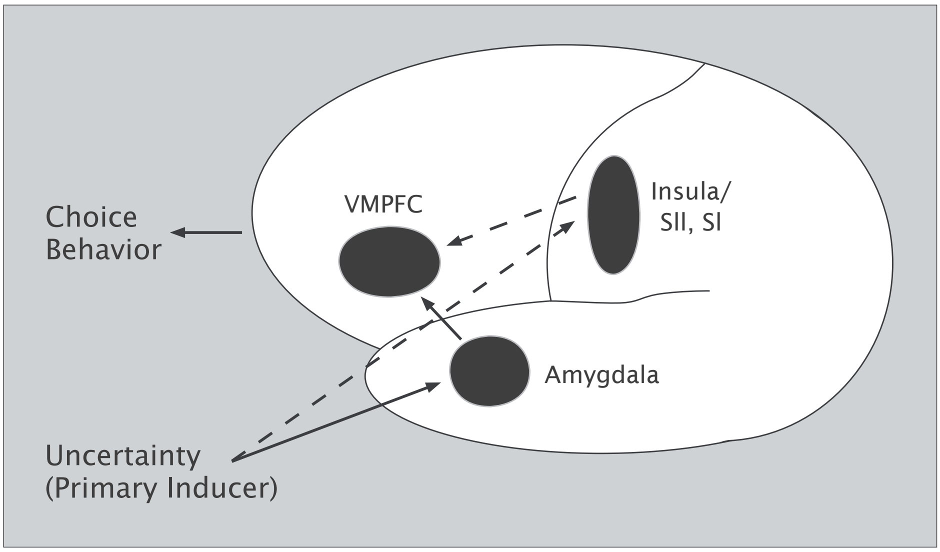

FIGURE 3.9: *Neural Model of Decision Making Under Uncertainty*[27]

These studies underline psychological research when they provide evidence, that in fact affective processing can be prior to cognitive processing as suggested by the meta studies of Mohr et al. (2010) and Levin et al. (2012). Based on these numeral studies and experiments, in neuroscientific literature it is nowadays most commonly accepted that the following brain areas are suggested to be involved in decision making appropriate for different processes.

[27]Source: Levin et al. (2012), Figure 1 on page 2

Amygdala: The Amygdala is involved in the formation of the immediate emotion fear and plays an important role in the emotional evaluation, recognition and analyzing of aversive situations and dangers. The Amygdala processes the external stimuli and initializes the vegetative reactions. The Amygdala is suggested to process the "Fight or Flight?" mode.

Prefrontal Cortex: The Prefrontal Cortex is located in the front parts of the frontal lobe. It is the target of the dopaminergic reward system. The Prefrontal Cortex is assumed to be involved in cognitive and executive functions of decision making. The Orbitofrontal Cortex and the Ventromedial Cortex are part of the Prefrontal Cortex.

Insula: The Insula is assumed to be involved in the emotional evaluation of pain.

Striatum: The Striatum is part of the Basal Ganglia. The Nucleus Accumbens (NAcc) is the reward system and is part of the Striatum.

3.4 The Important Concepts in Decision Making Under Risk

This chapter provides a detailed literature review of the existing models of decision making in economics, psychology and neuroscience, which are appropriate as a basis for further analysis how to integrate affect into decision making under risk.

When a subject is about to make a decision, the most important factors are possibly the prospective outcomes in which his decision might result. In the existing economic literature, it has become a general assumption that a subject evaluates a prospective outcome according to some subjective utility. The assumed properties of the utility function differ to some extent within the economic theories. As discussed in Section 3.1, models of behavioral economics include the idea that preferences are not just based on cognitive assessment but also on some anticipations and expectations. At this point, the AH, FaI and RaF (as discussed in Section 3.2) can tie in with research about the role of affect within decision making under risk. These theories extend the idea of integrating expected emotions into a subject's utility function by providing results which suggest that affective properties of a prospective outcome elicit direct emotional reactions which lead to different processing. Research in neuroscience also suggests that the properties of a prospective outcome are important for further evaluation of a decision to be made, as discussed in Section 3.3. Thus, it is a promising approach to analyze *how* a prospective outcome is evaluated (as will be discussed in Section 4.1) and how the findings from economics, psychology and neuroscience can be merged to explain the cognitive-affective interplay in the evaluation of prospective outcomes.

As, within this thesis, the focus is on decision making under risk, the probability distribution over the prospective outcomes is known to the subject and needs to be taken into account. Within economic literature, it is most commonly accepted that probabilities are weighted subjectively as suggested by Kahneman and Tversky (1979). However, for the sake of simplicity, in most theories probabilities are considered linearly. Yet, the authors are aware of the fact that subjects actually do not really weight probabilities linearly. With regard to this Köszegi and Rabin (2006) state:

> "Despite the clear evidence that people's evaluation of prospects is not linear in probabilities, our model simplifies things by assuming preferences are linear."(Köszegi and Rabin (2006), p. 1137)

Further, economic literature doesn't make any assumption *why* probabilities are weighted other than linear and *how* this weighting might depend on the properties of a prospective outcome. At this point, research in psychology and neuroscience might provide some explanations. Considering the role of affect in decision making under risk reveals some interesting observations about the subjective weighting of probabilities and implies that in fact this subjective weighting is due to the affective properties of a prospective outcome (Rottenstreich and Hsee 2001). There is also research in neuroscience providing input to the question of how and why probabilities are subjectively weighted.[28] Thus, it might be promising to discuss how the probability distribution is evaluated by a subject and how the role of affect (from the psychological as well from the neuroscientific perspective) can shed light on the question why probabilities are weighted subjectively in Section 4.2. Research in neuroscience, especially within the imaging techniques however reveals one important point: the concept of probabilities is somehow artificial, introduced in mathematics and economics to overcome the lacking knowledge about future states of the world. Thus investigating decision making with the focus on subjective probability weighting in the brain is very hard to capture. To analyze *how* and *why* subjects subjectively weight probabilities might be a promising approach in two ways: it first might extend the understanding of the cognitive-affective interplay in decision making under risk and second this might provide the opportunity for further research in neuroscience and thus a better understanding how the brain deals with probabilities.

Subjects form their preferences based on the evaluation of the prospective outcomes as well as on the given probability distribution. Yet, in some situations, subjects seem to be different according to their risk preferences. Economics take a subject's risk attitude into account, often following the observations of Kahneman and Tversky that subjects are risk averse in the face of gains and risk seeking in the face of losses. However, in economic literature, it is assumed, that a subject's risk attitude is given and does not change due to situational factors. Yet, it is commonly accepted and often observed that one subject likes to gamble as well as to buy insurance.[29] In psychology as well as in neuroscience there is evidence, that a subject's risk attitude in fact is context specific. It is assumed that the affectivity of a decision situation influences a subject's risk attitude.[30] Thus, to analyze how a subject's risk attitude can be captured within decision making under risk and to further discuss how this helps to understand the cognitive-affective interplay is an issue to be discussed in more detail

[28] cf. Paulus and Frank (2006), Hsu et al. (2009), Berns et al. (2008), Takahashi et al. (2010)
[29] cf. Kahneman and Tversky (1979)
[30] cf. Slovic et al. (2007), Loewenstein et al. (2001), Knoch et al. (2006), Kuhnen and Knutson (2005), Engelmann and Tamir (2009)

within Section 4.3.

Thus, based on the review of the economic literature in this chapter, the following three components of decision making under risk are indispensable to discuss.

- How is a prospective outcome evaluated?
- How is the probability distribution evaluated?
- How can a subject's risk attitude be captured?

The analysis of these three components of decision making under risk within the disciplines of economics, psychology and neuroscience is based on several underlying concepts. A clear definition of these concepts is important for the understanding of the further discussion of decision making under risk within this thesis. In economics, decision making under risk is defined as follows:

Decision Making under Risk: Decision making under risk in economics is modeled by a choice problem over a set of lotteries, where a lottery is defined as a distribution of probabilities over a set of prospective outcomes.

As discussed in Section 3.2 and Section 3.3, literature in psychology and neuroscience suggests that affect and cognition are interacting while a decision is made and that affective reactions are very often even primary to cognitive appraisal.[31] Based on the literature review within this chapter, the following psychological and neuroscientific concepts are indispensable to understand the following deliberations and analyzes within Chapter 4. In Section 2.1.2 affect is suggested to be the "umbrella-term" of all emotional concerns as the opposite to cognitive concerns. In the rest of this thesis I follow the definition of Slovic et al. (2007) and understand affect as follows:

Affect: Affect encompasses emotions, feelings and mood by demarcating a positive or negative quality of a stimulus.

There is no unitary definition of the three concepts emotions, feeling and mood. Based on the discussed psychological and neuroscientific literature, I understand

[31] cf. Zajonc (1980) and Bechara and Damasio (2005)

these concepts as follows. First, as discussed in Section 2.1.2 there is not one definition of an emotion but there exist several strands of literature which provide different definitions and characterizations of emotions. I follow the definition of an emotion by Bechara and Damasio (2005):

Emotion: An emotion is a collection of body and brain states triggered by a dedicated brain system that responds to specific contents of a subject's perceptions, actual or recalled, relative to particular object or event.

Further, I follow the definitions of Loewenstein et al. (2008) who further distinguish between the following characterization of emotions which are relevant in the decision making.

Immediate Emotions: Immediate emotions are immediate visceral reactions to stimuli.

Expected Emotions: Expected emotions are anticipated to be experienced as reactions to stimuli in the future.

Integral Emotions: Integral emotions are immediate emotions, which are elicited by a stimulus directly related to the decision.

Incidental Emotions: Incidental emotions are immediate emotions, which are elicited by a stimulus **not** directly related to the decision.

Second, Bechara and Damasio (2005) provide a definition of feelings which is widely accepted and adopted.

Feeling: A feeling is the subjective experience associated with an emotion.

Third, mood, other than feelings and emotions, can best be understood as a state that is of low intensity and longer duration. In the rest of this thesis I understand mood as suggested by Scherer and Peper (2001) and Bechara and Damasio (2005).

Mood: Mood is an emotional state which is positive or negative and extended in time.

The affectivity of a stimulus within a decision under risk, for example a prospective outcome, induces a mental image. That is, a subject can somehow imagine how it will feel to receive such a prospective outcome. In the rest of this thesis, based on the definition in Slovic et al. (2007), I understand a mental image as follows.

Mental Image: A mental image is an image of an object or event marked with positive or negative feelings and is induced by emotions.

Emotions, feelings and mood mark an object positive or negative with a mental image of the object and trigger a change of a subject's affective state. The context and content of the provided information in the decision situation trigger affect (emotions, feelings or mood) of different valence which leads to different affective states.

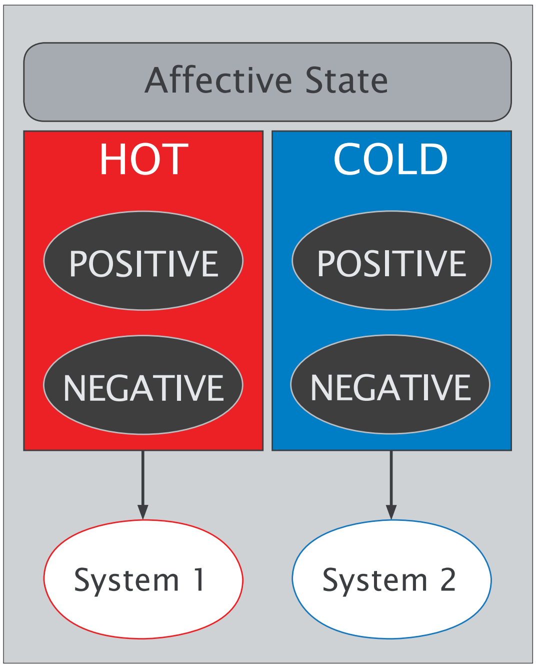

FIGURE 3.10: *The Characteristics of an Affective State*

As depicted in Figure 3.10, an affective state can either be positive or negative. Depending on how emotionally vivid and imaginable the information is presented, the subject enters a hot, i.e. exited affective state, or cold affective state. As discussed in Section 2.1, within psychology it is assumed that a subject forms his decision according to the processing of two systems, as proposed by Epstein (1994) and Sloman

(1996). The affective state is appropriate for triggering either System 1 or System 2. A hot affective state triggers System 1 and leads to a fast, unconscious processing of the decision. On the other hand, if the provided information is pallid and not very impressive, the subject stays in a cold affective state. This triggers System 2 and leads to slow, conscious and deliberate processing of the decision task. A subject may also enter a hot affective state, independent of the decision task, which may also lead to a change in preferences due to the processing by System 1. According to Schwarz and Clore (1983) this will not be the case when the subject is aware of the fact that he is in a hot affective state due to an incidental situation. If the affective state is cold, System 2 is triggered.

According to Loewenstein et al. (2001) I understand an affective state as follows:

Affective State: An affective state is characterized by a fourfold pattern. It can either be hot or cold. Each state can adopt two attributes: positive or negative. It changes spontaneously with the influence of feelings, mood and emotions.

System 1: The experiential or associative system bases its processing on affect. It operates pleasure-pain oriented and evaluates according to "What feels good?".

System 2: The rational or rule-based system bases its processing on cognition. It operates reason oriented and evaluates according to "What is sensible?".

As discussed in Section 2.1.2, psychophysiological research provides the know-how to identify emotions according to physiological reactions. Using this methodology, Antonio Damasio and Antoine Bechara developed the SMH introduced in Section 3.3.1, which suggests that somatic markers guide behavior in order to make advantageous decisions and prove this suggestion by showing that these markers express themselves as somatic states which can in fact be measured prior the decision making. This rather neuroscientific perspective underlines the psychological concept of mental images which, via emotions, feelings and mood, influence a subject's affective state and thus trigger either System 1 or System 2.

Somatic Marker: A somatic marker can either be positive or negative and serves as a start signal for a decision or a warning signal respectively and expresses itself in an emotion or feeling.

Somatic Marker are triggered by primary or secondary inducers and result in a somatic state.

Primary Inducer: A primary inducer is a direct reaction to a stimulus and results in an immediate emotion.

Secondary Inducer: A secondary inducer is a thought about the reaction to a stimulus and results in an expected emotion.

Somatic State: The body responses referred to a stimulus result in a somatic state which includes physiological reactions, such as changes in HR, SC and respiration.

The current state of neuroscientific knowledge has broadened during the last century. New technology, such as fMRI, allows for better understanding how the brain works and which parts of the brain are relevant in different processes. As discussed in Section 3.3, the following regions are known to be relevant for decision making: the Amygdala, the Prefrontal Cortex, the Striatum and the Insula.

Part I of this thesis first focused on the interdisciplinary approach used in this thesis and provided an introduction of the history and relevant methodology of economics, psychology and neuroscience. Further it provided a detailed review of the existing literature within the three disciplines. Based on this discussion the focus was on Research Question 1 and Research Question 2. The following Part II analyzes how economics, psychology and neuroscience deal with the relevant components of decision making under risk based on the above defined underlying concepts in order to develop the ADMF.

TABLE 3.2: *Selected Literature on Investigating the Neural Systems in (Economic) Decision Making*

(ES = Experimental Study, RE = Review, FW = Framework)

Author(s)	Problem	ES	RE	FW
Levin et al. (2012)	A neuropsychological approach to understanding risk-taking for potential gains and losses		X	
Mohr et al. (2010)	Meta study on neural processes of risk		X	
Symmonds et al. (2010)	A behavioral and neural evaluation of prospective decision-making under risk	X		
Christopoulos et al. (2009)	Neural correlates of value, risk, and risk aversion contributing to decision making under risk	X		
Martino et al. (2009)	The neurobiology of reference-dependent value computation	X		
Engelmann and Tamir (2009)	Individual differences in risk preference predict neural responses during financial decision-making	X		
Fox and Poldrack (2009)	Prospect theory and the brain		X	
Hsu et al. (2009)	Neural response to reward anticipation under risk is nonlinear in probabilities	X		
Tobler et al. (2009)	Risk-dependent reward value signal in human prefrontal cortex	X		
Knutson et al. (2008)	Nucleus accumbens activation mediates the influence of reward cues on financial risk-taking	X		
Rangel et al. (2008)	A framework for studying the neurobiology of value-based decision making			X
Coricelli et al. (2007)	Brain, emotion and decision making: the paradigmatic example of regret	X		
Gold and Shadlen (2007)	The neural basis of decision making			X
Knutson et al. (2007)	Neural predictors of purchases	X		
Seymour et al. (2007)	Differential encoding of losses and gains in the human striatum	X		
Tom et al. (2007)	The neural basis of loss aversion in decision-making under risk	X		
Weller et al. (2007)	Neural correlates of adaptive decision making for risky gains and losses	X		
Martino et al. (2006)	Frames, biases, and rational decision-making in the human brain	X		
Knoch et al. (2006)	Disruption of right prefrontal cortex by low-frequency repetitive transcranial magnetic stimulation induces risk-taking behavior	X		
Yacubian et al. (2006)	Dissociable systems for gain- and loss-related value predictions and errors of prediction in the human brain	X		
Gonzalez et al. (2005)	The framing effect and risky decisions: Examining cognitive functions with fMRI	X		
Kuhnen and Knutson (2005)	The neural basis of financial risk taking	X		
Matthews et al. (2004)	Selective activation of the nucleus accumbens during risk-taking decision making	X		
Breiter et al. (2001)	Functional imaging of neural responses to expectancy and experience of monetary gains and losses	X		
Knutson et al. (2001)	Anticipation of increasing monetary reward selectively recruits nucleus accumbens	X		

Part II

Framework Development

Chapter 4

Decision Making under Risk: Affect and Cognition

THE last chapter discussed the models and theories within economics, psychology and neuroscience which are considered to be relevant to gain a better understanding of the cognitive-affective interplay in order to develop the ADMF. The prospective outcomes, the probability distribution and a subject's risk attitude are the relevant components of decision making under risk which are analyzed within this chapter. The literature review in Chapter 3 further identified the underlying concepts in each discipline which are important for a profound understanding of decision making from the perspective of each discipline.

4.1 Evaluating Prospective Outcomes

4.1.1 Economics

The evaluation of prospective outcomes is, as derived from the discussion in Chapter 3, one of the three relevant components of decision making under risk. How does a subject assign value to a prospective outcome? Most of the decision situations a subject is actually facing, allow for the comparison of prospective outcomes in the sense of better, equal or worse. That is, a subject has a preference relation over all prospective outcomes. However, a preference ordering as the result of evaluating a prospective outcome does not allow for further interpretation of the prospective outcomes *value* for a subject which might in fact depend on several factors. Thus, it is not possible to make further calculations as for example calculate the expected value of a lottery. Thus, in economics it has become usual to assign a numerical value to each prospective outcome, a so-called subjective utility. As shortly introduced in Section 2.1.1, Bernoulli first introduced the concept of utility to evaluate a prospective outcome. The analysis of the St. Petersburg Paradox led him to the idea, that subjects in fact evaluate prospective outcomes according to a subjective value or utility for each prospective outcome. He proposed a utility function to explain a subject's choice behavior which is not a linear function but it is a concave evaluation of prospective outcomes. The concave shape of the utility function describes the decreasing marginal utility which results from the assumption that changes of wealth that are farther away from the initial endowment have less impact than changes that are close. That is, if you start with nothing and receive 10 Euros this is a lot. If, however, you already have 100 Euros, 110 Euros is not significantly more. Nowadays, in economics, it is most commonly accepted that the value, which a subject assigns to a prospective outcome, can be expressed by his subjective utility. That is, a utility function, e.g. the intrinsic utility $u(x)$, assigns a numerical value to each prospective outcome $x \in C$.[1] However, in the sense of the economic models of decision making under risk, the shape of the utility function expresses a subject's risk attitude and not, as in the sense of Bernoulli's initial idea, the decreasing marginal utility.[2]

Utility Function A function $u : C \to \mathbb{R}$ is a utility function representing the preference relation $\succeq$ if, for all $x, y \in C$,

$$x \succeq y \Leftrightarrow u(x) \geq u(y) \tag{4.1}$$

[1] Refer to Mas-Colell et al. (1995) for an introduction into utility functions.

[2] Refer to Section 4.3.1, where it is analyzed how economic models of decision making under risk deal with a subject's risk attitude.

A preference relation $\succeq$ can be represented by a utility function if it is rational, that is, if the preference relation is complete and transitive.[3] Utility is a key concept in economic theory to evaluate prospective outcomes. Utility can be ordinal or cardinal. Ordinal utility is identified by the uniqueness of the utility function up to increasing transformations. Cardinal utility is identified by the uniqueness of the utility function only up to linearly increasing transformations.[4] That is, for ordinal utilities, a subject's utility for a prospective outcome can only be interpreted with respect to better, equal or worse than another. It is not possible to draw any conclusion about how much better a prospective outcome is compared to another. Cardinal utility, however, assigns meaning to utility differences, which is necessary for mathematical operations on utilities.[5] The theories discussed in this section all have in common that, after the evaluation, a subject decides for the lottery which provides the highest overall utility, which is represented by the expected utility of its prospective outcomes.[6] As the utilities of the prospective outcomes are summed up and multiplied by their corresponding probability, it is obvious that a subject's utility is cardinal, as a numerical utility is depending upon the possibility of comparing differences in utilities, not between subjects but within one subject. Monotone transformations of utility functions, which are allowed for ordinal utility functions in the sense of Bernoulli, might for example transform a concave utility function into a convex function which may change a subject's expected utility and thus his preferences over lotteries.

[3]Refer to Section 3.1.1 for a short explanation of completeness and transitivity.

[4]If u(x) is a utility function representing a subject's preferences in an ordinal utility situation, any transformation $f[u(x)]$ of the utility function such that $f' > 0$, also represents his preferences. In a cardinal utility situation, only linearly increasing transformations of the form $au(x) + b$, where $b > 0$, represent the subject's preferences. These transformations are also called "affine positive" (Fishburn 1970).

[5]In economic literature there is a large debate on ordinal and cardinal utilities. This debate is often rather checkered. Refer to Niehans (1990) or Schumpeter (1954) for a detailed discussion of the history in the debate on the concept of utility.

[6]The expected utility of a lottery's prospective outcomes includes the corresponding probability distribution. The evaluation of a probability distribution in order to derive a decision is captured within Section 4.2, as I consider it to be promising to discuss the components of decision making separately. This section only captures the evaluation of prospective outcomes.

TABLE 4.1: *Cardinal Utility in Economic Models of Decision Making under Risk*

(EUT = Expected Utility Theory, PT = Prospect Theory, RT = Regret Theory, DT = Disappointment Theory, RDP = Reference Dependent Theory)

Theory	**Formal**	**Evaluation**	**RP**
EUT	$u : C \to \mathbb{R}$ $u'(x) > 0, u''(x) >,<,= 0$	absolute	no RP
PT	$v : C \to \mathbb{R}$ $v(0) = 0$ $v'(x) > 0, v'(x) < v'(-x) \forall x > 0$ $v''(x) < 0$ for $x > 0$, $v''(x) > 0$ for $x < 0$	relative	status quo
RT (Bell)	$\mu : C \times C \to \mathbb{R}$ $\mu(x\|y) = u(x) + v(u(x) - u(y))$ $\forall$ pairs x,y $u : C \to \mathbb{R}$ $v : \mathbb{R} \to \mathbb{R}$ $v(0) = 0, v'(\cdot) > 0, v''(\cdot) < 0$	absolute & relative	foregone asset y
RT (Loomes&Sugden)	$\mu : C \times C \to \mathbb{R}$ $\mu(x\|y) = u(x) + v(u(x) - u(y))$ $\forall$ pairs x,y $u : C \to \mathbb{R}$ $v : \mathbb{R} \to \mathbb{R}; v(0) = 0, v'(\cdot) > 0$	absolute & relative	foregone asset y
DT (Bell (simple model))	$\mu : C \times C \to \mathbb{R}$ $\mu(x\|\bar{x}) = u(x) + v(u(x) - \bar{x}))$ $\bar{x} = px_1 + (1-p)x_2$ $u : C \to \mathbb{R}$ $v : \mathbb{R} \to \mathbb{R}; v(0) = 0$ $v(u(x) - \bar{x}) = \begin{cases} d(u(x) - \bar{x}) & \text{if } x < \bar{x} \\ e(u(x) - \bar{x}) & \text{if } x > \bar{x}. \end{cases}$ $d,e \geq 0$ reflects degree of disappointment/elation	absolute & relative	expectation $\bar{x}$
DT (Loomes&Sugden)	$\mu : C \times C \to \mathbb{R}$ $\mu(x\|y) = u(x) + v(u(x) - \bar{x})$ $\bar{x} = px_1 + (1-p)x_2$ $u : C \to \mathbb{R}$ $v : \mathbb{R} \to \mathbb{R}; v(0) = 0$ $v'(\cdot) \geq 0; v'(\cdot) < 1$ $v''(z) > 0$ for $z > 0$ $v''(z) < 0$ for $z < 0$	absolute & relative	expectation $\bar{x}$
RDP	$\mu : C \times C \to \mathbb{R}$ $\mu(x\|r) = u(x) + v(u(x) - u(r))$ $u : C \to \mathbb{R}; u'(x) > 0$ $v : \mathbb{R} \to \mathbb{R}; v(0) = 0$ $v'(z) > 0, v'(z) < v'(-z) \forall z > 0$ $v''(z) < 0$ for $z > 0$, $v''(z) > 0$ for $z < 0$	absolute & relative	expectation

The question of how economic models and theories deal with the evaluation of prospective outcomes can be captured within two dimensions. First, how are the prospective outcomes evaluated per se, i.e. can the utility, derived from the prospective outcome, be interpreted absolutely or relatively? Second, if the prospective outcome is evaluated relative to a reference point the question arises what the reference point actually is.

Table 4.1 depicts the basic assumptions of a utility function as considered by the economic models and theories, introduced in Section 3.1. All these theories have in common that they use the concept of utility to assign value to a prospective outcome, however each theory implies different assumptions about the properties of the utility function and its formal implementation. The utility functions differ in the way *how* value is assigned to a prospective outcome. The evaluation can be classified in three categories. Value can be assigned absolutely, denoted by the intrinsic utility function u, relative to a reference point r, denoted by the reference-dependent utility function v, or by a combination of both, denoted by a modified utility function μ. This section discusses, on the one hand, the basic idea, similarities and main differences of the properties of the underlying utility function of each theory and, on the other hand, how each theory deals with the idea of an underlying reference point.

To evaluate a prospective outcome x absolutely, as in EUT, means that a subject only considers the intrinsic taste for the prospective outcome itself integrated into his asset. von Neumann and Morgenstern (1944) state that

> "The conceptual and practical difficulties of the notion of utility, and particularly of the attempts to describe it as a number, are well known and their treatment is not among the primary objectives of this work. We shall nevertheless be forced to discuss them in some instances [...]." (von Neumann and Morgenstern (1944), p. 8)

Von Neumann and Morgenstern use $u(x)$ to assign a numerical value to any prospective outcome $x \in C$. u describes a subject's preferences, that is, every subject has an individual intrinsic utility function. An intrinsic utility function is characterized by its shape, which can be concave, convex or linear.[7] That is, a subject's individual properties are only expressed by his individual u.

With PT, Kahneman and Tversky propose an alternative approach of decision making under risk.[8] They also use the concept of utility, yet they follow a rather different approach to identify how a subject assigns value to a prospective outcome. Other than within EUT, where value is assigned absolutely, PT assigns value to changes in wealth. That is, relative to a reference point, a prospective outcome is evaluated as a gain or a loss. Kahneman and Tversky introduce a reference-dependent utility function v which assigns a number $v(x)$ to each prospective outcome x. $v(x)$ can be interpreted as the utility difference of prospective outcome x and a reference point r. Thus, $v(x)$ reflects the subjective value of a prospective outcome. Kahneman and Tversky assume that, for a subject a loss looms larger than a gain, which is expressed by the assumption that $v(x)$ is generally steeper for losses than for gains. Further, the value function is concave for gains and commonly convex for losses.[9,10] To account for these basic assumptions of the value function, Kahneman and Tversky need to introduce the concept of a reference point, which serves as a benchmark to identify a prospective outcome of a lottery as a gain or a loss. The concept of a reference point is one of the major extensions compared to EUT and with this concept, it is possible to approach the observation that subjects show a different attitude towards risks in the domain of gains and the domain of losses and that losses loom larger than gains.

Kahneman and Tversky state, that

> "Our perceptual apparatus is attuned to the evaluation of changes or differences rather than to the evaluation of absolute magnitudes. When

[7]The shape of the utility function gives rise to the question of a subject's risk attitude. Refer to Section 4.3, where the concept of risk attitude is discussed in detail.

[8]Please refer to Section 3.1.2, where the basic assumptions of PT are discussed.

[9]The concavity for gains and convexity for losses of the value function further implies that subjects are risk averse in the domain of gains and risk seeking in the domain of losses. The concept of risk attitude is very important to capture how a subject deals with a risky decision, thus risk attitude is analyzed in more detail within Section 4.3.

[10]Figure 3.1 depicts a typical value function.

we respond to attributes such as brightness, loudness, or temperature, the past and present context of experience defines an adaptation level, or reference point, and stimuli are perceived in relation to this reference point." (Kahneman and Tversky (1979), p. 277)

However, the authors only propose a very ambiguous definition of how the reference point really is computed. In PT and its more generalized extension CPT, the reference point is exogenous. It is most commonly assumed that this reference point is the status quo. Yet, Kahneman and Tversky (1979) discuss three interesting situations which might result in a shift of reference and the resulting evaluation of prospective outcomes as gains or losses without a further specification of these points.

Expectations: There might be situations in which gains and losses are evaluated relative to expectations which differ from the status quo.

Adaption: The reference point might differ from the status quo if there are recent changes in wealth which have not yet been adapted.

Problem Formulation: The reference point might differ from the status quo if the decision situation is formulated in terms of final assets than in terms of gains and losses.

Based on the observations that subjects show several systematic anomalies in behavior and the resulting idea that subjects in fact evaluate a prospective outcome relative to some reference point, other theories of decision making under risk have been developed. RT was proposed simultaneously by Bell (1982) and Loomes and Sugden (1982). As discussed in Section 3.1.3, the basic idea of RT is, that a subject incorporates both, the prospective outcome x as well as the foregone prospective outcome y into his decision, with y being the reference point r. That is, the intrinsic utility of x is increased or decreased by a reference-dependent 'regret/rejoice' function v such that the modified utility μ assigns a value to each $x \in C$ with respect to the forgone outcome y. Bell, as well as Loomes and Sugden understand regret as the difference between the utility of what a subject actually gets ($u(x)$) and what he would have got if he had chosen differently ($u(y)$). The difference might be negative which induces a decrease of utility or positive which induces an increase of utility. That is, other than proposed earlier by Savage (1951), minimizing the maximum regret is not the only criterion how to decide. Yet, regret relative to the foregone asset is traded off against the absolute value of a prospective outcome. To be more precise, by incorporating regret into his decision, a subject compares all prospective outcomes of one lottery to all prospective outcomes of the other lotteries at choice. That is, a subject compares his utility of *what is*, to the utility of the situation that *might have been* if he had chosen the other lottery (given, that the same state of the world occurs). Then a subject's degree of experienced regret or rejoice depends only on the difference between the intrinsic utility of *what is* and the intrinsic utility of the reference point *what might have been*. In order to concentrate on the effect of regret and rejoice on the modified utility, $u(x)$ is assumed to be linear, such that $u(x) = x$.

The modified utility function μ expresses how $u(x)$ changes when it is compared to the (not chosen) prospective outcome y. The difference between $\mu(x|y)$ and $u(x)$ is interpreted as an increment or decrement of utility corresponding with the sensations of regret or rejoice (expressed by v). That is, while choosing the best lottery, a subject compares the prospective outcomes of the lottery with those of the reference point in the same state of world and not with prospective outcomes in other states of the world. Thus, the emotion of regret is expected if $v(\cdot)$ is negative, i.e. if the prospective outcome of the chosen lottery is smaller than the reference point, given a state of the world i. For example a subject has to choose between the two lotteries X and Y. He decides for X and then the *ith* state of the world occurs. Now he experiences the prospective outcome x_i. He knows that, if he had chosen Y, he would now experience the prospective outcome y_i. This leads to the feeling of regret or rejoice, depending on the fact if the *not chosen* prospective outcome is better or worse.

The RT as proposed by Bell (1982) and Loomes and Sugden (1982) are quite similar in their assumptions. However, the models differ in one major point: Bell's model only allows for the decision between two lotteries with two prospective outcomes. Loomes and Sugden provide a more general model which allows for the choice between two lotteries with n prospective outcomes. Both models require to incorporate regret as a reference point into a decision, thus a subject needs full information about all prospective outcomes.

DT by Bell (1985) and Loomes and Sugden (1986) were developed in addition to RT rather than as a competing model.[11] In fact, it is possible that a subject incorporates both, regret and disappointment, into his decision. However, for the sake of simplicity and the clear focus on the possible explanations of a subject's behavior, which integrating disappointment can provide, the authors discuss regret and disappointment separately. The basic idea of DT is, that a subject incorporates both, the prospective outcome x as well as his expectations $\bar{x}$ about the realization into his decision. His expectations serve as his reference point. $u(x)$ assigns a number to the subject's intrinsic taste of x. $u(x)$ is increased or decreased by a reference-dependent 'disappointment/elation' function v such that $\mu(x|\bar{x}) = u + v$ finally assigns value to each $x \in C$.[12] Bell (1985), as well as Loomes and Sugden (1986) understand disappointment as the difference between the intrinsic utility of what a subject actually gets ($u(x)$) and what he expected to get. The difference might be negative which induces a decrease of utility or positive which induces an increase of utility. As proposed within PT, a subject's expectations about the realization of a prospective outcome might induce a shift of the reference point away from the status quo. Thus, DT make more concrete assumptions about how to incorporate a subject's expectations into a decision. In order to anticipate disappointment (and its counterpart relief), a subject needs to have some expectations about the realization of the lottery. That is, a subject compares each lottery separately to his expectations of the other prospective outcomes. Thus, a subject compares his utility of *what is*, to the utility he *expected to*

[11] Please refer to Section 3.1.4, where DT is discussed. If it is not explicitly mentioned I refer to Bell's simple model in the rest of this thesis. The intuition of disappointment as a factor of utility is sufficient in the simple model.

[12] Note that, as in RT, intrinsic utility is assumed to be linear.

have. In DT the reference point is the expectation about the realization of a lottery and thus computed endogenous. As in RT, DT, proposed by Bell, only allows for the evaluation of lotteries with two prospective outcomes $x_1, x_2 \in C$, where it is always assumed that $x_1 > x_2$. DT, as proposed by Loomes and Sugden allows for a preference relation over lotteries with n prospective outcomes.

Table 4.1 depicts the properties of $\mu(\cdot)$ as assumed by Köszegi and Rabin (2006) for riskless outcomes and deterministic reference points.[13] This reveals, that up to the additive constant u, μ is equivalent to Kahneman and Tversky's value function v. However, and these are their main contributions, they extend their model by a stochastic component and they approach a subject's content and context sensitivity with respect to the properties of μ (Köszegi and Rabin 2007).[14] RDP allows the reference point to be stochastic. That is, a subject compares a prospective outcome x to an uncertain reference point represented by the Lottery Y with probability distribution G. Then, the subject's utility is given by the weighted modified utility $\mu(x|r)$ over all reference points, such that:

$$U(x|Y) = \int \mu(x|r) dG(r) \tag{4.2}$$

That is, a subject who decides according to the model of RDP compares a prospective outcome x to what he thinks might occur on the basis of his expectations. With their model of RDP, Köszegi and Rabin adopt the idea that expectations in fact play a role in decision making under risk. The idea, that expectations are somehow determining the reference point is similar to DT. Yet, the main difference to DT is first, that the reference point is stochastic and second, that the authors use an equilibrium concept as solution how to evaluate a lottery.[15] That is, their model requires consistency of expectations and choice. One important question, which they address, is how do sub-

[13] Please refer to Section 3.1.5, where the model of RDP is discussed.

[14] As they mainly approach context sensitivity by analyzing reference dependency of risk attitudes, I discuss this issue in more detail within Section 4.3.1.

[15] Please refer to Section 4.4, where I discuss how the utility, assigned to a prospective outcome, will be incorporated into the overall utility of a lottery.

jects react to deviations from their reference point, and a second interesting question is: what is the reference point? They argue that the reference point might actually be the status quo if a subject expects to maintain the status quo, but there might be several circumstances leading to expectations different from the status quo. That is, Köszegi and Rabin (2006) propose on page 1134, that a subject's "reference point is the probabilistic beliefs he held in the recent past about outcomes". When evaluating a prospective outcome as a gain or a loss, it makes a difference if a subject's reference point is the status quo or expectations. If a subject receives an unexpected amount of 5.000 Euros this will probably be assessed as a gain. If a subject expects to receive a gratification of 6.000 Euros but only receives 5.000 Euros, this may be perceived as a loss.

To sum up, as suggested by economic literature, the evaluation of a prospective outcome can be classified in one of three categories:

- Absolute evaluation with u
- Evaluation relative to a reference point with: v
- Combination of both with $\mu = u + v$

Based on the above discussed theories, the underlying reference point may be determined by either one or more of the following aspects:

- Status quo as assumed within PT
- Regret and rejoice, which are expected emotions of prospective outcomes
- Expectations of prospective outcomes are determined by the underlying probability distribution of a lottery and lead to disappointment or elation.

The discussion within this section reveals that economic models already incorporate the idea that the measurement of welfare might not be a one-dimensional evaluation but that other factors, such as expected emotions, might somehow play a role in the determination of utility. This section concludes that the assumptions within the discussed models all reveal important factors which provide that including affect into the evaluation of a prospective outcome seems to be a promising approach. This can be captured within four different aspects:

1. Kahneman and Tversky suppose that losses *loom* larger than gains.
2. A reference point might be based on *expectations* and expected *emotions* about the future
3. The discussion of how the economic models deal with the evaluation of a prospective outcome reveals that they all differ between gains and losses. However, the definition of what a loss actually is, is quite contentious. Compared to a reference point, receiving a positive prospective outcome might be *perceived* as a loss. This leads to the result that there is a difference between a real loss (compared to the status quo) and a relative loss (compared to *unaccomplished expectations*).
4. The evaluation of a prospective outcome is context and content sensitive.

The next section discusses how psychological and neuroscientific research sheds light on the role of affect while evaluating a prospective outcome.

4.1.2 Psychology

How does a subject psychologically assign value to a prospective outcome? As introduced in Section 2.1.2, psychology research on decision making comprises emotion theory and cognitive psychological as well as the idea of a cognitive-affective interplay. Hereby, the important role of affect in the formation of preferences is indisputable yet, there exist different approaches how to capture this influence. On the one hand, affective reactions result from the cognitive evaluation of a prospective outcome. This has been, as derived from the analysis of the economic evaluation of prospective outcomes in Section 4.1.1, integrated into economic research. This approach is a rather consequential perspective as subjects base their decisions on the consequences of a decision situation.

Loewenstein et al. (2001) state, that

> "[...] EU-type theories posit that risky choice can be predicted by assuming that people assess the severity and likelihood of the possible outcomes of choice alternatives, albeit subjectively and possibly with bias error, and integrate this information through some type of expectation-based calculus to arrive at a decision. Feelings triggered by the decision situation and imminent risky choice are seen as epiphenomenal, that is, not integral to the decision-making process." (Loewenstein et al. (2001), p. 267)

On the other hand, as introduced in Sections 2.1.2 and 3.2, there are psychological models and theories considering the Dual-Processing Theory which, contrary to the consequential perspective, suggest that immediate emotions directly influence a subject's evaluation of prospective outcomes.[16] Thus, this strand of literature suggests, that affective reactions are also a source of information on which subjects base their evaluation. Zajonc (1980) goes even further and states, that:

> "In fact, it is entirely possible that the very first stage of the organism's reaction to stimuli and the very first elements in retrieval are affective. It is further possible that we can like something or be afraid of it before we know precisely what it is and perhaps even without knowing what it is. And when we try to recall, recognize, or retrieve an episode, a person, a piece of music, a story, a name, in fact, anything at all, the affective quality of the original input is the first element to emerge." (Zajonc (1980), p. 154)

Integrating both approaches addressing affective meaning in the formation of preferences results in the idea of a Dual-Processing Theory as discussed in Section 2.1.2.

[16] As discussed in Section 2.2.2, immediate emotions can be integral as well as incidental to the concrete decision situation.

The result from the analysis of the economic evaluation of prospective outcomes in Section 4.1.1 reveals, that economic literature considers three categories how to assign value: absolute, relative to a reference point or a combination of both. This section discusses how affect influences the evaluation of prospective outcomes during decision making under risk in order to assign value to a prospective outcome and how the integration of affect can be put in the context of this economic categorization of utility functions. This section is structured as follows. It first discusses how the psychological theories assign an absolute value to a prospective outcome. Second, it discusses the psychological aspects of a reference dependent evaluation and third it identifies a correlation of the prospective outcomes properties and the need for a reference dependent evaluation.

Following the approach of Dual-Processing, the evaluation of a prospective outcome serves as a stimulus which elicits affective reactions expressed by different types of emotions, feelings or changes in a subject's mood.[17] Psychologists work with the concept of mental images to capture how subjects assign value to prospective outcomes in order to form preferences. Mental imagery is understood as the recall and re-experiencing of a personal affective event. That is, when making a decision, a subject considers the prospective outcomes which may elicit strong positive or negative emotional reactions. Therefore, as suggested within the RaI Theory by Loewenstein et al. (2001), images of losses evoke vivid negative mental imagery whereas images of gains evoke positive mental imagery. Within the AH, Slovic et al. (2007) make similar suggestions. They suppose, that representations of prospective outcomes in subjects minds are tagged to varying degrees with affect. In the process of decision making, people consult or refer to an object pool containing all the positive and negative tags consciously or unconsciously associated with these representations. That is, they refer to mental images that are marked by positive and negative feelings in order to build preferences.

To put this in the context of the cognitive-affective interplay, it is supposed that

[17]Please refer to Section 3.4, where the definitions of emotion, feelings and mood are summarized.

a prospective outcome which evokes vivid positive or negative mental imagery is considered to be *affective*. A prospective outcome, which doesn't elicit such strong mental images is considered to be *non-affective*. As discussed in Section 3.2 and 3.4, strong mental images lead to a hot affective state whereas benign mental images lead to a cold affective state.

The following example by Hsee (1996) illustrates the difference between an affective outcome and a non-affective outcome. If a subject is asked to evaluate a prospective outcome of 10.000.000 Euros, the challenge is not really hard. Probably everybody would evaluate 10.000.000 Euros as a very attractive gain because the joy about it elicits very vivid positive mental images how it would feel to have so much money. A prospective outcome of 10.000.000 Euros is affective. Yet, there are also prospective outcomes that do not elicit strong mental images. Consider for example the following situation. If a subject were to evaluate a prospective outcome of 9 Euros he will find it quite a hard challenge, because without any context he probably cannot tell how much he would like those 9 Euros. A prospective outcome of 9 Euros is non-affective. The situation changes as soon as there is some information added which makes it possible to compare the 9 Euros with something. If, on the one hand, the alternative outcome was 1 Euro, 9 Euros would probably have been perceived as quite attractive. If, however the alternative outcome was 100 Euros, a 9 Euros outcome would rather be perceived as a loss and not a gain.[18]

In order to adopt a categorization, which approaches a terminology that is more related to the evaluation of prospective outcomes, it will further be denoted that, according to their affectivity, prospective outcomes are easy-to-evaluate or hard-to-evaluate.[19]

Easy-to-evaluate: A prospective outcome is easy-to-evaluate if it elicits positive or negative emotions which trigger a mental image of how good or bad it feels to receive

[18]The affectivity or non-affectivity of a prospective outcome is not limited to monetary outcomes.

[19]I use the terminology of easy-to-evaluate and hard-to-evaluate on the basis of Hsee (1996). He derived these notions from a slightly different context, when he investigated preference reversals observed when alternatives are evaluated joint or separate. Yet, I expanded their applicability by several assumptions, these notions in terms of my understanding can still be applied in the original sense.

this outcome.

Hard-to-evaluate: A prospective outcome is hard-to-evaluate if it doesn't elicit strong emotions which trigger a mental image of how good or bad it feels to receive this outcome.

These deliberations indicate, that a prospective outcomes property of being easy or hard to evaluate corresponds with how a subject assigns value to it. A prospective outcome which doesn't carry strong affective meaning is hard-to-evaluate and thus needs a reference to compare it with, that is, in terms of economics, utility is assigned relative to a reference point. Hsee (1998) suggests that preferences are constructed ad hoc and depend on whatever comparison information is available at the time of the evaluation. This can also lead to the struggling result that a prospective outcome which is objectively worse than another is evaluated as better. He comes to this conclusion by discussing the following example. If a subject buys ice cream and gets a 8 cl cup filled with only 7 cl and his friend buys a 5 cl cup filled with 6 cl this may lead to a better evaluation of the smaller cup even though there is less ice cream. Subjects seem to use different information as their reference points. If the reference associated with the high-value option is better than the high-value option itself, and/or if the reference associated with the low-value option is worse than the low-value option itself, the less-is-better effect may emerge. These findings may possibly only occur if first, the prospective outcomes to be evaluated are non-affective, thus hard-to-evaluate and second, the prospective outcomes are quite easy to compare them to a reference (i.e. the cup size). Hsee (1998) refers to this fact as the domination by the relation-to-reference attribute. This relation-to-reference attribute can also be fleshed out by consideration of the following pictures.[20] Figure 4.1 depicts a grey, single-colored bar. If this bar, however is considered in comparison to a shaded frame, it seems that the bar was also shaded.

How to compute the reference point is an important question within this thesis. The economic models, discussed in Section 4.1.1, make several assumptions how it is com-

[20]These pictures are often used examples for visual illusions.

FIGURE 4.1: *Relation to Reference*

puted and the idea emerges that the reference point is computed ad hoc depending on the specific content and context of the decision based on a subject's expectations and expected emotions about the prospective outcomes.

Based on the analysis in this section, the possible determinants of the reference point are extended by the affectivity of the prospective outcomes.

- Status quo as assumed within PT
- Regret and rejoice, which are expected emotions of prospective outcomes
- Expectations of prospective outcomes, which are determined by the underlying probability distribution of a lottery and lead to disappointment or elation
- **Affectivity of the prospective outcomes**

The status quo, expected emotions and expectations of prospective outcomes as possible determinants are derived from the discussion of the economic models in Section 4.1.1.

Psychological deliberations, based on the models discussed in Section 3.2, extend this list in two dimensions. First, it is assumed that the affectivity of prospective outcomes, based on their properties, are relevant for the computation of a reference point. Second, interpreting all determinants on the basis of the Dual-Processing Theory (as discussed in Section 2.1.2) reveals some interesting results with respect to *how* a subject makes a decision under risk.

To consider the status quo as a reference point, as proposed by Kahneman and Tversky, is definitely very practicable in some situations. A subject who is struggling for his daily food will judge a gain of 9 Euros as great compared with the status quo. The status quo also seems to be important when a subject evaluates a potential loss. As discussed in Section 4.1.1, there might be a difference in the evaluation of a *real* loss and a *relative* loss.[21] In terms of loss aversion and the endowment effect there is evidence that subjects do not want to lose anything of what they already have, i.e. from their status quo.[22]

One would intuitively assume, that integrating expected emotions and expectations into a subject's utility function, as proposed within RT, DT and RDP, addresses the affective evaluation of a prospective outcome. However, regret, rejoice, disappointment or relief are expected emotions for which it is assumed that they do not change a subject's affective state and thus might not trigger affective processing.[23] Thus, as discussed by Loewenstein et al. (2001) expected emotions only address the cognitive evaluation of a prospective outcome.

Expectations about a prospective outcome are influenced by the subject's knowl-

[21] In neuroscience, there is a large body of research investigating the question of distinct neural systems processing gains and losses to give rise to the question why losses loom larger than gains. This issue is discussed in Section 4.1.3.

[22] Refer to Thaler (1980), who introduces the idea of the so-called endowment effect.

[23] Refer to Section 2.1.2, where the different categorization of emotions is discussed and Section 3.4, where the concepts, as applied within this thesis, are established.

edge and experience of similar situations. That is, a subject anticipates how it could feel if his expectations were not fulfilled. According to RaF, incorporating these expectations is also part of a cognitive evaluation.

However, additionally to such a cognitive, consequential analysis of the prospective outcomes, the affectivity of a prospective outcome elicits immediate affective reactions (e.g. immediate emotions such as: desire, greed, hope and fear) which result in mental images and therefore lead to different affective states. Affective prospective outcomes do not really need to be compared to a reference point. Yet, non-affective prospective outcomes are hard-to-evaluate without a reference point. Further, prospective outcomes may not be evaluated separately but by comparing the alternatives to each other. To be more precise, sometimes it is not even possible at all to evaluate a prospective outcome without a reference. That is, the reference point to which a prospective outcome is compared might change as the possible alternatives change.

To put this in the context of the Dual-Processing theory, this discussion summarizes as follows. Prospective outcomes can be characterized as affective and non-affective outcomes. Thus, a prospective outcome can be easy-to-evaluate or hard-to-evaluate. Based on this characterization, the evaluation of a prospective outcome is more or less based on the comparison to a reference point. The affectivity of a prospective outcome influences a subject's affective state which determines the processing system, System 1 or System 2.[24]

To sum up, when a subject evaluates a prospective outcome he assesses the following three properties:

- Condition of a prospective outcome
    - Monetary
    - Material

[24] Refer to Section 2.1.2 and Section 3.4, where the characteristics of System 1 and System 2 are discussed.

  - Non-material (emotional)
  - Imminent
  - Future

- The magnitude of the change

- The reference point, determined by
  - Status quo as assumed within PT
  - Regret and rejoice, which are expected emotions of prospective outcomes
  - Expectations of prospective outcomes, which are determined by the underlying probability distribution of a lottery and lead to disappointment or elation
  - Affectivity of the prospective outcome

The condition of a prospective outcome as well as the magnitude of the change determine its affectivity which is a relevant determinant of the underlying reference point.

4.1.3 Neuroscience

This section discusses how the brain reflects the cognitive-affective interplay while evaluating a prospective outcome during decision making under risk in order to identify how neuroscience contributes to the development of the ADMF.

Despite the large progress in the development of new technology, it is still not easy to test how the brain works. As discussed in Section 2.1.3, the usual approach is to identify those regions in the brain that are active during a specific decision task. With respect to what is already known about the function of such a specific brain area, its activation during the decision task is interpreted and conclusions about decision making are inferred. Thus, these results are dependent on the specific decision task and do not allow drawing conclusions about a more general function about how the brain works while making decisions. Yet, it allows (to a certain extent) for approving or rejecting specific hypotheses about how a subject processes a decision task. The more profound and detailed the understanding of the specific decision task is, the easier it is to control for some isolated variables. As derived from the discussion in Section 4.1.1 and Section 4.1.2, it is not quite clear yet what actually serves as a reference point while evaluating a prospective outcome and how it is computed. Thus, it is not easy to test for the reference dependent evaluation in the brain. However, it is possible to test for the processing of absolute gains and absolute losses. Additionally, in neuroscience there is much knowledge about those brain regions that process emotional input and those regions that process cognitive input.[25] To draw conclusions from those areas, known to be involved in emotional and cognitive processes may also give rise to the question of when stimuli are processed emotionally and when cognitively.

Considering the cognitive-affective interplay, Weller et al. (2007) propose a model which is based on the findings of the SMH. Within the SMH, it is assumed that decision making is guided by two separate neurological processes, both generating emotion. Bechara and Damasio (2005) assign the Amygdala to be responsible for processing primary inducers and the VMPFC for processing secondary inducers. Weller et al. (2007) suggest that, on the one hand, the first process generates an automatic, fast and affective judgment focused on immediate outcomes and that this judgement is triggered by a primary inducer. A primary inducer puts affective value to a stimulus and in neuroscience it is most commonly believed that this is processed by the Amygdala. On the other hand they suggest a second process which operates more deliberative, focused on emotional responses associated with anticipated outcomes and that this judgement is triggered by secondary inducers. A secondary inducer puts affective value to the thought of a stimulus or the imagination of a stimulus and in neuroscience it is most commonly believed that this is processed by the VMPFC. The VMPFC is also responsible for linking together working memory and emotional sys-

[25] Refer to Section 3.3, where the relevant neuroscientific studies are discussed.

tems. The authors propose that Amygdala-generated responses trigger the VMPFC. Based on the findings of Kahneman and Tversky and other behavioral research, that losses loom larger than gains, the authors conduct an experimental study to investigate these origins in the brain. The results of this experiment reveal that in fact there might be two distinct neural systems at stake, depending on the domain (gains or losses). They find that patients whose Amygdala is destroyed are not able to make advantageous decisions when gains are at stake. However this is not the case when losses are at stake. They suggest that for decisions involving losses there are redundant processes involving the Insula. They suppose that these redundant processes have evolved to minimize the possibility to disrupt the processing of prospective losses.

Gonzalez et al. (2005) propose a cognitive-affective tradeoff model which offers a possible explanation for the observation that subjects tend to avoid sure losses and also tend to avoid risky gains. The model differentiates between cognitive effort (for example the effort to calculate expected values of a lottery) to evaluate a lottery and the effort to identify the affective value of a lottery. It is assumed that a decision is based on the tradeoff between a good decision in the affective sense (what feels correct?) and a minimal cognitive effort. Subjects tend to avoid costly cognitive processing as well as outcomes which might result in feelings of displeasure. This cognitive-affective tradeoff is supposed to be easier in the domain of gains than in the domain of losses. Thus, the model supports the idea that losses are processed differently than gains. Using the "Asian Disease Problem" described by Tversky and Kahneman (1981), Gonzalez et al. (2005) intend to show why the compromise is easy to achieve in the domain of gains and more difficult in the domain of gains.

Positive frame:

If Program A is adopted, exactly 200 people will be saved.

If Program B is adopted, there is a 1 in 3 probability that all 600 people will be saved and a 2 in 3 probability that no people will be saved.

Negative frame:

If Program C is adopted, exactly 400 people will die.

If Program D is adopted, there is a 1 in 3 probability that nobody will die and a 2 in 3 probability that all 600 will die.

On the one hand, results of the underlying fMRI study reveal that the choice of a sure gain requires less cognitive effort than the choice for the risky gain. The authors suggest that the tradeoff between minimizing cognitive effort and minimizing affective effort (expressed by feelings of displeasure) is easy in the domain of gains. Thus, individuals execute a decision very fast and prefer the sure outcome. On the other hand, the tradeoff between minimizing cognitive effort and minimizing affective effort is more complex in the domain of losses because both, the sure loss and the lottery involve costs. Choosing the lottery, the subject needs to compute its expected value and an affective cost involved in the possibility of accepting a loss. Yet, the choice for the sure outcome involves a higher affective cost because the subject needs to accept a sure loss.

Within neuroscience, it is most commonly accepted that the Amygdala and the VMPFC are involved in the decision making process, whereas the Amygdala processes emotional stimuli, mostly aversive such as fear or anxiety and that the VMPFC mediates emotional and cognitive processing.[26] That is, the neuroscientific perspective of understanding the decision making process also supports the idea that decision making is based on two different processes. Further, research in neuroscience also supports the idea that gains and losses are processed differently, i.e. there might be different neural systems at stake when evaluating a gain or a loss.[27] With neuroscientific methods, most commonly fMRI studies, it is possible to identify those regions which are involved in the processing of prospective outcomes. Levin et al. (2012) provide a meta study to investigate if qualitatively and quantitatively different processes may be involved in risky decision making for gains and losses. They find that, in order to be able to answer this question, one has to take into account the point of

[26]cf. Weller et al. (2007), Bechara and Damasio (2005)

[27]cf. Tom et al. (2007), Yacubian et al. (2006), Seymour et al. (2007)

time when the fMRI data is collected. If it is measured before the decision is made, i.e. in the evaluation phase, most of the studies support the idea that there are different neural systems processing gains and losses. However if the data is collected during the anticipation phase,i.e. when a decision has already been made there is less support for the idea of different systems.

The results of the existing neuroscientific studies indicate that, in fact, affect influences the different perceptions of gains and losses because the driving positive and negative emotions are processed by distinct neural systems. Aversive emotions are mostly processed in the Amygdala which is, from an evolutionary point of view a very old part of the human brain. This can interpreted such as nature prepared humans to be able to detect danger and potential loss very quickly, i.e. to decide very fast between "fight or flight". Therefore it results in stronger reactions when a potential loss is at stake instead of a potential gain. It seems that evolution prepared humans to be able to spontaneously evaluate an absolute loss as well as a sure gain without the need of a reference point.

4.2 Probability Distribution

4.2.1 Economics

As discussed in Section 4.1.1, a subject assigns value to a prospective outcome with a subjective utility function. However, as this thesis considers decision making under risk, a subject will not obtain the prospective outcome which provides him with the highest subjective utility, yet each prospective outcome is associated to a probability with which it might be realized.[28] That is, in order to make a decision under risk, a subject needs to evaluate both, the prospective outcomes as well as the underlying probability distribution.

Approaching the probability distribution within decision making under risk allows

[28]Refer to Section 2.1.1, where I shortly introduce the history of probability theory and its use in economics.

for a discussion in two dimensions. First, there are several objective concepts which provide the possibility to compare lotteries with regard to its risk. Second, there are two approaches how to model a subject's integration of a probability into his evaluation of a lottery: linear or non-linear. This section will first introduce the objective concepts to approach the probability distribution. Yet, as the thesis concentrates on the subjective perspective of a decision making under risk, it skimps with this depiction. For a detailed discussion of these concepts please refer to Mas-Colell et al. (1995) (Chapter 6) and Laux et al. (2012) (Chapters 4 and 5). Second, it will go into detail analyzing the observation that subjects actually tend to weight probabilities non-linearly.

The expected value is a simple concept which allows to compare two lotteries because it is very easy to compute. $E(X)$ denotes the expected value of Lottery X. Lottery X is expressed by the probability distribution p and the prospective outcomes x. The expected value is the weighted average of the k prospective outcomes $x \in C$ of the lottery. The weights are the probabilities p assigned to these prospective outcomes.

$$E(X) = \sum_{i=1}^{k} x_i p_i \tag{4.3}$$

However, the expected value is not really an appropriate concept to compare lotteries because it does not take into account how risky a lottery is, i.e. how the prospective outcomes are spread.

The concept of the variance takes the risk of a lottery into account. The variance is described as the expected quadratic deviation from the expected value. Thus, the variance measures how far a set of prospective outcomes is spread out. A variance of zero indicates that all the values are identical. A non-zero variance is always positive. A small variance indicates that the prospective outcomes of a lottery tend to be very close to the expected value. A high variance indicates that there is a great spread from the expected value and from each other.

$$Var(X) = E[(X - E(X))^2] \tag{4.4}$$

These two concepts indicate, that there are two ways to compare probability distributions over prospective outcomes. The expected value of a lottery comprises the outcome level whereas the variance comprises the dispersion of outcomes. However, it is easy to construct examples which imply that these concepts often collide as for example a higher variance of one lottery coexists with a smaller expected value of the other. That is, the variance itself is as well not a sufficient concept to compare two lotteries.

The (μ,σ)-principle combines those concepts. According to this principle, μ refers to the expected value $E(X)$, as defined in Equation 4.3, and σ refers to the standard deviation which is the root of the variance $Var(X)$, as defined in Equation 4.4.[29,30]

Thus, in the sense of the (μ,σ)-principle Lottery X is evaluated as follows:

$$U(X) = E(X) - \alpha Var(X) \tag{4.5}$$

That is, the expected value enters the (μ,σ)-principle positively such that subjects prefer lotteries with a higher expected value and the variance enters negatively such that subjects prefer lotteries with a smaller variance. Here, $\alpha > 0$ weights the importance of the variance and thus represents the degree of a subject's risk aversion.[31]

There is one major point of criticism towards the (μ,σ)-principle. There are examples which show that the evaluation according to the (μ,σ)-principle can collide with First Order Stochastic Dominance (FSD).[32] This however, contradicts the assumptions of rationality as shown in the following.

[29] cf. Laux et al. (2012), Chapter 4

[30] Please note that, within this thesis $\mu(\cdot)$ refers to the modified utility of a prospective outcome x. However, as in the economic literature, the (μ,σ)-principle is a well known principle, I abstain from changing its notation within this section.

[31] Refer to Section 4.3.1, where the concept of risk attitude is discussed.

[32] For an example cf. Laux et al. (2012)

The concept of the stochastic dominance takes into account, that, as mentioned above, there are lotteries which cannot be evaluated according to their expected value and their variance: FSD and Second Order Stochastic Dominance (SSD).[33] FSD evaluates a lottery according to its prospective outcomes. A lottery dominates another in the sense of FSD if it tends to result in higher prospective outcomes.

FSD Given two lotteries X, Y with the distribution functions H, G. Then X stochastically dominates Y ($X \succ_1 Y$) in the sense of FSD if:

$$\forall x : G(x) - H(x) \geq 0 \tag{4.6}$$

That is, Lottery X dominates Lottery Y in the sense of FSD if all subjects, who are rational in the sense of Neumann and Morgenstern, prefer Lottery X over Lottery Y. Thus, FSD is an appropriate concept to compare probability distributions over prospective outcomes. However, FSD is not suitable to compare every probability distribution.

SSD evaluates a lottery according to its risk. A lottery dominates another in the sense of SSD if it contains lower risk.

SSD Given two lotteries X, Y with the distribution functions H, G. Then X stochastically dominates Y ($X \succ_2 Y$) in the sense of SSD if:

$$\forall x : \int_{-\infty}^{x} (G(x) - H(x))dx \geq 0 \tag{4.7}$$

Lottery X dominates Lottery Y in the sense of SSD if all subjects, who decide rational in the sense of Neumann and Morgenstern and who are risk averse, prefer X over Y. However, this concept is not appropriate for all subjects. To evaluate a lottery according to its risk requires assumptions about a subject's risk attitude as every subject seems to perceive risk differently. That is, a subject who prefers lotteries in the

[33]cf. Mas-Colell et al. (1995), Chapter 6

sense of SSD is risk averse.[34] FSD always implies SSD but not vice versa. However, Stochastic Dominance does not necessarily represent a total ordering: there exist pairs of lotteries, neither one stochastically dominates the other, yet they are not equal.

The above described concepts objectively compare two lotteries (given by their probability distribution over a set of prospective outcomes). All these concepts are different to some extent as they consider the riskiness and the prospective outcomes of a lottery differently (if at all). Yet, they have in common, that it is assumed that a subject considers each given probability linearly.

Besides one exception, the economic theories discussed in Section 3.1 follow the expectation principle which claims that the utility of a lottery is linear in the underlying prospective outcome probabilities. Nevertheless many of them are aware of the evidence that subjects do not weight probabilities linearly.

Köszegi and Rabin (2007) state that:

> "For simplicity, we abstract from nonlinear decision weights: given a (stochastic or deterministic) reference point, a stochastic wealth outcome is evaluated according to its expected reference-dependent utility. Our model of how utility depends on beliefs could be combined with any theory of how these beliefs are formed. As an imperfect but at the same time disciplined and largely realistic first pass, we assume that a person correctly predicts her probabilistic environment and her own behavior in that environment, so that her beliefs fully reflect the true probability distribution of outcomes."(Köszegi and Rabin (2007) p. 1048)

Instead, there is evidence that subjects tend to underweight large probabilities and overweight small probabilities, which for example manifests in the certainty effect on the one hand and simultaneous gambling and insurance purchasing on the other hand.[35] Kahneman and Tversky (1979) take these findings into account and introduce

[34]The economic concept of a subject's risk attitude is discussed Section 4.3.1.

[35]Refer to Section 2.1.1, where I shortly announced that it was Allais (1953) who first introduced the some examples to exploit the certainty effect. This effect has also been discussed by many authors

a weighting function $\pi(p)$, which associates decision weights to the given probabilities. The probability weighting function measures the impact of the probability of an event on the desirability of a lottery. It is not a linear function of probability, however, and decision weights are not themselves probabilities.

PT is a rather procedural approach, that is, other than normative theories which focus on the right prediction of choice, Kahneman and Tversky follow a descriptive approach to model a subject's behavior. As already mentioned in Section 3.1.2, it is one point of criticism towards PT that the non-linear weighting of probabilities leads to non-monotonicity.[36] Quiggin (1982, 1992) accounts for this problem by developing the Rank-Dependent Expected Utility Theory (formerly "A Theory of Anticipated Utility"). He introduces a probability weighting function which transforms the whole probability distribution over prospective outcomes rather than transforming each probability by itself. By presenting CPT, Tversky and Kahneman (1992) incorporate this type of weighting function and thus attend to the criticism of PT's non-monotonicity.

As depicted in Figure 3.2 in Section 3.1.2, PT implies an inverted s-shaped form of the probability weighting function, holding the following properties:

Endpoints The probability weighting function is not continuous in the endpoints. This reflects the unpredictability of behavior under conditions of extremely small or extremely large probabilities. In other words, the variance in the probability weighting function is not constant and is quite large in the region near 0 or 1.

Small Probabilities Small probabilities are overweighted. Experimental evidence suggests that this holds for probabilities smaller than 0.3.

Large Probabilities Large probabilities are underweighted.

from a descriptive as well as normative perspective (cf. Slovic and Tversky (1974), MacCrimmon and Larsson (1979)).

[36]To postulate monotonicity accounts for the fact that First and Second Order Stochastically Dominating lotteries should be preferred to lotteries which they dominate.

Slope The weighting function is very steep near the endpoints. That is, changes in probabilities near 0 or 1 have disproportionately large effects on the evaluation of lotteries. Subjects are very sensitive towards changes in probabilities near the endpoints. This captures the certainty effect. In the range of medium probabilities the weighting function is flatter, i.e. subjects are not very sensitive to changes in probabilities in this range.

Losses Capturing the modifications of CPT, the weighting function is slightly different for gain and losses.

Yet, the shape of PT's weighting function is not tested and estimated but rather inferred from the observed preferences over lotteries. There exists a wide range of literature with regard to the elicitation of the probability weighting function, both parametric elicitation as well as non-parametric elicitation.[37,38]

Based on the fact that each subject *subjectively* weights the given probabilities, the idea emerged, that there might exist some factors to influence probability weighting. Lattimore et al. (1992), Abdellaoui (2000), and Cohen et al. (1985) find that the prospective outcome domain, i.e. gains or losses, influences the weighting of probabilities. Etchart-Vincent (2004) finds that the magnitude of the prospective outcome as well influences the weighting of probabilities. Thus, approaching the idea of non-linear probability weighting during decision making under risk consolidates the idea that decision making is context and content specific.

The next section discusses the psychological side of this issue and shows how the properties of the weighting function can be explained by discussing the role of affect within the non-linear probability weighting.

[37]For a parametric elicitation cf. Tversky and Kahneman (1992), Prelec (1998), Camerer and Ho (1994). For a non-parametric elicitation cf. Wu and Gonzalez (1996), Abdellaoui (2000). Their basic tenet is the approval of an inverted s-shaped probability weighting function.

[38]Refer to Starmer (2000), who provides a very detailed literature overview and discussion of alternatives to the EUT and thus literature on the weighting of probabilities.

4.2.2 Psychology

The psychological models and theories discussed in Section 3.2 provide several approaches which explain when and why subjects weight probabilities other than linear. As derived from the discussion of the economic theories and models in Section 3.1, evaluating a lottery's probability distribution over the prospective outcomes is one of the three relevant components of decision making under risk. Kahneman and Tversky suggest that subjects seem to weight probabilities not linearly but by adding some subjective weight to an objective probability and take these findings into account by introducing an inverted s-shaped weighting function. However, they don't make any statements why subjects weight probabilities as they do.[39] Psychological research on non-linear probability weighting intends to explain the large jumps near the endpoints of the weighting function, i.e. considering very small and very large probabilities and the diminishing sensitivity towards probabilities within a mid-range of probabilities. The role of affect in the sense of the Dual-Processing Theory plays an important role here.

Rottenstreich and Hsee (2001) suggest that the shape of the weighting function is influenced by affect. That is, the weighting function will be more inverted s-shaped for lotteries involving affective prospective outcomes than for lotteries involving non-affective prospective outcomes. Subjects are more sensitive to probabilities with non-affective prospective outcomes than with affective prospective outcomes. The emotions which are of interest to explain subjective probability weighting are hope and fear. Hope and fear are immediate emotions which influence a subject's affective state.[40] The affective state of a subject is important for triggering System 1 or System 2. Hope and fear come to play in a fourfold pattern, depending on the domain of prospective outcomes (i.e. if gains or losses are at stake):

- Fear of missing a gain when probabilities are high

[39] Refer to Section 3.1.2 and Section 4.2.1 where the PT is introduced and discussed with respect to the subjective weighting of probability.

[40] cf. Loewenstein et al. (2001), Loewenstein et al. (2008), Slovic et al. (2007)

- Hope for avoiding a loss when probabilities are high
- Hope for winning when probabilities are small
- Fear of losing when probabilities are small

Within RAI, Loewenstein et al. (2001) suppose that immediate emotions are immediately elicited as reactions towards risks. Those immediate emotions may serve as an explanation for a subject's insensitivity to probability variations. The impact of changes in probabilities near the endpoints may be so high because emotions such as fear and hope in the face of decisions under risk have an all or none characteristic. They are sensitive to the possibility rather than the probability of negative prospective outcomes. When the probability of a prospective outcome turns greater than zero, the emotions of fear and hope appear. That is, whenever the probability of winning turns greater than zero there is a slight sparkle of hope arising and on the other hand, whenever there is only a really small possibility of losing, fear is arising. Further increase of probability however does not change the perception of the specific emotion and the mental image which has been elicited and therefore, further changes in probabilities have little impact on the evaluation of a lottery. That is, changes in probability within a broad mid-range have little effect on immediate emotions maybe because, as discussed in 4.1.2, emotions arise in part as a reaction to mental images. The mental image that arises when hoping for winning the jackpot of a state lottery is probably the same, no matter if the probability to win is 1/10.000.000 or 1/10.000. Affective prospective outcomes, elicit greater degrees of hope and fear and, therefore, larger jumps at the endpoints of the weighting functions. More precisely, as discussed in Section 4.1.2, prospective outcomes eliciting a hot affective state lead to more pronounced overweighting of small probabilities, more pronounced underweighting of large probabilities, and less sensitivity to intermediate probability change, thus a more pronounced inverted s-shaped weighting function than lotteries with non-affective prospective outcomes.

Considering non-affective prospective outcomes however, Slovic et al. (2004) suggest that there is a proportion or probability dominance when lotteries are evaluated. That is, subjects are more sensitive to changes in probabilities with non-affective prospective outcomes. This refers to lotteries where the associated prospective outcome doesn't elicit vivid mental images. The assumption of a proportion or probability dominance gives rise to the idea that subjects might develop mental images of prospective outcomes when probabilities are presented as relative frequencies instead of individual probabilities. This can be explained with the fact that subjects tend to neglect the denominator and image the numerator when probabilities are represented as relative frequencies. Slovic and Peters (2006) use the following example to imply the difference of this probability representation. When subjects are asked to decide if a psychiatric patient can be dismissed from the clinic, they might be provided with the following information: Patients with the same history as Mr. Jones commit an act of crime with a probability of 20% when they are dismissed. 21% of the subjects that were asked would refuse to let him go. If the information was provided differently in the way of: 20 out of 100 patients like Mr. Jones commit an act of violence when they are dismissed, 42% of the subjects refused to let him go. When the information is provided as an individual probability, this leads to the mental image of **one** individual. This individual can either commit an act of crime or not. This may lead to a slightly pallid image of Mr. Jones and thus, lead to a more analytic and cognitive evaluation of the lottery and therefore to a more deliberate over- and underweighting of probabilities near the endpoints and less diminishing sensitivity in the mid-range. In contrast, a frequency format elicits a mental image that includes **a number of** violent patients and is thus frightening and affective. This leads to fast and experiential processing and results in a more pronounced over- and underweighting and highly diminishing sensitivity.

Hertwig et al. (2004) make another interesting observation with respect to non-linear probability weighting. Subjects do not always overweight very small probabilities, but instead they sometimes underweight them. When this phenomenon occurs, subjects do not decide on the basis of numerically presented probabilities but instead they learn about the probabilities by experience. This leads to the suggestion that there may be a difference in behavior when subjects are provided with a description of probabilities instead of when they learn about probabilities through experience.[41]

The main result from the discussion within this section is, that subjects do not evaluate prospective outcomes and probabilities independently. Instead, the properties of a prospective outcome are important for the information processing system which is elicited.[42] If a prospective outcome elicits very affective mental images the subject will be in a hot affective state, either positive or negative. This leads to a neglect of probabilities besides the large jumps near the endpoints. The jumps are higher if losses are at stake, probably because losses evoke stronger emotional reactions and therefore a more affective evaluation.

If prospective outcomes are non-affective, the form of the weighting function is less pronounced. Changes in probabilities have more impact on the evaluation of a lottery and the shape of the weighting function is close to the identity line.

4.2.3 Neuroscience

Although there has been a lot of research investigating the shape of the weighting function, little is known about the underlying neural systems responsible for the nonlinear weighting of probabilities (Paulus and Frank 2006).[43] Research in psychology provides evidence that the affective nature of the corresponding prospective outcome influences how a subject weights the given probability. Neuroscience studies usually identify those regions which are critical in specific tasks and draw conclusions from other known functions of the identified areas to interpret the results. As discussed

[41] This observation is important in the context of capturing a subject's risk attitude. I further discuss this in Section 4.3.2.

[42] Please refer to Section 4.1.2 where the condition and the magnitude of the change of a prospective outcome are pointed out to be the characteristics of a prospective outcome, derived from the discussion of the relevant psychological models and theories.

[43] Fox and Poldrack (2009) provide a very good overview of studies considering the PT and the brain.

before, results from neuroscientific experimental studies depend on the decision task to be investigated.

Experiments in neuroscience consider the perception of risk from different perspectives. There are several studies that investigate which brain areas are active while processing risky decisions and how the brain might possibly integrate value and probabilities to compute an expected value.[44] However, there are only few (especially compared with the number of studies on risk and reward as a whole) studies which take into account that subjects tend to transform objective probabilities into a subjective decision weight, i.e. that subjects weight probabilities other than linear. What these studies have in common, is that they all try to reveal those brain regions which are active during a decision task considering the non-linearity of probability weighting. Neuroscientific studies reveal several brain regions to be involved in a non-linear transformation of probabilities. Paulus and Frank (2006) find that the Anterior Cingulate Cortex (ACC) shows different activation among subjects who display different degrees of non-linear probability weighting. Subjects with a stronger activation in ACC show a more linear probability weighting whereas subjects with a smaller activation level show a more non-linear probability weighting. The authors interpret these results with both, a cognitive approach and an affective approach. The ACC is supposed to be involved in the processing of various tasks: planning, conflict-monitoring, implementation of strategic processes to reduce cognitive conflicts, decision making, reward or goal expectancy.[45] It is also hypothesized that strong activation in ACC is related to behavior with focused attention whereas weak activation should be related to less focused attention. The revealed ACC activation pattern supports the idea that linear probability weighting is associated with the cognitive evaluation of a lottery and non-linear probability weighting is associated to the affective evaluation of a lottery.[46]

[44] cf. Christopoulos et al. (2009), Tobler et al. (2009), Mohr et al. (2010), Engelmann and Tamir (2009), Gonzalez et al. (2005)

[45] cf. Paulus and Frank (2006)

[46] Refer to Section 4.2.2, where this association is discussed from the psychological perspective.

Hsu et al. (2009) find that activity in the Striatum during evaluation of monetary gambles is non-linear in probabilities in the pattern predicted by PT, suggesting that probability distortion is reflected at the level of the reward encoding process. This underlines the results from psychological research, where it is suggested that the weighting of probabilities depends on the evaluation of the prospective outcome, as discussed in Section 4.2.2. The degree of non-linearity reflected in individual subjects' decisions is also correlated with striatal activity across subjects.

Berns et al. (2008) conduct an fMRI study in which subjects choose between two lotteries which result, with a given probability, in an electric shock. They find a sequence of several brain regions to be active during the decision task. The regions activated first are the Visual and Parietal Cortex. These regions are supposed to be important for perceptual accounts. That is, the non-linear weighting of probabilities might be interpreted as a result from the way how probabilities are presented visually. This underlines psychological research, which suggests that it is in fact important for the evaluation of a lottery, how probabilities are presented.[47] They suggest this question to be interesting for future research. Takahashi et al. (2010) find in a Positron Emission Tomography (PET) study, that lower striatal D_1 binding is related to non-linear probability weighting. They suggest that non-linear probability weighting which leads to gambling behavior or drug abuse might be modulated by dopamine transmission.

To learn which regions are involved in the non-linear weighting of probabilities helps to draw conclusions how and why subjects weight probabilities other than linear. However, neuroscientific studies often have very strong limitations. Fox and Poldrack state that each neuroscientific study is only as good as the underlying decision task. A better understanding of the decision making process itself and the associated economic, psychological and neuroscientific concepts might, on the one hand, provide an environment to develop decision tasks which can reveal a more detailed picture of how the brain works. On the other hand, a more detailed picture of the

[47] There is a difference if a probability is presented as a relative frequency or as an individual probability. Please refer to Section 4.2.2 where it is discussed how a subject deals with a probability distribution from a psychological perspective.

human brain provides the basis for a more profound analysis of the decision making process. That is, there exist a lot of questions which still are not close to be answered.

4.3 Capturing Risk Attitude

4.3.1 Economics

The introduced economic theories all assume a subject to evaluate each prospective outcome according to its subjective utility function and to decide for the lottery with the highest utility.[48] However, subjects show different attitudes towards risk. That is, the subject's preference relation over a set of lotteries is not only determined by the prospective outcomes and the probability distribution but also by his risk attitude. The basic idea behind risk attitude is, that a subject faces a decision between a lottery and the sure outcome of the lottery's expected value. Within EUT it is possible to express a subject's risk attitude by the curvature of the utility function. Based on EUT, the most prevalent definition of risk attitude is the following.[49] A subject is risk neutral if he is indifferent between a sure outcome and a risky alternative with the same expected value. In other words, the expected utility of Lottery X, is as high as the utility of the expected value of X, such that $E(u(X)) = u(E(X))$. Risk neutral subjects are modeled by linear utility functions. A subject is risk averse if he prefers a sure outcome to a risky alternative with the same expected value. In other words, the expected utility of Lottery X is smaller than the utility of the expected value of X, such that $E(u(X)) < u(E(X))$. Risk averse subjects are modeled by concave utility functions. A subject is risk seeking if he prefers a risky alternative to a sure outcome with the same expected value. In other words, the expected utility of Lottery X is higher than the utility of the expected value of X such that $E(u(X)) > u(E(X))$. Risk

[48] Please refer to Section 3.1, where the economic models and theories are discussed and Sections 4.1.1 and 4.2.1, where I analyze how economic models evaluate a prospective outcome and the underlying probability distribution.

[49] see for example Kreps (1990)

seeking subjects are modeled by convex utility functions. A real number $CE(X)$ is called Certainty Equivalent of Lottery X if $u(CE(X)) = E(u(X))$, that is, a CE implies the value for which the subject is indifferent between the utility of the CE and the expected utility of the lottery. A subject is risk neutral if $CE(X) = E(X)$ for all X , risk averse if $CE(X) < E(X)$ for all X, and risk seeking if $CE(X) > E(X)$ for all X. The Risk Premium (RP) is defined as $RP(X) = E(X) - CE(X)$. That is, RP describes the value which a subject is willing to pay in order to avoid risk. A subject is risk neutral if $RP(X) = 0$, risk averse if $RP(X) > 0$, and risk seeking if $RP(X) < 0$.

In economics, it is most commonly assumed that subjects are risk averse. Raiffa (1968) states that:

> "Studies of utility commonly make hypotheses about properties of the utility function that should hold for "most people." These studies generally assume that people are risk averse in monetary gambles and for the extent of their risk aversion (Pratt) to decrease as they become wealthier." (Raiffa (1968) p. 91)

As mentioned above, risk aversion is a subject's objection to accept a lottery with an uncertain outcome rather than another lottery with a more certain, but possibly lower, expected outcome. For example, a risk averse subject will put his money into a bank account with a sure but small interest rate, rather than into a stock where there might be a much higher interest rate but also the risk of losing all the money. That is, if it is assumed that a subject is risk averse and rational according to EUT, two lotteries can objectively be compared according to their risk by the use of the concept of SSD.[50] The Arrow Pratt Measure of absolute risk aversion is given as follows:[51]

$$ARA(x) = -\frac{u''(x)}{u'(x)} \tag{4.8}$$

[50]Refer to Section 4.2.1, where the concept of SSD is introduced.
[51]cf. Arrow (1965), Pratt (1964)

If $ARA(x)$ is increasing with x, this displays an increasing absolute risk aversion. If $ARA(x)$ is decreasing with x, this displays a decreasing absolute risk aversion and if it is constant, this displays a constant absolute risk aversion. In economic experiments, a subject's risk attitude is usually tested with a risk aversion test by Holt and Laury (2002), which allows to measure the individual degree of a subject's risk aversion. This allows to control for possible influences of a subject's risk aversion during a laboratory experiment such as bidding and pricing tasks for example in auctions or by eliciting selling and/or buying prices for simple lotteries.

However, there is evidence that subject's do not only show risk aversion. Tversky and Wakker (1995) state:

> "Three clusters of phenomena reflecting risk attitude have challenged the descriptive validity of the classical theory. First, although risk aversion is prevalent, there are situations in which risk seeking is commonly observed. Gambling is a case in point. Second, there is a considerable body of evidence that preferences between risky prospects are not linear in probabilities. The certainty effect, demonstrated by Allais, is the best-known example of this phenomenon. Third, people's preferences depend not only on the degree of uncertainty but also on the source of uncertainty."(Tversky and Wakker (1995) p. 1255)

There are several approaches to capture mixed risk attitudes, which are not in line with EUT: theories introducing a decision weight (cf. PT, Tversky and Kahneman (1992), Quiggin (1982) as discussed in Section 4.2.1), theories introducing expected emotions as an additional attribute within the utility function (cf. RT and DT) and theories which differentiate the source of risk (cf. Tversky and Wakker (1995), Köszegi and Rabin (2007).[52]

[52] There exist many other attempts to explain risk attitude, see for example Yaari (1987), Gilboa (1987), Schmeidler (1989), Luce and Fishburn (1991). However, I don't go into detail with these approaches as they, to varying degrees, imply different assumptions of the probability distribution (e.g. subjective probabilities, ambiguity).

PT approaches risk attitude from two sides: First, the utility function which is inferred from the observation of subjects' behavior as discussed in Section 4.1.1, imputes a fourfold pattern of risk attitudes to a subject:

- Risk aversion in the domain of gains when probabilities are moderate/high
- Risk affinity in the domain of gains when probabilities are small
- Risk aversion in the domain losses when probabilities are small
- Risk affinity in the domain of losses when probabilities are moderate/high

Second, a probability weighting function, as discussed in Section 4.2.1, with an inverted s-shape is introduced. Tversky and Wakker (1995) argue that "[...] such a weighting function gives rise to fourfold pattern described above, under plausible assumptions concerning the value function."(p. 1257).

While PT introduces probability weights as well as a value function to approach mixed risk attitudes, RT approaches risk attitude with so-called regret aversion. With respect to the above mentioned pattern of risk attitude Bell (1982) states that:

> "It is also easy to explain such behavior in terms of regret. In a long odd situation where the potential payoff to gambling is great, the consequence with the largest regret is that in which you choose not to bet but hear that you would have won." (Bell (1982) p. 971-972)

To analyze risk attitude within RT, Loomes and Sugden (1982) consider two independent lotteries of the following form: $X = (x, p; \frac{-px}{1-p}, (1-p))$ and $Y = (0,1)$, with $x > 0$, $0 < p < 1$ and $E(X) = E(Y) = 0$.[53] That is, depending on p these lotteries can describe different situations. The subject decides between buying a tombola-ticket (Lottery X) or not (Lottery Y) or between buying an insurance (Lottery Y) or not (Lottery X). Depending on p, Lottery X comprises a high prospective outcome with small

[53]Bell (1982) considers slightly different lotteries, yet of the same structure.

probability (e.g. winning the tombola) compared to a small loss with high probability (not winning the tombola but having paid for the ticket) or a small prospective outcome with high probability (saved cost for not bought insurance) compared to an extremely negative prospective outcome with small probability (damage in case of no insurance). Since the expected value of X and Y is equal, observed shifts in preferences point to different risk attitudes. Applying that $u(x) = x$ the modified utility function is given with $\mu(x|y) = x + v(x - y)$.[54] With v being decreasingly concave it can be shown that $Y \succ X$ if $p > 0.5$ (risk aversion), $Y \prec X$ if $p < 0.5$ (risk affinity) and $Y \sim X$ if $p = 0.5$ (risk neutrality).[55] Mixed risk attitudes thus are consistent with RT. However, this only holds for constant marginal utility of a prospective outcome: $u(x) = x$. Implying u to be concave only allows for a prediction of risk aversion if $p \geq 0.5$. Bell (1982) even states that:

> "As [u] is made more and more concave, the decreasing marginal value of dollars is eventually sufficient to counteract the influence of regret and produce risk averse behavior even for low probability, high payoff bets." (Bell (1982) p. 972)

Within DT, risk attitude can be analyzed similar to RT. Here, subjects are assumed to be disappointment-averse and elation-loving. Bell (1982) models the influence of disappointment with the factor d and the influence of elation with the factor e with $d,e > 0$ such that $\mu(x|\bar{x}) = x + d(x - \bar{x})$ if $x < \bar{x}$ and $\mu(x|\bar{x}) = x + e(x - \bar{x})$ if $x > \bar{x}$.[56] Thus, he implies constant marginal utility. Within DT as proposed by Bell, risk attitude is strongly depending on the individual attitude towards disappointment and elation. If his experience of disappointment and elation is equally compelling in its intensity, such that $d = e$, they are traded off against each other such that the subject

[54] Refer to Section 4.1.1, where it is discussed how utility is assigned to a prospective outcome with respect to the different formal implementation of a utility function within the economic theories.

[55] Refer to Bell (1982) and Loomes and Sugden (1982) who both provide a detailed analysis of mixed risk attitudes.

[56] Refer to Section 3.1.4, where DT is introduced and to Section 4.1.1, where it is discussed how utility is assigned to a prospective outcome with respect to the different formal implementation of a utility function within DT.

is, due to constant marginal utility, risk neutral. If a subject suffers very much from experiencing disappointment but is quite less influenced by elation ($d > e$) he is risk averse, if he is very exited when he experiences elation but suffers not very much from being disappointed ($d < e$) he is risk-seeking. This implies a global risk attitude for every subject. This led Bell to introduce another assumption, which implies that the sensation of disappointment and elation depends on probability p. He considers the following lotteries. Lottery X' is given with $(\frac{1}{p}, p; 0, 1-p)$. It is assumed that disappointment from receiving 0 increases with p. Lottery Y' is given with $(1, p; \frac{-p}{1-p}, 1-p)$. It is assumed that elation from receiving 1 decreases with p. This implies that there exists a probability p^* (which can also be 0 or 1) such that a subject is risk averse if $1 > p > p^*$, risk neutral if $p = p^*$ and risk seeking if $0 < p < p^*$.

As discussed in Section 3.1.4, Loomes and Sugden (1986) introduce a more general idea of DT, as they do not imply any differences in the intensity of disappointment and elation such that $v(x - \bar{x}) = -v(\bar{x} - x)$ for all $x, \bar{x}$.[57] As they assume constant marginal utility and imply that $v''(z) > 0$ for $z > 0$ and $v''(z) < 0$ for $z < 0$, it can be shown that, using the same lotteries X and Y: $X = (x, p; \frac{-px}{1-p}, (1-p))$ and $Y = (0, 1)$, with $x > 0$, $0 < p < 1$ and $E(X) = E(Y)$, DT is consistent with mixed risk attitudes such that a subject does both, gamble where the probabilities to win are very low and insure against low probability losses. That is, v in the sense of Loomes and Sugden (1986) incorporates a subject's attitude towards disappointment and elation such that he is generally disappointment averse and elation loving. These attitudes implicitly lead to risk aversion for $p > 0.5$ and risk affinity for $p < 0.5$.

PT, RT and DT indeed allow for mixed risk attitudes in the sense of risk aversion, risk neutrality or risk affinity. It is mostly assumed that risk attitude depends on the domain of gains or losses (compared to the underlying reference point) and the given probability distribution, that is, risk attitude in the sense of PT and DT is content specific. As RT assigns value to a lottery by comparing it to the other lottery included

[57] Refer to Section 4.1.1, where it is discussed how utility is assigned to a prospective outcome with respect to the different formal implementation of a utility function within DT.

in the decision situation, risk attitude in the sense of RT is content and context specific. RDP goes one step further and specifically analyzes how the environment of a decision influences a subject's risk attitude, that is, in how far risk attitude is context specific.[58] RDP replicates PT's pattern of risk attitudes for immediately-resolved surprise modest-scale risks. However, considering modest scale risk, Köszegi and Rabin (2007) analyze two different contexts in the sense of decision environments to imply different patterns of risk attitude. First, they compare surprise risk (a subject did not expect the loss, which can also be a forgone gain) to situations in which a subject expected the loss and the possibility to insure it. They imply that a subject shows more risk aversion to expected risks than to surprise risks.

Second, they analyze risk attitudes towards expected risks as a function of how far in advance decisions are committed to. That is, risk attitudes regarding prospective outcomes that are resolved long after all decisions are committed to. This situation applies to most insurance decisions. The expectations, to which a decision's prospective outcomes are evaluated, are formed afterwards. Thus, the expectations incorporate the implications of the decision. RDP distinguishes between two solution concepts, suitable to model content and context specific risk attitude. UPE/PPE is applicable in situations where the prospective outcome soon realizes after the decision is made and CPE is applicable in situations with a long time span between decision and realization.[59] Thus, Köszegi and Rabin (2007) adopt the observation that subjects are sensitive to the source of risk within modest scale risk environments as follows:

> "We identify two implications of our model: a person is more risk averse when she anticipates a risk and the possibility to insure it than when she does not - always displaying first order risk aversion - and among such decisions regarding anticipated risk, she is more risk averse when she can commit to insure ahead of time." (Köszegi and Rabin (2007) p. 1049)

[58] Refer to Section 3.1.5, where RDP is introduced and Section 4.1.1, where it is discussed how RDP assigns value to a prospective outcome.

[59] Refer to Section 3.1.5

However, a subject's sensitivity towards the economic environment of the decision is restricted to situations with modest scale risk, that is, in situations where the reference dependent component of the utility function dominates the absolute component.[60] In situations with large scale risk, the absolute component dominates the reference dependent component and subjects show a different pattern of risk attitude. In other words, in situations with large scale risk, the reference dependent component of the modified utility function can become irrelevant in determining risk attitudes as the intrinsic utility can no longer be assumed to be linear anymore. Then, risk attitudes are mostly determined by u which corresponds to the classical notion of outcome-based utility. That is, for large scale risks, RDP reconciles risk attitudes corresponding to context unspecific classical economic theory. Thus, RDP models both, context specific and context unspecific risk attitudes.

Table 4.2 depicts the basic assumptions of a subject's risk attitude as supposed by the economic theories.

Remembering, that the affectivity of a prospective outcome predetermines the absolute or reference dependent evaluation of this outcome it seems to be promising to take a closer look at the role of affect within a subject's risk attitude to gain a deeper understanding of how the content and context influences the risk attitude.

4.3.2 Psychology

In the economic sense, a subject can either be risk neutral, risk averse or risk seeking. It is commonly assumed that a subject's risk attitude is given by nature and isn't influenced by any factors - integral or incidental of the concrete decision situation.[61] There is evidence however, that a subject's risk attitude will change in different situations. The core idea in psychology is that affect in fact "affects" a subject's risk attitude within decision making under risk. Integrating affect into the decision making pro-

[60] Refer to Section 4.1.1 where the classification of absolute and reference dependent evaluation is discussed.

[61] Please refer to Section 4.3.1, where the economic concept of risk attitude is introduced and discussed.

TABLE 4.2: *Risk Attitude in Economic Models of Decision Making under Risk*
(EUT = Expected Utility Theory, PT = Prospect Theory, RT = Regret Theory, DT = Disappointment Theory, RDP = Reference Dependent Theory)

Theory	**Risk Attitude**	**static**	**content specific**	**context specific**
EUT	risk neutral risk averse risk seeking	x		
PT	risk aversion for gains and risk aversion for losses		x	
RT (Bell)	mixed risk attitudes		x	x
RT (Loomes&Sugden)	mixed risk attitudes		x	x
DT (Bell)	mixed risk attitudes		x	
DT (Loomes&Sugden)	mixed risk attitudes		x	
RDP	modest scale risk: more risk aversion if risk is expected than surprising; if expected, more risk aversion if possible to commit ahead of time large scale risk: classical economic predictions		x	x

cess, especially by investigating the role of the cognitive-affective interplay, may help to explain when and why a subject's risk attitude changes and where this will lead to a change in preferences.[62]

This section identifies the content- and context-specific nature of risk attitude by discussing the role of affect in the sense of the Dual-Processing Theory in decisions under risk. It identifies possible factors, characterized by their different nature, which might be responsible for influencing a subject's risk attitude because they influence a subject's affective state.

The first question which needs to be answered here is: 'What are the determinants of risk attitude?' The second question is: 'What role does a subject's risk attitude play within the decision making process?' Considering the question of the determinants of a subject's risk attitude, it is assumed that these factors are defined by very different characteristics and attributes. Within the RaI Theory, Loewenstein et al. (2001) suggest that fear and anxiety (and thus a negative affective state) tend to favor cautious risk averse decision making whereas happiness and pleasure (thus a positive affective state) tend to favor risk seeking decision making. These issues have also been studied within the AH, where it is discussed how the differently communicated information affects a subject's risk attitude. If it says benefit is high, the positive affective state leads to more risk seeking behavior whereas the information, that a potential loss is high leads to a negative affective state which induces risk aversion.

Based on the deliberations within this section, the following factors to be influencing a subject's risk attitude ar suggested. These factors can be distinguished by their characteristics and are assigned to different categories:

- Direct relation to the decision task
  - Vividness (content)
  - Time course (context)

[62] Please refer to Chapter 2 for the details of the two-system based processing as proposed by Epstein (1994) and Sloman (1996).

  - Time pressure (context)
  - Experience (context)
- Individual properties of a subject
  - Experience
  - Cognitive ability
  - Evolutionary preparedness
- No relation to the decision task
  - Mood

The factors which are directly related to the decision task are all determined by the structure and presentation of the decision task itself. Vividness considers the way how a decision problem is presented. On the one hand it can contain pure numbers and pale facts. On the other hand the prospective outcomes and probabilities can be described as being rather vivid and imaginable. That is, the more vivid the description of a decision problem is, the more images and associations are released in a subject (Loewenstein et al. 2001). A prospective outcome presented as "many thousands road casualties" evokes more images and associations than a prospective outcome presented as "10 % higher rate in road casualties". In this case, this may lead to a more risk averse behavior because there is a negative affective state. Using an example by Epstein (1994), Slovic et al. (2007) show that the same is true for the way a probability is presented. Subjects are offered to receive a reward when they drawing a red jelly bean from an urn. They could choose between an urn with a proportion of 7 in 100 or 1 in 10. As most of the subjects chose the first urn Slovic and his colleagues suggest that these subjects are imaging the enumerator and neglecting the denominator. That is, 7 winning beans in the first urn seem to dominate 1 winning bean in the second urn regardless of the higher winning chance. This obviously leads to risk seeking attitude. Representations of risk in the form of individual probabilities

(10%) lead to relatively benign images whereas frequentistic representations lead to affective images.

Loewenstein et al. (2001) suggest that the time course of a decision task addresses the immediacy with which a prospective outcome is realized. A prospective outcome which is only realized far in the future might not elicit such strong emotional reactions as a prospective outcome which is realized immediately. That is, a subject may decide more risk averse if the prospective outcome will be realized very soon. This underlines the findings within RDP as discussed in Section 4.3.1.

Several decisions need to be made in a certain time span. If this time span is short due to the complexity of the task this may result in time pressure. Time pressure may influence decision making by changing the affective state. A higher level of arousal makes experiential, affective processes more salient than analytic processes (Finucane et al. 2000). Maule et al. (2000) report changes in strategies under time pressure although none of these changes are directly associated with risk taking. But there is a strong reliance between strategy effectivity and risk attitude. Risk attitude is not affected as long as the chosen strategy is successful in solving the task in the given time. If the strategy isn't appropriate, an increase in risk aversion is observable.[63] This might be due to a negative affective state.

Experience is a factor which needs to be considered in two different ways. Experience, as a factor which is directly related to the decision task, plays an important role in the distinction between decision from description and decision from experience. Decisions made from experience result in underweighting rare events contrary to decisions from description. According to the context of a decision this may lead to a change in a subject's risk attitude either towards more risk seeking or risk averse decisions. The available information relevant to the decision task may either be provided by description or is based on the subject's experience with similar decisions. Decisions from experience and decisions from description can lead to different behavior (Hertwig et al. 2004). Hertwig and his colleagues posit a very intuitive ex-

[63]For a good literature overview on time pressure research refer to Maule et al. (2000).

ample to explain how the different processing of experience and description results in different behavior: Why are doctors and patients often at odds with each other? Concerning the question of whether to vaccinate children or not doctors and parents base their decisions on different types of information. While most parents can only rely on the numbers and facts stated in newspapers or books, i.e. on description saying that one child out of 14.000 might experience seizure, doctors can also rely on their personal experience, which shows that in their career no child ever experienced seizure after vaccination. Tobler et al. (2009) state that there might be a difference in behavior when subjects rely on experience rather than description of a lottery. In the case of decisions from description, subjects overweight the probability of rare events, as described by PT. In the case of decisions from experience, subjects underweight the probability of rare events. That is, subjects may rely on relatively small samples of information and overweight recently sampled information which may cause the underweighting of probabilities in information sampled from experience.

In addition to the factors related to the decision task there are also factors which are individual properties of a subject, which may also influence the risk attitude. Experience as an individual property considers the experience of prospective outcomes. That is, a subject's experience of gains and losses in former similar decision tasks, as well as a subject's education and life experience can affect a subject's risk attitude. The image of a recently perceived gain or loss may elicit strong emotions which change the affective state. If the decision situation changes the affective state, because of emotional reactions towards the decision, this may lead to fast and unconscious changes in risk attitude. If a decision leads to a cold affective state, this may result in a change of the reference point which leads to a change in risk attitude in further decisions: experiencing an anticipated gain results in a change towards risk aversion and vice versa (Barkan and Busemeyer 1999). A subject's cognitive ability may also play a role as a factor influencing risk attitude. Dohmen et al. (2010) suggest that risk aversion may be related to cognitive ability. Evolutionary preparedness may help to explain why some decisions are made much more risk averse than others. Smoking and the abuse of other drugs, in the evolutionary sense, are considered as relatively young risks. This may explain why subjects are not able to take them into account.

It is also possible, that factors which are not even directly related to the decision task may influence a subject's risk attitude. Stress which is due to other circumstances may be misinterpreted and result in time pressure within the decision task. Porcelli and Delgado (2009) induce stress by putting a subject's hand in ice-cold water before the experiment. This affects the subject's risk attitude expressed by an increase in the reflection effect. That is, under stress due to ice-cold water, a subject decides more risk seeking in the face of losses and more risk averse in the face of gains. Consistent with dual process theories this might be explained with a hot affective state when subjects fall back to automatized reactions under stress instead of analyzing the task deliberately. This is supported by the FaI Theory by Schwarz and Clore (1983). According to this theory, a good or bad background mood may result in a change of risk attitude even though the mood does not belong to the decision task itself. However, if the subject is aware of its incidental affective state, there is no influence on the subject's risk attitude (Schwarz and Clore 1983).

Surely, the individual differences in subjects concerning how emotions and feelings are processed play an important role here. There might be subjects who react very strongly towards emotional triggers whereas there might be others who might stay cool in the same situation.

4.3.3 Neuroscience

As suggested in psychology, risk attitude may not be a static individual property but may be a context as well as content specific variable which is influenced by different factors. By using neuroscientific methods, it is possible to take a look at those brain regions which might be involved in processing risk preferences.[64] Research in

[64]Within neuroscientific studies considering a subject's risk attitude there are several appropriate methodologies. As introduced in 2.1.3 there is a long history in neurological studies of the brain with a development from very invasive methods to noninvasive methods.

neuroscience underlines the results from psychology, which suggests that a positive affective state leads to risk affinity and a negative affective state leads to risk aversion.[65] To date little is known about how the brain processes risk and individual risk preferences. However, it is suggested that risk attitude is a modifiable behavior that depends on right hemisphere prefrontal activity. Kuhnen and Knutson (2005) suggest that risk attitude may be driven by distinct neural circuits. NAcc indexes positive affective states. aINS respectively indexes negative affective states and activating one of these can lead to a shift in risk preferences. NAcc leads towards more risk affinity, aINS leads towards more risk aversion. NAcc is related to positive emotions such as the pleasure for anticipated reward which activates NAcc. aINS is related to negative emotions such as fear or anger.

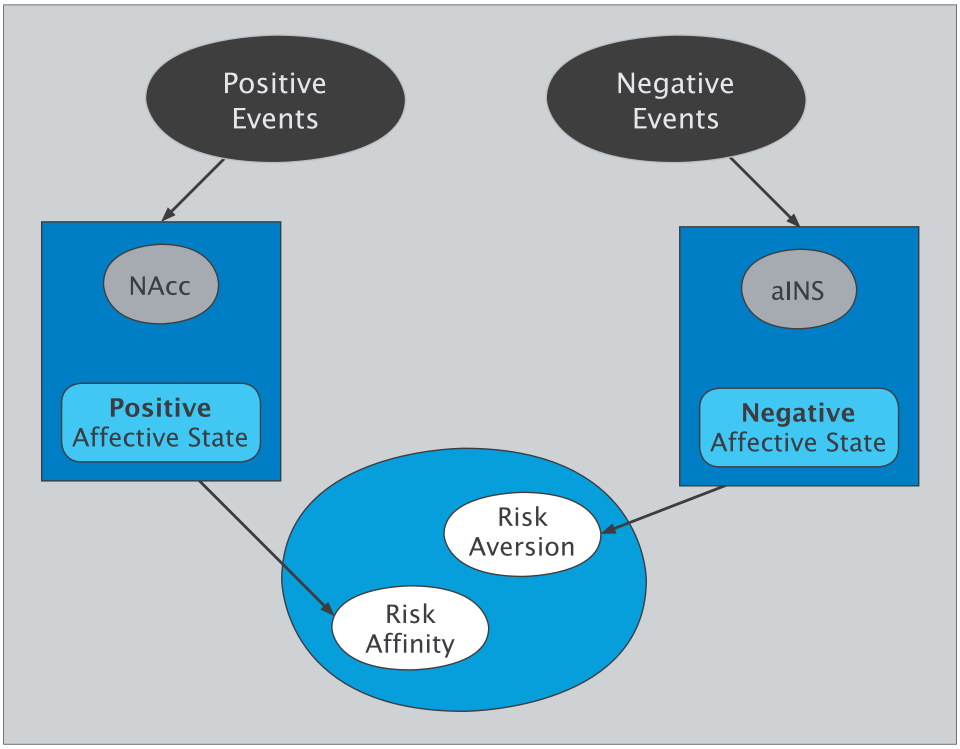

FIGURE 4.2: *Distinct Neural Circuits Drive Risk Attitude*

[65]Please refer to Section 4.3.2 for a discussion of the psychological research on risk attitude.

As discussed in 4.2.2, psychology research assumes that risk processing is influenced by affect. However, it is not yet fully specified how emotions are implicated in the decision making process. Mohr et al. (2010) use quantitative meta-analyses of fMRI studies on risk processing in the brain to investigate how risk processing is influenced by emotions. Underlining the results from psychological studies discussed in Section 4.3.2, they find that aversive emotions such as fear and anger are implicated in risk processing independent of the context. That is, also incidental emotions which are not related to the decision situation influence a subject's judgement of risk. Precisely, risk preferences may shift when subjects perceive fear or anger no matter if they are related or not to the decision task. Knoch et al. (2006) find that risk attitude is a modifiable behavior that depends on right hemisphere prefrontal activity. They use low frequency, repetitive Transcranial Magnetic Stimulation (rTMS) to disrupt the left or right DLPFC before applying a gambling task. They show that subjects display significantly riskier decision making after disruption of the right, but not the left, DLPFC. The possible reason for the more risk seeking decision making after right prefrontal stimulation is that happy individuals tend to overweight probabilities of positive and underweight probabilities of negative prospective outcomes. More precisely, risk seeking behavior after rTMS could be caused by an increase in happiness induced by rTMS. That is, positive emotions such as happiness may also be implicated in risk processing.

Engelmann and Tamir (2009) investigate the individual differences in risk preferences when making decisions. They separate the decision making process into three steps: the selection phase where the decision between two lotteries is made, the anticipation phase where a subject waits for the risk to be resolved while anticipating a prospective outcome and the outcome phase where the risk actually is resolved.

The difference between the anticipated and the realized prospective outcome forms the Reward Prediction Error (RPE) which "provides the basis for adjustments of future behavior and reward expectation" (Engelmann and Tamir 2009). They summarize that risk attitude is related to the decision strategy. That is, if a subject is driven

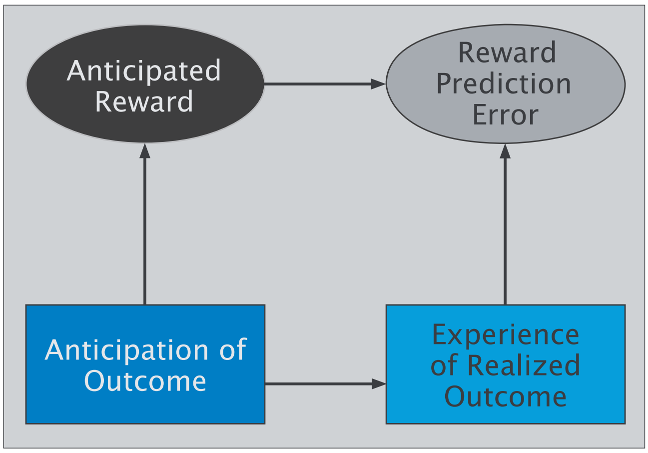

FIGURE 4.3: *Reward Prediction Error*

by affect, this manifests in more risk averse behavior, whereas if as subject follows a rather deliberate strategy this leads to more risk neutral decisions. These results are partly in accordance to the psychological findings and the above discussed assumptions. Yet it skimps that risk aversion is related to a negative affective state.

4.4 Aggregation and Implications

Chapter 4 structured the analysis of decision making under risk along two dimensions. First, the decision making process has been separated into three relevant components: evaluation of a prospective outcome, evaluation of a probability distribution and a subject's risk attitude. Second, each component, from the perspective of economics, psychology and neuroscience has been discussed with respect to the role of affect within decision making under risk.

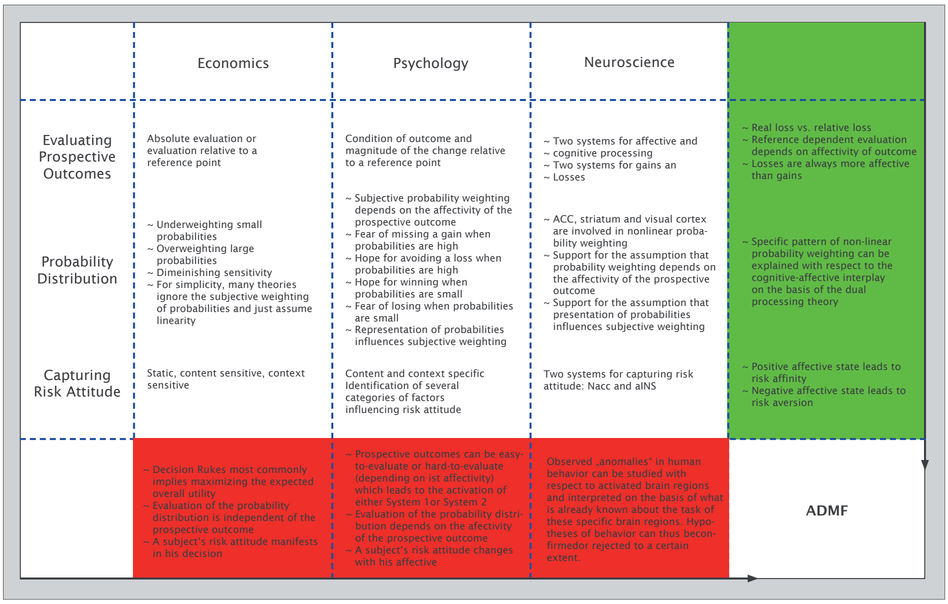

FIGURE 4.4: *Discussion*

Figure 4.4 provides the main results of the discussion within this chapter. The last row of this table, represented by red boxes, provides how each discipline actually puts the three relevant components of decision making together. In the economic literature it has not been usual to look at these components separately within decision making under risk. Thus, identifying the economical decision rules within each model, which actually integrate all three components of decision making, is no part of the "hard work". To put together how psychology and neuroscience deal with the three components of decision making however provides deeper understanding of decision making under risk as in these disciplines the focus of research in recent years has been more punctual on specific research questions rather than on decision making under risk as a whole. However, the main focus of this thesis is not to understand the results provided by each column of Figure 4.4 but to understand the conclusions that can be drawn from each row, represented by the green boxes. That is, how can psychology and neuroscience be integrated in the economical aspects of each component of decision making in order to finally put the results of each row together. This will finally result in the ADMF as discussed in Chapter 5.

Table 4.3 depicts the main results from the discussion of the economic models and theories. For each theory, it is first represented how a prospective outcome is evaluated, second if the underlying probability distribution is integrated linearly or not, third how the subject's risk attitude can be captured within the model, and fourth how these components are integrated into a decision rule. All theories have in common, that they compute an expected overall utility, yet they differ in the content and context on which they base a subject's utility function. A subject is context sensitive if he incorporates the context of a decision situation into his utility function and if the utility of a lottery changes with changes in the context. A subject's context sensitivity within a decision can be expressed by his utility function. A reference-dependent utility function indicates context sensitivity whereas an absolute evaluation with an intrinsic utility function indicates context insensitivity. A subject's degree of context sensitivity can also be expressed by his risk attitudes, such that risk attitudes can be context specific, content specific or static. Besides EUT, where utility is only context insensitive, all theories capture a subject's context sensitivity in the sense of a reference dependent utility function. RT, DT and RDP approach utility with respect to the fact that there is a modified utility function composed of a context insensitive intrinsic utility and context sensitive reference dependent utility. However, RDP is the only theory to approach the different impact of u and v on the overall utility with respect to context specific risk attitudes in large scale or modest scale risk situations.[66] As discussed in Section 3.1.5 Köszegi and Rabin (2006, 2007) introduce two equilib-

[66]Note, that RT as well models context specific risk attitudes. However, this is not for the purpose to capture the impact of different risk situations (different context) but context specific risk attitudes are implicitly given as a subject can only assign value to a lottery by incorporating the context of a decision (i.e. the other lottery).

TABLE 4.3: *Decision Rules of Economic Models of Decision Making under Risk*

POE = Prospective Outcome Evaluation, PD = Probability Distribution, RA = Risk Attitude, DR = Decision Rule

Theory	**POE**	**PD**	**RA**	**DR**
EUT	absolute	linear	risk averse for $u''(x) < 0$ risk seeking for $u''(x) > 0$ risk neutral for $u''(x) = 0$	$\max U(X) = \sum_i u(x_i)p(x_i)$
PT	relative	decision weight π	risk averse for $x > 0$ risk seeking for $x < 0$	$\max U(X) = \pi(p_1)v(x_1) + \pi(p_2)v(x_2)$
RT (Bell)	absolute + relative	linear	mixed risk attitudes	$U(X\|Y) > U(Y\|X)$ if $p\mu(x_1\|y_1) + (1 - p)\mu(x_2\|y_2) > p\mu(y_1\|x_1) + (1 - p)\mu(y_2\|x_2)$
RT (Loomes&Sugden)	absolute + relative	linear	mixed risk attitudes	$U(X\|Y) > U(Y\|X) if \sum_{i=1}^{n} p_i\mu(x_i\|y_i) > \sum_{i=1}^{n} p_i\mu(y_i\|x_i)$
DT (Bell - simple model)	absolute + relative	linear	mixed risk attitudes	$U(X) > U(Y)$ if $p[x_1 + e(x_1 - \bar{x})] + (1 - p)[x_2 + d(x_2 - \bar{x})] > p[y_1 + e(y_1 - \bar{y})] + (1 - p)[y_2 + d(y_2 - \bar{y})]$
DT (Loomes&Sugden)	absolute + relative	linear	mixed risk attitudes	$\max U(X) = \sum_{i=1}^{n} p_i\mu(x\|\bar{x})$
RDP	absolute + relative	linear	modest scale risk: more risk aversion if risk is expected than surprising; if expected, more risk aversion if possible to commit ahead of time large scale risk: classical economic predictions	UPE, CPE

rium concepts (UPE, CPE), which model how a subject should choose between two or more lotteries. Differentiating between these two solution concepts, RDP captures how subjects are sensitive to different decision contexts. Within the concept of UPE, the utility of the chosen lottery is compared to the utility of all other lotteries, given that the reference point is the chosen lottery. According to the authors, this solution concept is best to be applied when the time between the commitment to a decision and its realization is short. Within the concept of CPE, it is assumed that the reference point can be adapted. That is, the authors discuss the underlying time span as an aspect of a decision situation which determines a subject's choice expressed by context specific risk attitudes. They imply context sensitivity which is expressed by different risk attitudes within a different context.

Figure 4.5 depicts the psychological relations between the prospective outcomes and the probability distribution, the hereby triggered emotions, the associated implications for the affective state and the resulting change of a subject's risk attitude. The main result of the discussion of the psychological models and theories within this chapter is, that a decision may be processed by two systems. System 1 is the experiential or associative system which bases its processing on affect. It operates pleasure-pain oriented and evaluates according to "What feels good?". System 2 is the rational or rule-based system which bases its processing on cognition. It operates reason oriented and evaluates according to "What is sensible?". The processing of either System 1 or System 2 is triggered by a subject's affective state. It changes spontaneously with the influence of mood and emotions. A hot affective state triggers System 1 and a cold affective state triggers System 2. The affective state changes with the input of the different components of decision making and thus influences a subject's risk attitude.

Table 4.4 depicts the results from the neuroscientific discussion of prospective outcome evaluation, probability evaluation and the according risk attitude.

In order to develop the ADMF in the following chapter, the issue of affect has been discussed in this chapter, structured along the evaluation of prospective outcomes,

TABLE 4.4: *Neuroscientific Perception of Decision Making under Risk*

POE = Prospective Outcome Evaluation, PD = Probability Distribution, RA = Risk Attitude

	POE	**PD**	**RA**
Involved Brain Region	Amygdala VMPFC	ACC Striatum Visual Cortex	NAcc aIns
Coherence	primary inducer trigger Amygdala secondary inducer trigger VMPFC	the identified brain regions correlate with non-linear probability weighting	NAcc processes positive events aIns processes negative events
Interpretation	Cognitive-Affective trade-off during the evaluation of a prospective outcome	cognitive evaluation leads to linear probability weighting affective evaluation leads to non-linear weighting correlation of visual process underlines the importance of presentation of probability format	integral as well as incidental affective reactions induce a shift in risk attitude such that positive events lead to risk affinity and negative events lead to risk aversion

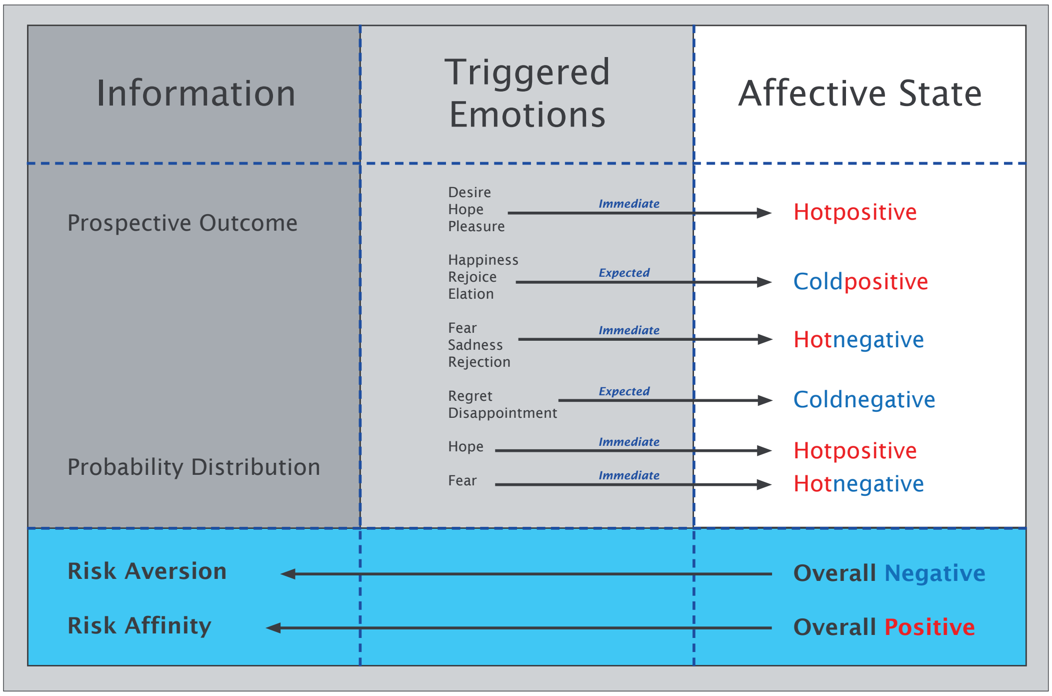

FIGURE 4.5: *Aggregation of Psychology*

the probability distribution and a subject's risk attitude. At this point, the horizontal discussion (see Figure 4.4) comes into the focus, where research in psychology and neuroscience ties in by integrating the role of affect within the evaluation of the decision making process.

The discussion of the economic evaluation of a prospective outcome in Section 4.1.1 concludes with the following points, which reveal how economics assigns value to a prospective outcome.

- Absolute evaluation with intrinsic utility u
- Relative evaluation with reference dependent utility v
- Combination of both with modified utility $\mu = u + v$

In economics, a subject's preferences are usually expressed by a subjective utility function to assign value to a prospective outcome. Economic theories differ in how this subjective utility is derived. It is either measured absolutely, relative to a reference point or with a combination of both. In order to highlight the influence of regret or disappointment, RT and DT imply $u(x) = x$, such that $\mu(x|\cdot) = x + v(x|\cdot)$. That is, they do not approach the different impact of u and v for a decision. RDP however approach different situations. They state that within situations with modest-scale risk, u can be considered linearly, within large-scale risk situations however, u cannot be assumed linearly. Instead its influence on the modified utility predominates the influence of v. In other words, in situations with large risk, the reference point becomes less important and the subject is less sensitive to any context. Yet, they only motivate this differentiation with respect to the risk of a situation and not with different characteristics of a prospective outcome. This is, where psychology ties in, suggesting that there are conscious and unconscious processes which associate a value to each prospective outcome of a lottery, which can explain when value is assigned absolutely or relatively. Prospective outcomes seem to differ not only in their valence (gains or losses) but also in their property of being easy-to-evaluate or hard-to-evaluate. Literature in psychology suggests that easy-to-evaluate prospective outcomes are affective and provide vivid mental images. They are therefore intuitively desirable or undesirable and don't need a reference to be compared to. Yet, hard-to-evaluate prospective outcomes need a reference point to be compared to, to get a clue how much a prospective outcome is actually worth to a subject. As suggested by the reference dependent theories, discussed in this thesis, there may be two types of losses to be relevant in the decision making process. The first is a real loss, in the sense that, compared to the status quo, the subject's wealth is reduced after the realization of the prospective outcome. This type of loss seems to be easy-to-evaluate. A real loss elicits a vivid mental image of how it feels to lose it and thus immediate emotions. The second type of loss is a loss compared to the expectations and beliefs of a subject. These types of prospective outcomes seem to be hard-to-evaluate and the computation of a reference point is an important step to evaluate such a prospective outcome. Neuroscientific research suggests that there are two different processes for evaluating gains and losses. This may explain why "real" losses generally seem to be evaluated more easily than gains and, in the same sense seem to loom larger, as implied by PT. The Amygdala is suggested to play an important role in processing losses. In the evolutionary sense, the Amygdala is a very *old* part of the brain. The Amygdala is known to be a processor of aversive emotions which help to identify and to recognize dangerous stimuli. The Amygdala helps to decide between fight or flight - very fast, unconscious and necessary to survive. This may give rise to the idea that, whenever the Amygdala is active, this may be with respect to easy-to-evaluate prospective outcomes and thus may lead to a hot affective state.

Besides the evaluation of a prospective outcome, a lottery needs to be evaluated according to its probability distribution. Economic literature suggests, that prospective outcomes and probabilities are evaluated independently during the decision making process. That is, a prospective outcomes properties do not influence a subject's perception of the given probabilities. However, based on several observations that subjects do not weight probabilities linearly, PT introduces a subjective probability weighting function, which shows that subjects tend to overweight very small probabilities, underweight high probabilities and that changes in probabilities only have little impact on the evaluation of a decision within moderate probabilities. As Section 4.2 discusses, the evaluation of probabilities and prospective outcomes in fact is not independent. Intuitively and confirmed by psychological and neuroscientific research, one assumes, that when making a decision, the characteristics of a prospective outcome are clearly not independent of the probability with which they are distributed. To be more precise, the evaluation of both seems to be dependent of the properties of the prospective outcome. An affective prospective outcome which evokes strong mental images is easy-to-evaluate. Further, such a prospective outcome seems to bring a subject into a hot affective state which leads to a more pronounced inverted s-shaped weighting function. The more affective a prospective outcome is, the more pronounced is the inverted s-shape of the weighting function. That is, there are large jumps at the endpoints describing highly overweighting and underweighting and the function is very flat in the middle, describing disproportional low impact of changes in probabilities to the evaluation of a lottery. That is, subjects tend to neglect probabilities when evaluating lotteries, except when the certainty of a gain or a loss turns to the possibility of not winning or maybe winning/not losing. As a potential loss seems to be more affective, the shape of the probability weighting function is more pronounced for losses than for gains. If the prospective outcome of a lottery is benign and pallid, i.e., non-affective, the jumps near the endpoints are moderate and there is larger impact of changes in probabilities to the evaluation of the lottery. This means that probabilities are taken into account cognitively when evaluating a lottery. Not only prospective outcomes can induce vivid mental images which lead to a hot affective state. If probabilities are represented as relative frequencies this may induce a more pronounced affective reaction. Neuroscientific research underlines these assumptions. As discussed in Section 4.2.3, neuroscientific studies reveal that cognitive evaluation leads to linear probability weighting whereas affective evaluation leads to non-linear weighting. Found correlation of visual processes underlines the importance of the probability format. To sum up, it is assumed that if subjects subjectively weight the probabilities, this weighting is more or less pronounced according to the affective state which changes with the affectivity of the prospective outcome. That is, the evaluation of the probability distribution and the resulting subjective weighting of the probabilities depend on the properties of the prospective outcomes.

When a subject evaluates a lottery, he evaluates the prospective outcomes, the probability distribution and thereby computes somewhat of a subjective utility function. However, subjects seem to react differently to the presence of risk. This manifests in a different risk attitude. Within EUT, it is assumed that risk attitude is a static individual property. A subject can either be risk averse, risk neutral or risk seeking, expressed by the shape of its utility function, as discussed in Section 4.3.1. Human behavior, however, shows that risk attitude is a context and content specific variable. PT, RT and DT allow for mixed risk attitudes which depend on the decision content.

RDP even reveals how, in this model, risk attitude is context specific. In psychology and neuroscience it is assumed that affect plays a role in influencing a subject's risk attitude. Psychological research reveals different factors influencing a subject's risk attitude. These factors can be classified in three categories: relation to the decision task, no relation to the decision task and individual properties, whereof factors with relation to the decision task can be further categorized as context specific and content specific. As discussed in Section 4.3.2, all these factors, to some extent, change a subject's affective state and thus influence his risk attitude. A positive affective state leads to more risk seeking behavior whereas a negative affective state leads to more risk averse behavior. Neuroscientific research underlines the psychological results and suggests that there are two different systems in the brain processing positive and negative affective states. NAcc is responsive to positive emotions such as pleasure and happiness. There is evidence that subjects decide more risk seeking if they are happy. aINS is responsive to negative emotions such as fear and anger. Subjects decide more risk averse if they are scared. Engelmann and Tamir (2009) state that risk averse subjects seem to base their decisions more on affect than risk neutral or risk seeking subjects. But the causality is not quite clear here. Risk averse subjects rely on System 1 which is triggered by a hot affective state. The reason for the hot state may be a negative emotion such as fear or anger. It may be more accurate to say that the activated System 1 leads to a risk averse decision than to say that a risk averse subject relies on System 1. In fact, it is important that only a hot negative state leads to a risk averse decision if System 1 is triggered. If the hot affective state is positive due to pleasure or happiness, System 1 is also triggered but leads to a risk seeking decision.

The following Chapter 5 develops a formal framework which integrates the affectivity of a decision situation into the computation of an expected overall utility of a lottery.

Chapter 5

A Framework for Affective Decision Making under Risk (ADMF)

THE review of the existing theories and models of decision making under risk in economics, psychology and neuroscience and the analysis how these disciplines deal with prospective outcomes, probability distribution and a subject's risk attitude show, that subjects base their decisions not only on cognitive but also on affective processing. It is suggested that there are two parallel processes which are activated depending on the subject's affective state. This chapter focuses on Research Question 4: "How can affective decision making under risk be described and analyzed in a formal decision making framework?" Thus, it provides the ADMF which reveals the human decision making process in its particular steps. By providing this ADMF, this Chapter introduces a standardized environment to identify the cognitive-affective interplay in decision making under risk and its implications as a testable environment of the relevant variables.

5.1 Requirements of the ADMF

The literature review in Chapter 3 shows that, on the one hand, economic approaches exist to structure decision making under risk with respect to some affective component.[1] These models, however, concentrate on expected emotions like regret or disappointment. Yet, expected emotions are part of the cognitive processing not the affective processing. Kahneman and Tversky address affective components, e.g. a subjective probability weight, without further specification of their source. On the other hand, the literature review shows that psychological and neuroscientific approaches exist to model the role of affect in decision making in detail.[2] These models indeed focus on immediate emotions, expected emotions and mood. Yet, there doesn't exist a structured approach to first specify the triggers of such affective reactions within an economic decision under risk and second its impact on a subject's affective state. Thus, the ADMF is required to structure the decision making process such that different types of emotions and mood, subsumed under the name affect, can be analyzed with respect to their triggers within the evaluation of a lottery.

The economic models account for the fact that the objective elements of each lottery are somehow subjectively perceived, by introducing a subjective probability weight and a subjective utility function and further allowing for different risk attitudes. Psychological models work with the concept of mental images to account for the fact that a subject transforms an objective lottery into a subjectively perceived lottery. Kahneman and Tversky describe this transformation as the editing phase from a rather cognitive perspective, Slovic describes this transformation as the AH from a rather affective perspective. Loewenstein indeed accounts for subjectively perceived components of the lottery as he models the influence of anticipated outcomes and subjective probabilities on the cognitive evaluation which is influenced by feelings. Yet, he doesn't account for any specification of how the objective lottery is transformed into the subjectively perceived components. Thus, the ADMF is required to structure the decision making process such that it can be analyzed how affect impacts the transformation of the objective lottery into the subjectively perceived components of

[1] cf. Kahneman and Tversky (1979), Bell (1982, 1985), Loomes and Sugden (1982, 1986), Köszegi and Rabin (2006, 2007)

[2] cf. Slovic et al. (2007), Finucane et al. (2000), Slovic et al. (2004), Slovic and Peters (2006), Loewenstein et al. (2001), Schwarz and Clore (1983), Schwarz (2011), Bechara and Damasio (2005), Gold and Shadlen (2002), Rangel (2008)

a lottery.

Research in psychology and neuroscience reveals that there are distinct neural systems processing the affective and cognitive evaluation of a lottery, elicited by the subject's affective state. However, neither economic nor psychological and neuroscientific theories provide a structured approach how to model the difference between the cognitive and affective evaluation of a lottery and its impact on the decision. Thus, the ADMF is required to structure the evaluation of a lottery such that it can be analyzed when and why a lottery is evaluated by the affective system or the cognitive system and to specify the different computation of an overall value of the lottery.

The economic models, discussed in Section 3.1, all have in common that a subject bases his decision between lotteries on the overall utility of a lottery. The overall utility of a lottery is given by the subjective utility of each prospective outcome, weighted by the corresponding probability influenced by the subjective risk attitude. Therefore, the analysis of the decision making process within each discipline has been structured along these three components of decision making under risk. The decision making process has been disassembled in order to shed light on those constituents, where it is possible and promising to integrate the idea that affect is also a crucial part of decision making under risk. Based on this analysis in Chapter 4, the economic decision making process is now reassembled, extended by the results of the psychological and neuroscientific analysis. This Chapter develops a framework which realistically models human decision behavior under risk. It allows to interpret the cognitive-affective interplay within each decision such that economic decision behavior can be modeled in a detailed standardized way in the sense of economics, psychology and neuroscience. To sum up, the ADMF should be structured such that:

- Economic decisions under risk can be analyzed by integrating psychological and neuroscientific components.
- Prospective outcomes, probability distribution and risk attitude can be analyzed separately as well as with respect to their interplay.

- Each trigger of the affective state can be identified and analyzed.
- It can be analyzed how affect is involved in the transformation of the objective lottery into a subjectively perceived lottery.
- The cognitive or affective computation of lottery's overall value can be analyzed and specified.

5.2 Development of the ADMF

The ADMF is based on a Decision Making Process which is composed of four phases which are briefly discussed in the following. The discussion then goes into detail with the analysis of the Evaluation Phase, as the role of affect and its interplay with cognition can best be analyzed within this phase.[3] The Evaluation Phase is analyzed graphically. Hereby, on the one hand, this section concentrates on the elements of the Evaluation Phase, as derived from the analysis within Chapter 4 and, on the other hand, it concentrates on the relations between these elements.

Figure 5.1 illustrates the four phases of the Decision Making Process: the Evaluation Phase, the Decision Phase, the Anticipation Phase and the Reaction to Realization Phase. The Evaluation Phase is the most important phase within this thesis and its components are illustrated in detail within the ADMF, which is developed within this section. Within the PT it is distinguished between the Editing Phase and the Evaluation Phase which are merged here as the Evaluation Phase. The Evaluation Phase is followed by the Decision Phase. In the Decision Phase, a subject actually makes a decision. So far, the phases of the Decision Making Process coincide with standard economic literature. The Anticipation Phase, as an important phase within the Deci-

[3] Surely, affect also plays a prominent role in the remaining phases of the Decision Making Process. Analyzing this impact on decision making under risk provides a large spectrum of future research. However, I believe that this research applies to sequential decision making in most cases. As the standard economic literature of decision making under risk usually considers one-shot decisions I did so too.

sion Making Process, is mostly suggested by neuroscientific literature.[4] During the Anticipation Phase, a subject anticipates the expected realization of the decision he made. That is, he is waiting for the prospective outcome which he expects to be realized. These expectations finally are either delivered or not. The Anticipation Phase is, as discussed in Section 4.3.3, important for further decisions as a subject's Risk Attitude correlates with the subject's reward prediction error. In the fourth and last phase the subject learns about the realization of his decision and reacts to it, consciously or unconsciously. This phase is also important from a psychological as well as neuroscientific point of view. The realization of a decision triggers immediate emotions, which in turn influence a future decisions (cf. the psychological and neuroscientific models discussed in Chapter 3 and analyzed in more detail in Chapter 4).

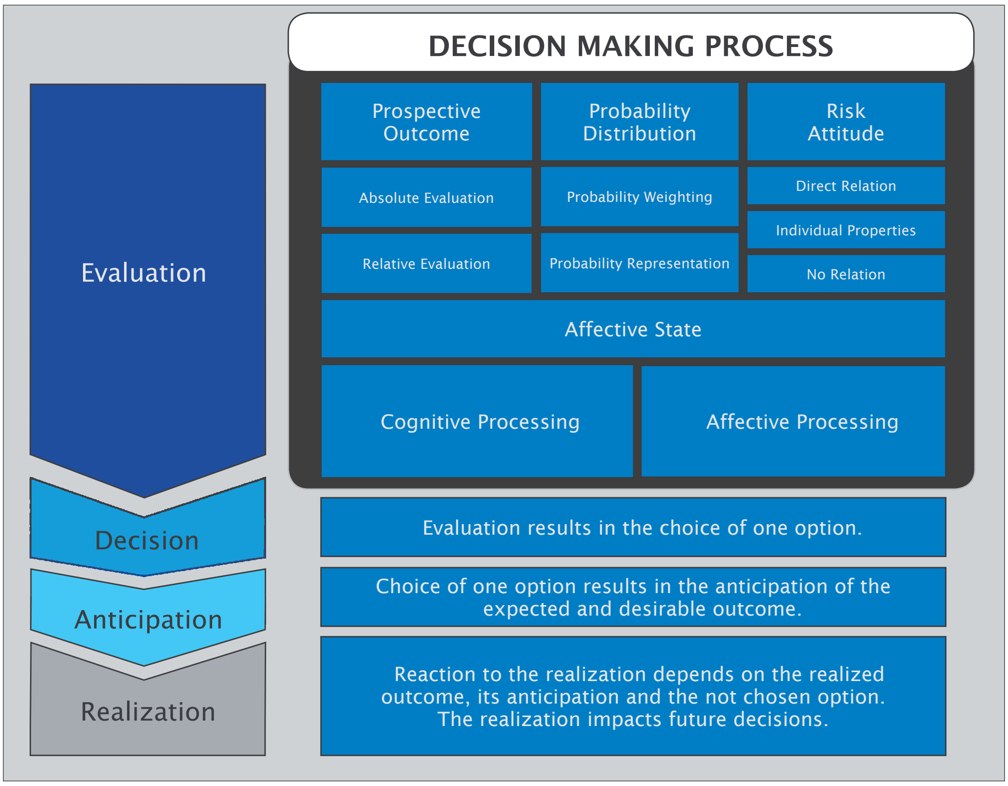

FIGURE 5.1: *The Decision Making Process*

[4] cf. Levin et al. (2012), Engelmann and Tamir (2009)

The following of this section concentrates on the Evaluation Phase in order to illustrate the ADMF in detail, analyzing each element and its corresponding relation to the other elements within the ADMF. Figure 5.2 depicts the ADMF and the relations between its elements. The ADMF represents a scheme which analyzes how an Overall Value is assigned to a Lottery.[5] Each Lottery is represented by a Probability Distribution over Prospective Outcomes. Within the ADMF this is depicted as the Objective Lottery (OL). Prospective Outcomes, the Probabilities and a subject's Mood trigger a change of the Affective State. The Affective State transforms the OL

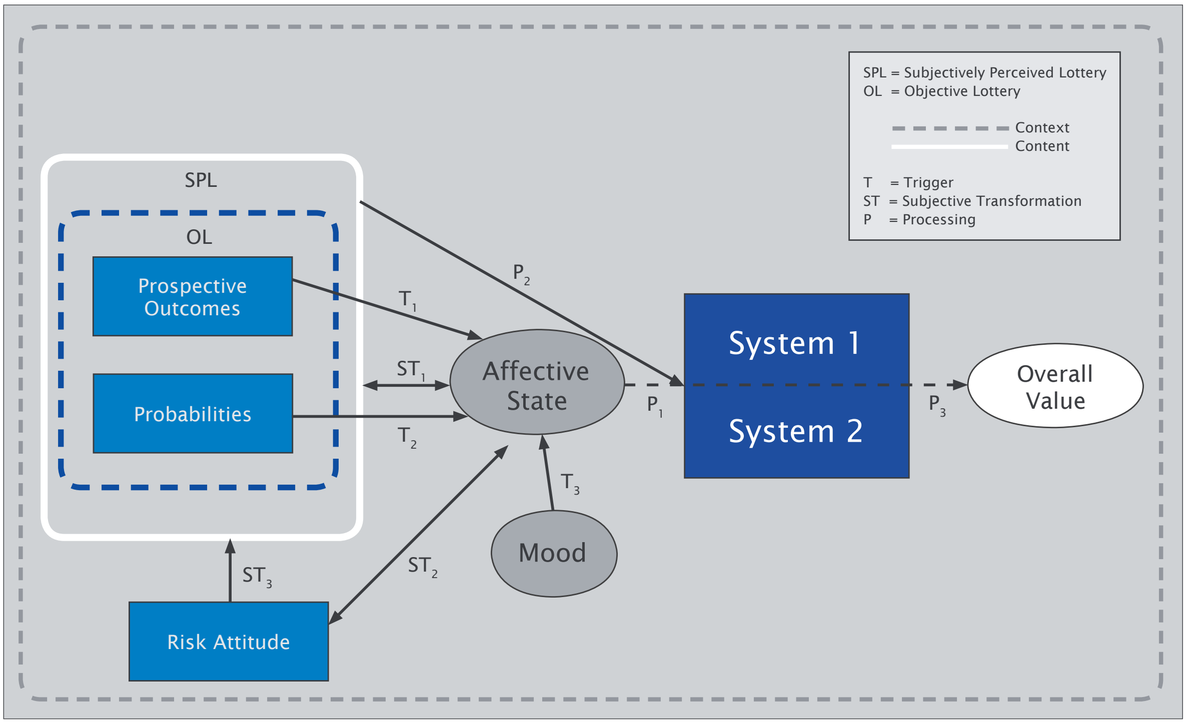

FIGURE 5.2: *The Affective Decision Making Framework (ADMF)*

[5]Within the ADMF, a subject is typically confronted with a decision problem of the following structure. A subject generally has to choose between two *lotteries*. A lottery can be any kind of problem with the following properties. A lottery consists of two *alternatives*. Each alternative results in an *outcome* with a given *probability*. The probabilities of the two alternatives of one lottery add up to one. The decision for a lottery results in an subject's *choice*. In the end a subject learns about the *realization* of his choice. The Decision Making Process, as it is described here, evaluates a lottery from a subject's perspective. That is, changes in any state of the world are not taken into account here.

into a Subjectively Perceived Lottery (SPL). The transformation from the OL into the SPL ends with an overall Affective State which finally triggers System 1 or System 2. Either one of these systems (however, as discussed in Section 5.3, both Systems are processing mostly parallel) computes an Overall Value of the SPL.

The sequence of action within the ADMF and its consequences can best be categorized in three steps.

1. **Trigger** (Prospective Outcome, Probability Distribution, Mood)

2. **Subjective Transformation**

3. **Affective or Cognitive Processing** of SPL: Overall Value

Trigger

The central element of the ADMF is the Affective State. It serves as a mediator during the Evaluation Phase. As discussed in Chapter 3, the Affective State can either be hot or cold, with each state being either positive or negative. On the one hand, the Affective State is triggered by immediate integral emotions.[6] The emotions are triggered by the representation of the elements of the OL: the Prospective Outcomes and the Probabilities. On the other hand, the Affective State is triggered by incidental emotions. Incidental emotions are immediate emotions which influence a subject's Mood and thus change the Affective State.

(T_1) Outcome Properties Relation (T_1) links a Prospective Outcome (as an element of the OL) to the subject's Affective State. That is, this relation describes how the properties of a Prospective Outcome trigger the Affective State.[7] Thus, the properties of a Prospective Outcome impact the intensity of the triggered immediate emotions. These emotions triggered by the imagination of achieving a Prospective Outcome

[6]Please refer to Section 2.1.2, where I shortly discuss emotion theories and possible definitions Section 3.4, where I summarize the underlying concepts used within this thesis.

[7]The analysis in Section 4.1.2 and Section 4.1.3 reveals, that from a psychological and neuroscientific point of view, Prospective Outcomes differ in their properties. Such properties are for example: monetary, material, non-material, imminent, future.

are either positive as desire, happiness, pleasure or negative as rejection, fear, sadness. The Affective State changes with the intensity of the triggered emotions. These emotions are expressed and experienced by vivid mental images about how it would feel to achieve this Prospective Outcome. Intense emotions which lead to vivid mental images trigger a hot (either positive or negative) Affective State. If, however, a Prospective Outcome doesn't trigger intense immediate emotions and thus there are only pallid, if at all, mental images about how it would feel to achieve this Prospective Outcome, the Affective state is cold (either positive or negative). A Prospective Outcome of 1 Million Euros triggers positive emotions. Then, a subject has vivid mental images about how it would feel to have 1 Million Euros. Thus, the subject is in a hot Affective State. A Prospective Outcome of 9 Euros does not trigger intense emotions. That is, a subject doesn't have vivid mental images about how it would feel to achieve this Prospective Outcome. This leads to a cold (either positive or negative) Affective State.

To sum up, Relation (T_1) describes a Prospective Outcome as a trigger of emotions which change the subject's Affective State.

(T_2) Probabilities Relation (T_2) links the Probabilities (as an element of the OL) to the subject's Affective State. That is, this relation describes how the given probabilities trigger the Affective State. As discussed in Section 4.2.2, probabilities can trigger immediate emotions. These immediate emotions, which are triggered with respect to high and small probabilities, can be represented in a fourfold pattern[8]:

- Fear of missing a gain when probabilities are high
- Hope for avoiding a loss when probabilities are high
- Hope for winning when probabilities are small
- Fear of losing when probabilities are small

[8]Please note how this pattern shows that it is not consequently given that the Affective State is positive if gains are at stake and negative if losses are at stake. Rather this pattern shows why a very desirable Prospective Outcome might be tagged with Fear. This issue is depicted within Relation ($ST1$), which describes how the OL is affectively transformed into the SPL.

Further, probabilities can be presented as relative frequencies or individual probabilities. A relative frequency carries more affectivity than the representation as an individual probability. With the representation as a relative frequency the subject tends to neglect the denominator and image the numerator. The difference between these two representation formats can best be understood with the example from Section 4.2.2. The potential criminality of a psychiatric patient can be represented with an individual probability: Patients with the same history as Mr. Jones commit an act of crime with a probability of 20% when they are dismissed. It can also be represented as a relative frequency: 20 out of 100 patients like Mr. Jones commit an act of violence when they are dismissed. When the information is provided as an individual probability this leads to the mental image of one individual. This individual can either commit an act of crime or not. This may lead to a slightly pallid image of Mr. Jones and trigger a rather cold Affective State. In contrast, a frequency format triggers a mental image that includes a number of violent patients and is thus frightening and affective and triggers a rather hot Affective State. However, there is no such thing like intuitive statistics. That is, as derived from the discussion in Section 4.2, subjects are not capable of evaluating slight changes in probabilities without a given context. To evaluate the Probability Distribution of a lottery a subject needs a context. This is captured within the Subjective Transformation which depicts how Probabilities are tagged with affective information.

(T3) Mood The Affective State also changes with the influence of a subject's Mood. The subject's Mood captures incidental emotions, that is, emotions which are triggered by factors not related to the evaluation of the lottery. As discussed in Section 2.1.2, the Affective State changes quite fast, whereas the Mood is a background emotional state extended in time, that can either be positive or negative.[9] The valence of the Mood influences a decision mediated by the Affective State. That is, a negative Mood triggers a negative Affective State and a positive Mood triggers a positive

[9]The FaI Model, introduced in Section 3.2, mostly concentrates on a subject's Mood and its implications on decision making.

Affective State.

Subjective Transformation

During the evaluation of a lottery, the OL is transformed into the SPL with the triggered Affective State playing the central role. That is, the OL is transformed such that there is **Subjective Perception** SP added to the objective factors. This information prepares the Lottery for the evaluation in the sense that the subject can answer the question: "How do I feel about the Lottery?"

(ST_1) Outcome - Probability - Dependency The Subjective Transformation tags the Prospective Outcomes and the corresponding Probability Distribution with affectivity such that the SPL is prepared for the Computation of the Overall Value. Thus, on the one hand, a Prospective Outcome is tagged as a gain or a loss as well as being easy-to-evaluate or hard-to-evaluate. On the other hand, the Probabilities are tagged with the subjective perception of probabilities. The reciprocal arrow of Relation (ST_1) implies that the Subjective Transformation of the OL into the SPL has to be understood as a finite cycle. That is, the subjective perception can in turn update the Affective State such that other affective information is tagged to the SPL (e.g. the desire elicited by the presence of a gain turns into fear of not winning it if probabilities are high). However, it is implied, that this update is finite such that in the end of the Subjective Transformation, there is an overall Affective State which initiates System 1 or System 2.

From the analysis of how a Prospective Outcome is evaluated in economics, psychology and neuroscience, Section 4.4 derives that the three disciplines complement one another in three points.

- The reference dependent evaluation of a Prospective Outcome depends on its affectivity
- There is a difference between a relative loss and a real loss
- Losses are more affective than gains

First, where economic literature presumes that the subjective utility, which assigns value to a Prospective Outcome, is either derived absolutely, relatively or by a combination of both, psychology approaches this issue with the affectivity of the Prospective outcome. That is, the evaluation of a Prospective Outcome is determined by its properties (condition, magnitude, reference point). As discussed in Section 4.1.2, a Prospective Outcome can, from the perspective of psychology, be easy-to-evaluate or hard-to-evaluate with respect to its Affectivity. Thus, with respect to the Subjective Transformation of the OL into the SPL, the Affective State handles the Prospective Outcomes properties and tags the Prospective Outcome as a gain or a real loss as well as being easy-to-evaluate or hard-to-evaluate. Two dimensions of a loss are implied. On the one hand, if a Prospective Outcome is easy-to-evaluate the identification as a gain or loss is easy. Usually, this comes along with a clear positive or negative quality of the Prospective Outcome, such as gaining or losing 1 Million Euros. On the other hand, if a positive Prospective Outcome is hard-to-evaluate, it might be perceived as a loss compared to another Prospective Outcome, such as gaining 9 Euros compared to 1.000 Euros. From these facts it is deduced that a subject's reference point depends very strongly on the Prospective Outcomes property of being easy-to-evaluate or hard-to-evaluate. If a Prospective Outcome evokes such strong mental images of desire, the reference point may be influenced by the 1 Million Euros themselves and every other Prospective Outcome would be perceived as a loss. If a subject has the possibility to gain 1 Million Euros, the imagination of not gaining it feels like a loss. If one outcome does not evoke any images, such as 9 Euros, there is a need to compare it to the alternative outcomes. 9 Euros compared to 1 Euro are great, whereas 9 Euros compared to 1.000 Euros are quite bad. In that case, the reference point is more determined by the status quo and the subject's expectations of all Prospective Outcomes. That is, after the Subjective Transformation of a Prospective Outcome it is prepared for the Computation of the Overall Value in the sense that the subject knows if it is easy-to-evaluate such that he immediately knows if he wants to achieve it or avoid it. In this case, the Prospective Outcome will be tagged as a gain or a real loss. If it is not possible to identify a Prospective Outcome as a gain or a real loss, it is tagged as hard-to-evaluate. The domain of gain or loss determines the slope of the subject's utility functions (Impulsive Value β and Deliberate Valueδ) such that losses loom larger than gains.

Relation (ST_1) further describes how the evaluation of a Probability depends on the affectivity of the Prospective Outcomes. This dependency is connected to the subject's Affective State, such that the properties of the Weighting Function w are predetermined by the affectivity of a Prospective Outcome. The non-linear weighting can be described by four features: small probabilities are usually overweighted and large probabilities are usually underweighted. These phenomena are usually more pronounced near the endpoints of the weighting function, expressed by 'jumps'. This leads to a diminishing sensitivity in the mid-range of the Weighting Function.[10] There is evidence that the affectivity of a Prospective Outcome directly influences the shape w. Fear and hope triggered by the Probabilities are more intense if the Prospective Outcome is affective and thus the Affective State is hot. That is, affective Prospective Outcomes induce a more pronounced inverted s-shaped probability weighting function whereas non-affective Prospective Outcomes induce a weighting function, which is closer to the identity line. In other words, when there is an affective Prospective Outcome, small probabilities are more overweighted because the triggered hope for winning or fear of losing is more intense than with a non-affective Prospective Outcome and large probabilities are more underweighted because the triggered fear of missing a gain or hope for avoiding a loss is more intense. Subjects playing Lotto is a good example of how a slight sparkle of hope leads to overweighting of very small probabilities. Further, sensitivity is more diminished in the mid-range of probabilities. Thus, after the Subjective Transformation, the properties of the Weighting Function w are determined such that probabilities can be transformed in subjective decision weights during the computation of the Overall Value.

(ST_2) Affective Risk Attitude The Affective State also transforms the subject's Risk

[10]Refer to Section 3.1 for a typical probability weighting function as proposed within the PT.

Attitude. As derived from the discussion in Section 4.3, a subject's Risk Attitude changes with the influence of several factors. That is, a subject's Risk Attitude is specific to the content and context of the decision situation and is mediated by the valence of the Affective State. Research in psychology and neuroscience reveal that the following factors influence a subjects Risk Attitude.

- Directly related to the decision task
  - Vividness in representation of Prospective Outcomes and probabilities (content)
  - Time course (context)
  - Time pressure (context)
  - Decision from experience or description (context)
- Individual properties of a subject
  - Experience
  - Cognitive ability
  - Evolutionary preparedness
- Not related to the decision task
  - Mood

A positive Affective State leads to a more risk seeking behavior, whereas a negative Affective State leads to a more risk averse behavior. Yet, the reciprocal relation indicates that each subject has a given Risk Attitude such that a very risk averse subject might generally rely more on his Affective State.

(ST_3) Shift in Risk Preference This relation links the subject's Risk Attitude to the SPL. In economics, it is generally assumed that a subject's Risk Attitude is expressed by the shape of his utility function. That is, within the ADMF, $ST3$ describes how the shape of the Impulsive Value and Deliberate Value is determined such that risk affinity implies convexity, risk aversion implies concavity and risk neutrality implies linearity. Thus, $ST3$ describes the fact that a change in Risk Attitude leads to a shift in risk preferences.

To sum up, the three relations ST_1, ST_2 and ST_3 describe the role of the Affective State within the Subjective Transformation. In the sense of the ADMF, the Subjective Perception SP adds affective information to the OL, as for example: How much is the Prospective Outcome liked or disliked? What is the subject's Reference Point? How are the probabilities perceived in the sense of a non-linear weighting? What is the subject's Risk Attitude? That is, $SP = \{a, \beta, \delta, r, w\}$ is a set which contains the following elements. $a \in \mathbb{R}$ reflects the degree of Affectivity of a Prospective Outcome such that $a_x >, <, = a_y$ implies that the Prospective Outcome x is more affective, less affective, equal to the Prospective Outcome y. The Subjective Perception of an OL determines the properties of the Impulsive Value $\beta : C \rightarrow \mathbb{R}$, which finally assigns an absolute value $\beta(x)$ to a Prospective Outcome $x \in C$ during the computation of the Overall Value.[11] SP as well determines the properties of the Deliberate Value $\delta : C \times \mathbb{R} \rightarrow \mathbb{R}$, which finally assigns a reference dependent value $\delta(x, r)$ to a Prospective Outcome $x \in C$ compared to a Reference Point $r \in \mathbb{R}$ during the computation of the Overall Value. In line with the assumptions of PT and RDP, Risk Attitude enters the Subjective Perception via the shape of β and δ. The Subjective Perception determines the properties of the Weighting Function $w : [0,1] \times \mathbb{R} \rightarrow [0,1]$ such that $w(p, a)$ finally assigns a weight to each probability p, depending on the Affectivity a. The higher a, the more pronounced inverted s-shape has w. As will be discussed in more detail in Section 5.3, each economic theory implies different assumptions of SP such as the properties of the utility function, the underlying reference point and other context to be taken into account. The Subjective Transformation of an OL into a SPL can formally be expressed as follows. Typically, OLs are given in the form of $(x_1, p; x_2, 1 - p)$. Let L_{OL} be the set of all OLs and L_{SPL} be the set of all SPLs. Then, the Subjective Transformation of the OL is a function F which maps an OL and particular Subjective Perception SP onto a SPL, i.e.

$$F : L_{OL} \times SP \rightarrow L_{SPL} \tag{5.1}$$

[11] Relation P_3 is described in more detail in the following of this section.

A SPL is then given in the form of $(x_1, p; x_2, 1-p; a_{x_1}; a_{x_2}; \beta; \delta; w; r)$ which means that every Prospective Outcome is tagged with the degree of Affectivity a. If x_1 is a very high loss, $a \to \infty$. Reflecting that subjects are risk seeking in the domain of losses, β and δ are convex and w incorporates a very pronounced inverted s-shape with large jumps near the endpoints and diminishing sensitivity such that the subject is insensitive to changes in probabilities in the mid-range. Thus, after the the Subjective Transformation, the Affective State has tagged the OL with affective information such that it is determined if System 1 or System 2 is dominant in the computation of the Overall Value.[12]

Cognitive or Affective Processing

The review of psychological and neuroscientific models and theories in Section 3.2 and 3.3 as well as the detailed analysis of the relevant components of decision making under risk in Chapter 4 reveals that, within the decision making process, there are two systems processing the given information in different ways.

(P_1) System 1 and System 2 A hot Affective State, which can either be positive or negative, triggers System 1. A cold Affective State, which can be positive or negative, triggers System 2. System 1 is characterized by fast and unconscious processing, literally spoken, it operates decisions from the heart. System 2 is characterized by deliberate and rational processing, literally spoken, it operates decisions from the head. It is assumed, that System 1 and System 2 are not processing exclusively. Instead, both systems are most likely processing parallel, with, depending on the Affective State, one system is dominant.

(P_2) SPL as Input Relation (P_2) depicts that either System 1 or System 2 evaluate the subjectively transformed SPL in order to compute its Overall Value.

(P_3) Computation of SPL's Overall Value Figure 5.3 depicts how the Overall Value $V(X)$ is computed.

[12]Refer to Section 5.3, where examples of the Subjective Transformation are discussed with respect to the existing economic theories.

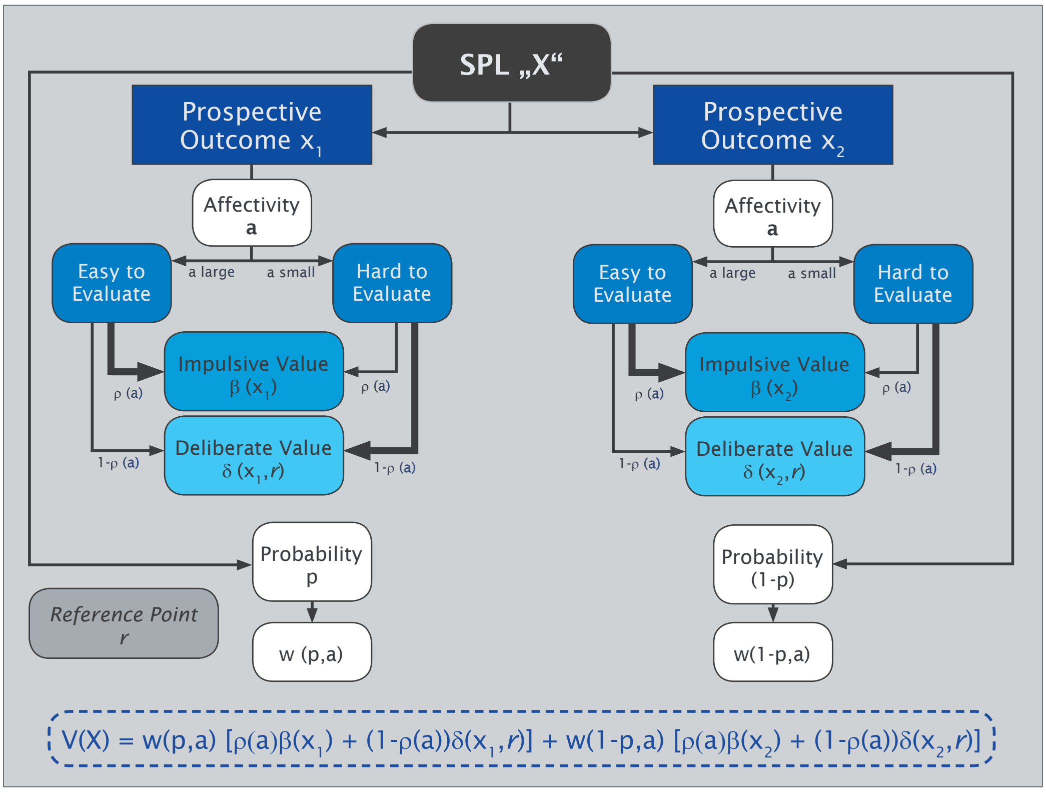

FIGURE 5.3: *The Overall Value of a Lottery*

Prospective Outcome x_1 and Prospective Outcome x_2 are tagged with affectivity measured by a. As described within Relation (T_1), an affective Prospective Outcome (i.e. a is large) is easy-to-evaluate whereas a non-affective Prospective Outcome (i.e. a is small) is hard-to-evaluate. System 1 is dominant when the Prospective Outcome is easy-to-evaluate, System 2 is dominant if the Prospective Outcome is hard-to-evaluate.

Within the ADMF, a subject's Overall Value $V(X)$ depends on an absolute component as well as on comparisons of the prospective outcomes x_1, x_2 to relevant reference points r. The absolute component is the Impulsive Value, expressed by $\beta(x)$ and the reference dependent component is the Deliberate Value, expressed by $\delta(x, r)$. These two components have a different impact ϱ on the Overall Value of the SPL, depending on the affectivity a of the lottery: $\varrho(a) \in [0, 1]$ with $\varrho(a) = 0$ for $a = 0$ and

$\varrho(a) = 1$ for $a \to \infty$. That is, the more affective a Prospective Outcome of a lottery is, the higher is the influence of the Impulsive Value. As for a less affective outcome it is not so easy to assign a value, in this case the influence of the Deliberate Value is higher. Each term is weighted with the Weighting Function $w(p,a)$ which depends on the associated probability p and affectivity a. For $a = 0$, $w(p,a) = p$. The higher a, the more pronounced is the inverted s-shape of the probability weighting function. That is, if a is large, changes in the endpoints of $w(w,p)$ have a huge impact on the Overall Value. If a is small, changes in the mid range of $w(p,a)$ are linear in the Overall Value. That is, the value of a lottery is composed of an Impulsive Value which is reduced or increased by a Deliberate Value. The Overall Value $V(X)$ of Lottery X in the sense of the ADMF is given as follows:

(5.2)

$$V(X) = w(p,a)[\varrho(a)\beta(x_1) + (1-\varrho(a))\delta(x_1,r)] + w(1-p,a)[\varrho(a)\beta(x_2) + (1-\varrho(a))\delta(x_2,r)]$$

In Section 5.3 the ADMF's workflow and implications are applied to the economic models of decision making under risk. This finally reveals, that the these models can all be subsumed under the ADMF as "special cases".

5.3 Discussion and Examples

The ADMF shows that expanding decision making under risk by affect offers several possibilities for a better understanding. In fact, this section provides in the following, that all the discussed theories of decision making under risk can be integrated into the ADMF as special cases. Interpreting them on the basis of the ADMF shows that all discussed economic theories can be approached as different cognitive decision rules, each appropriate in different situations due to the implemented reference point. It is shown that, although explicitly addressing the emotions of regret, rejoice, disappointment and elation, these models do not include affective accounts in the sense of the ADMF.

There are two desperate situations within the ADMF, a situation in which only System 2 is processing such that a lottery is evaluated purely cognitive and a situation in which only System 1 is processing such that a lottery is evaluated purely affective. However, it is assumed that in most cases economic decisions under risk comprise System 1 as well as System 2. Thus, the ADMF enables the analysis of different situations in the sense of economic context and its implications on a decision under risk. This section discusses the economic theories in the sense of a purely cognitive evaluation. It shows how each theory broadens its mind with respect to the context taken into account to derive the subjective utility function and deduce the possible implications made from the analysis in the sense of the ADMF. It further shows how the economic theories approach the idea that there are decision situations in which the intrinsic utility and the reference dependent utility have different impact on the modified utility function. That is, there are decision situations, in which a subject is more sensitive to the decision context than in other situations. This analysis derived from the discussion within this thesis highlights that, in order to describe and predict a subject's behavior correctly, every discussed economic theory makes different assumptions on the context to be taken into account. The economic interpretation is mostly based on the observation that subjects show different risk attitudes in different situations. The discussion in Section 4.3.1 highlights that these specific patterns of risk attitude are interpreted differently, e.g. with a subjective probability weighting function, with regret and disappointment aversion, with the differentiation of the source of risk. Eventually, all these economic descriptions and interpretations of decision making under risk can be reduced to the fact that, subjects obviously seek for pleasure and avoid pain wherever this is possible and are willing to tradeoff to achieve this. Thus, the economic theories mostly describe subjects behavior correctly however the analysis of the economic theories in the sense of the ADMF gives rise to the question *why* this is the case.

As developed in the last section, the ADMF evaluates a lottery in three steps.

- The Affective State is triggered.
  - (T_1) Prospective Outcomes
  - (T_2) Probability Distribution
  - (T_3) Mood
- The OL is transformed into the SPL.
  - (ST_1) Outcome-Probability Dependency
  - (ST_2) Change of Risk Attitude
  - (ST_3) Shift in Risk Preferences
- The SPL is evaluated by System 1 or System 2 resulting in V(SPL).

The Overall Value of Lottery X, in the sense of ADMF, is computed as follows:

(5.3)

$$V(X) = w(p,a)[\varrho(a)\beta(x_1) + (1-\varrho(a))\delta(x_1,r)] + w(1-p,a)[\varrho(a)\beta(x_2) + (1-\varrho(a))\delta(x_2,r)]$$

It can be shown that, specifying $w(p,a)$, $\varrho(a)$ and $\delta(\cdot)$, every economic theory discussed within this thesis can be represented as the above equation.

EUT is the common origin for all the theories of decision making under risk discussed within this thesis, where the context of a lottery is not taken into account when it is evaluated. As discussed in Section 4.1, a Prospective Outcome is thus evaluated absolutely. Predictions of subject's behavior in the sense of EUT can be interpreted in the sense of the ADMF when the decision situation is cold in its characteristics such as for example the choice between Lottery $X:(9,0.75;0,0.25)$ and $Y:(8,0.85;0,0.15)$. As EUT doesn't allow for any affective processing, a subject's Affective State is always cold. That is, neither the Prospective Outcomes (T_1), the Probability Distribution (T_2) nor the Mood (T_3) immediately trigger any emotions such as hope or fear. Based on the Affective State, the OL is then transformed into the SPL. The only element in SP is the intrinsic utility function u, induced by the subject's Risk Attitude. In the sense of the ADMF, every subject is characterized by a naturally given Risk Attitude (which a positive or negative Affective State might change). In fact, a subject's given (pattern of) Risk Attitude is the only subjective factor within a cold evaluation. It is assumed that each subject is characterized by his individual u such that each subject reacts differently to risk. Neither content nor context of a decision situation influence a subject's Risk Attitude. In the sense of EUT, this simply means that the SPL only differs from the OL by the influence of the Risk Attitude, expressed by the shape of the intrinsic utility function. Based on the subject's cold Affective State, System 2 is triggered to evaluate the lottery's Overall Value of the SPL. A Prospective Outcome which doesn't elicit any immediate emotions and thus mental images is categorized as hard-to-evaluate. As there is no affectivity associated to the SPL, $\varrho(a) = 0$. That is, there is no Impulsive Value assigned to the Prospective Outcomes and the lottery is only evaluated according the Deliberate Value. A subject, who decides in the sense of EUT, doesn't consider a reference point. Instead he evaluates each Prospective Outcome absolutely. With $w(p,a) = p$, $\varrho(a) = 0$ and $\delta(x,r) = u(x)$ this leads to

$$V(X) = U(X) = pu(x_1) + (1-p)u(x_2) \tag{5.4}$$

which is equal to the expected utility in the sense of EUT. Figure 5.4 depicts the computation of $V(X)$ in the sense of EUT graphically.

Many observations of a subject's behavior imply that mostly, lotteries are not evaluated as predicted by EUT. Thus, the other theories are extended by several assumptions which allow to approach differences in behavior with respect to sensitivity to the decision context. Yet, they still only consider the cognitive side of decision making as they do not intend to model *how* a subject decides. They differ in the underlying reference point and thus make different assumptions about the properties of u and v.[13]

[13]Refer to Section 4.1.1, where it is discussed how a prospective outcome is evaluated from the perspective of the economic theories.

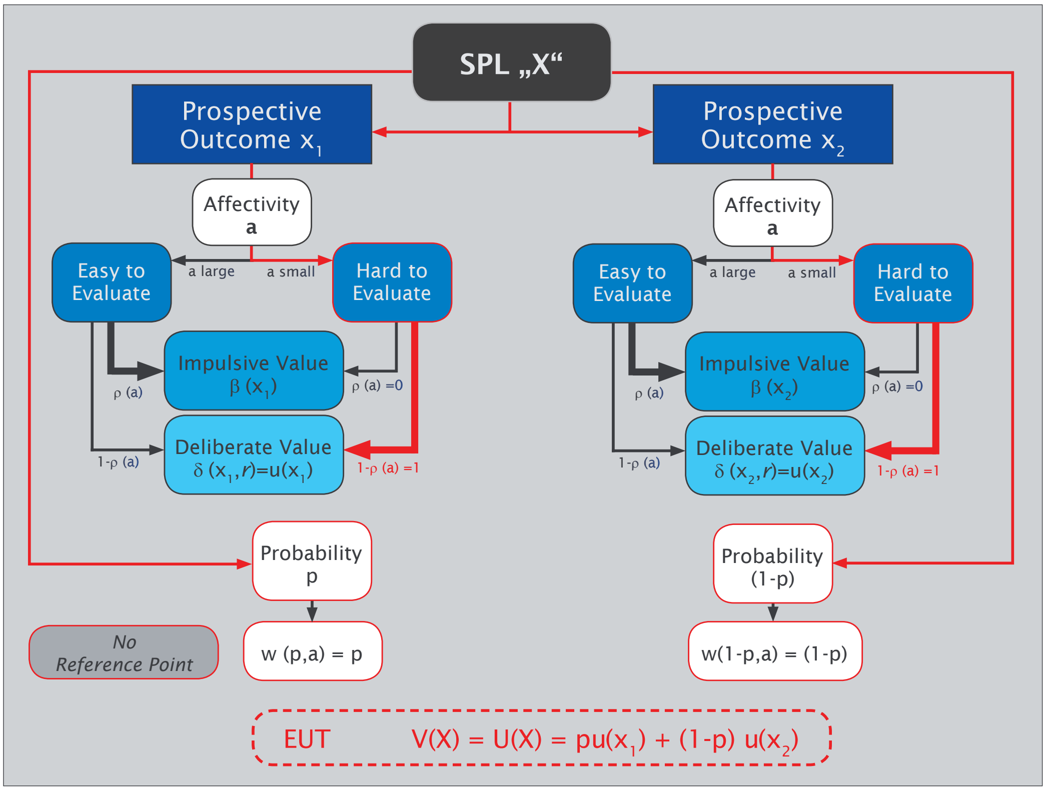

FIGURE 5.4: *The Expected Utility Theory as a Special Case in the ADMF*

PT extends the assumptions of EUT by modeling some sensitivity towards the decision context, i.e. specific pattern of risk attitude, larger looming of losses and a specific pattern of probability weighting. This sensitivity to the context is incorporated into the properties of v and π. This makes PT a descriptive theory, as it describes subjects' behavior by these subjective functions. In the sense of PT, a subject evaluates each Prospective Outcome according to an exogenously given reference point, mostly to be considered the status quo. Thus, in the sense of PT, SP contains the reference dependent utility function v and the probability weighting function π which both incorporate a subject's specific pattern of risk attitude. Kahneman and Tversky (1979) state, that:

> "According to the present theory, attitudes toward risk are determined jointly by v and π, and not solely by the utility function." (Kahneman and

Tversky (1979), p. 285)

That is, the subjective factors of the SPL in the sense of PT are v and π. PT doesn't allow for any affectivity, thus the affectivity of a Prospective Outcome is not taken into account. That is, a subject's Affective State is supposed to be cold and a subject treats every Prospective Outcome as if it was hard-to-evaluate. In the sense of PT, this simply means that the SPL differs from the OL by the influence of the Risk Attitude, expressed by the shape of the reference dependent utility function and the probability weighting function. This leads to the fact that Lottery X's overall value $V(X)$ only includes the Deliberate Value, with a reference point r being the status quo. That is, with $w(p,a) = \pi(p)$, $\varrho(a) = 0$ and $\delta(x,r) = v(x)$, this leads to

$$V(X) = U(X) = \pi(p)v(x_1) + \pi(1-p)v(x_2) \tag{5.5}$$

which is equal to the Overall Value in the sense of Kahneman/Tversky. Figure 5.5 depicts the computation of $V(X)$ in the sense of PT graphically.

As already mentioned above, PT is a descriptive theory which incorporates the observed economic behavior with respect to the value function and the probability weighting function. However, the authors do not make more than some vague statements about why subjects behave as they do. The ADMF can explain this context sensitivity with respect to the affectivity with which a lottery is described. The fact that losses loom larger than gains, as expressed by the slope of v, is not a secret in psychology and neuroscience. Evolution prepared subjects to intuitively identify losses and react unconsciously to avoid them.[14] In the sense of the ADMF this simply means that the imagination of a loss elicits strong immediate negative emotions such as fear, which leads to a hot negative Affective State (T_1). Negative emotions are generally more affective than positive emotions. Consider the Certainty Effect as an example how the ADMF interprets the subjective weighting of probabilities. Subjects mostly

[14] Refer to Section 4.1.2 and 4.1.3, where this is discussed.

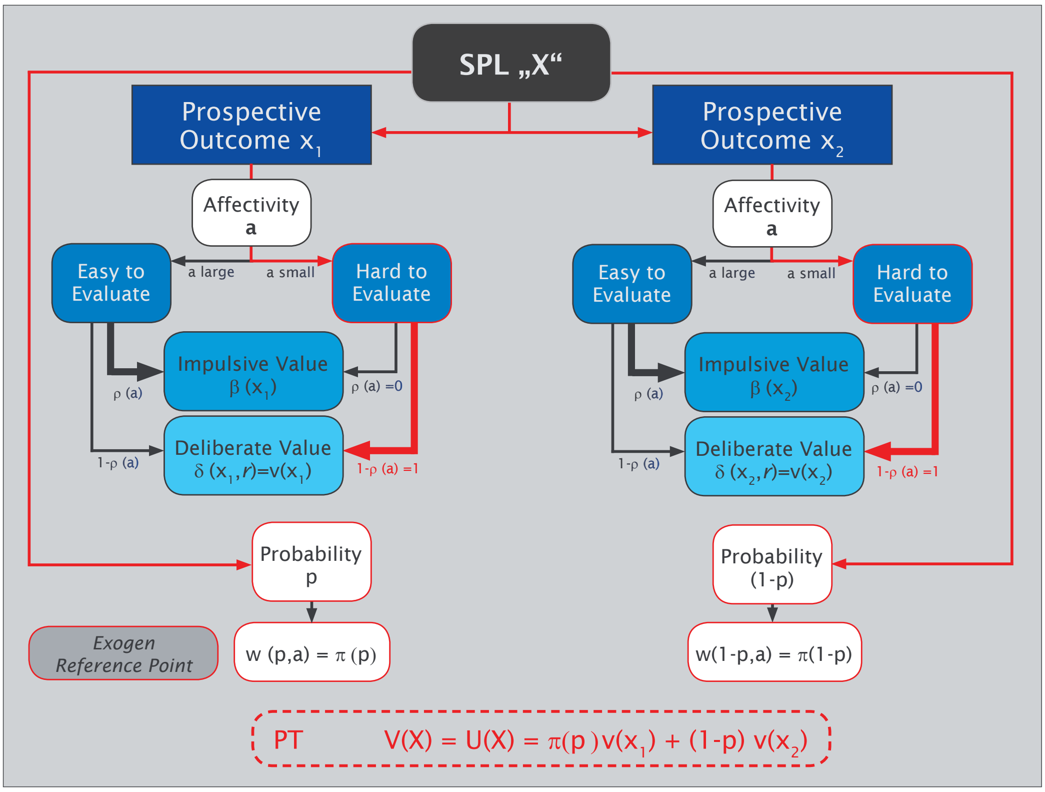

FIGURE 5.5: *The Prospect Theory as a Special Case in the ADMF*

prefer $X : (3.000, 1)$ to $Y : (4.000, 0.8)$. The transformation of the OL into the SPL depends very much on the subjective situation a subject is in such that it serves as a good example of the parallel processing of System 1 and System 2. How easy is it to assign an Impulsive Value to 4.000 Euros? A student who doesn't know how to pay rent for the next months will be more exited about 4.000 Euros than a manager who earns twice per months. From the student's perspective, the Prospective Outcome of 4.000 Euros is firstly imagined as very desirable. The Probability Distribution is then interpreted as a reduction from probability 1 to 0.8 (T_2). This immediately elicits the fear of missing this desirable gain such that the probability of 0.8 is underweighted (ST_1). The fear of missing this gain leads to a negative Affective State and the subject's Risk Attitude is (more) risk averse (ST_2). Thus, System 1 and System 2 are most likely to be processing parallel as the student might be aware of the fact that choosing

Y might provide him the higher expected value however System 1 is dominant. The manager however might not perceive 4.000 Euros as very desirable (T_1) such that evaluating the Probability Distribution doesn't immediately elicit the fear of not winning (T_2). That is, in this case the Affective State is moderate, which leads to a less pronounced probability weighting (ST_1) such that the probability of 0.8 is evaluated more linearly which might lead to the decision in favor of Lottery Y with System 2 being dominant ($\varrho_{student}(a) > \varrho_{manager}(a)$).

RDP, RT and DT are similar in the sense that they approach an endogenously given reference point and they presume a Prospective Outcome to be evaluated according to a value with an intrinsic component and a reference dependent component. Thus, what these theories have in common, is that each underlying utility function can be represented as $\mu = u + v$. The second component within these models, v, depends on an endogenously given reference point, which is either determined by the subject's expectations (sometimes in the sense of disappointment) or expected regret. Neither expectations in a general sense nor expected emotions as regret or disappointment are part of the affective processing in the sense of the ADMF.[15] The theories differ in what they assume to be the underlying Reference Point r and in how they approach sensitivity to the decision context.

RT incorporate the expected emotions regret and rejoice into the evaluation of a Prospective Outcome by comparing it to the forgone outcome y resulting from the not chosen lottery. The intrinsic value of a Prospective Outcome is considered linearly, the only transformation of the OL into the SPL, which is allowed within RT, is the regret/rejoice function v. The specific pattern of mixed risk attitudes in the sense of RT is correlated with a general regret-aversion, expressed by the shape of v. Comparing each Prospective Outcome to the forgone outcome is a purely cognitive deliberation, a subject's Affective State is cold and a subject treats every Prospective Outcome as if it was hard-to-evaluate. RT doesn't account for the weighting of proba-

[15] Please refer to Section 5.2 where the trigger of a hot Affective State and thus affective processing, are discussed and specified.

bilities. Thus, this leads to the fact that Lottery X's Overall Value $V(X)$ only includes the Deliberate Value, with a reference point $r = y$. That is, with

$w(p,a) = p$, $\varrho(a) = 0$ and $\delta(x,r) = \mu(x|y) = x + v(x-y))$ this leads to

$$V(X) = U(X) = p\mu(x_1|y_1) + (1-p)\mu(x_2|y_2) \tag{5.6}$$

which can be interpreted as the Overall Value in the sense of RT.

Figure 5.6 depicts the computation of $V(X)$ in the sense of RT graphically.

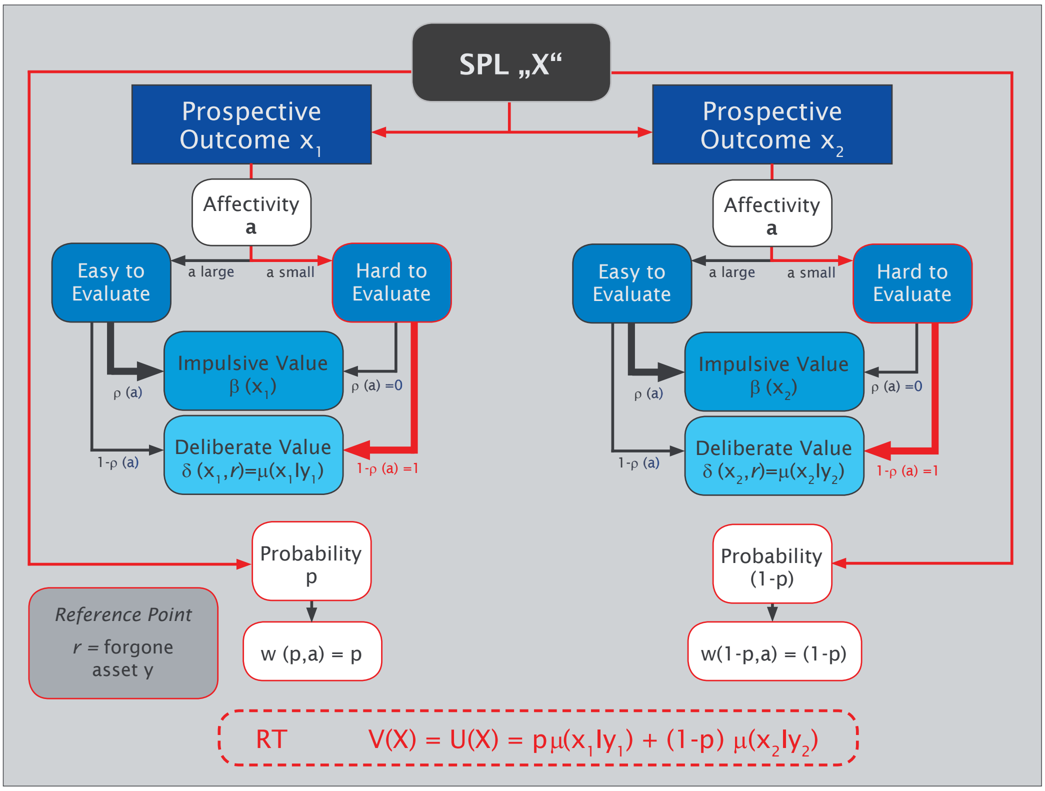

FIGURE 5.6: *Regret Theories as a Special Case in the ADMF*

RT has been developed as an alternative to PT in order to explain the observed anomalies in behavior (hurting the EUT axioms). Other than directly approaching mixed risk attitudes in the domain of gains and losses (exogenously predetermined as within PT), RT argues with a general aversion of regret. That is, gains and losses are identified endogenously by the comparison to the foregone outcome. Yet, this leads to a similar specific pattern of risk attitude.[16] The fact that subjects try to avoid the sensation of regret can be pictured with the example of playing Lotto. Consider the following decision between playing Lotto or not: $X : (-10, 0.999; 150Mio, 0.001)$, $Y : (0, 1)$. If a subject does not buy the Lottery-Ticket he will experience maximum regret if he learns afterwards that his numbers would have won. This implies that the subject is always better choosing Lottery X. However, as discussed in Section 3.1.3, it is essential for this motivation that a subject always knows in which state of the world a (not) chosen lottery results. Yet, it is obvious that this is not always possible. The analysis of this decision in the sense of the ADMF offers a different explanation. 150 Million Euros are imagined as a very desirable gain (T_1). The probability of 0.001 is perceived as a move from zero to the slight possibility of winning the jackpot. This immediately induces hope for winning which leads to a hot positive Affective State (T_2). Thus, 0.001 is very much overweighted (ST_1) and the subject turns risk seeking (ST_2). That is, a subject swaps the possibility of experiencing regret, which is associated to pain, against hope, which is associated to pleasure. To be more precise, minimizing expected regret goes along with maintaining the hope for winning. As the above discussed Certainty Effect, the Lotto-Phenomenon is also a good example for the parallel processing of System 1 and System 2, one of which being dominant. Obviously, there are two groups of subjects. First, there are subjects in Group 1 who base their decisions on affect, namely they are willing to pay for maintaining the hope for winning the jackpot even if they are fully aware of the fact that playing Lotto has a negative expected utility. Yet, the Prospective Outcome of winning the jackpot is so affective, that it is mostly evaluated according to its Impulsive Value β instead of its Deliberate Value δ. Group 2 bases its decisions on System 2, namely they are able to cushion their hope for winning the jackpot such that $\varrho_{group1}(a) > \varrho_{group2}(a)$.

DT incorporate the expected emotions disappointment and relief into the evalu-

[16]Refer to Section 4.3.1, where it is discussed how RT captures risk attitudes.

ation of a Prospective Outcome by comparing it to the expected value $\bar{x}$ resulting from the Lottery X. As within DT, the intrinsic value of a Prospective Outcome is considered linearly, the only only element of SP in the sense of DT, is the disappointment/elation function v. The specific pattern of mixed risk attitudes in the sense of DT is correlated with a general disappointment-aversion, expressed by the shape of v. The only way to avoid disappointment is to keep expectations realistic which goes along with a general aversion to any large scale risk. As this is a purely cognitive deliberation, a subject's Affective State is cold and a subject treats every Prospective Outcome as if it was hard-to-evaluate. DT doesn't account for the weighting of probabilities. Thus, this leads to the fact that Lottery X's Overall Value $V(X)$ only includes the Deliberate Value, with a reference point $r = \bar{x} = px_1 + (1-p)x_2$. That is, with $w(p,a) = p$, $\varrho(a) = 0$ and $\delta(x,r) = \mu(x|\bar{x}) = x + v(x - \bar{x})$ this leads to

$$V(X) = U(X) = p\mu(x_1|\bar{x}) + (1-p)\mu(x_2|\bar{x}) \tag{5.7}$$

which can be interpreted as the Overall Value in the sense of DT. Figure 5.7 depicts the computation of $V(X)$ in the sense of DT graphically.

RDP's utility function is similar to DT's utility function with respect to its representation as a function μ with an intrinsic utility u and a reference-dependent utility v. The differences to DT and also PT is, that RDP approaches context specific Risk Attitudes and it approaches a stochastic reference point Y. The transformation of the OL into the SPL, which is allowed within RDP, is the intrinsic utility u and the reference dependent utility v. The specific pattern of mixed risk attitudes in the sense of RDP is correlated with the source of risk and its scale. It is assumed that risk attitudes are context specific in situations with modest scale risks, such that they are determined by v, and not context specific in situations with large scale risk such that they are determined by u. Considering context specific risk attitudes ($u(x) = x$), RDP differs between situations in which risk is surprising or expected, implying more

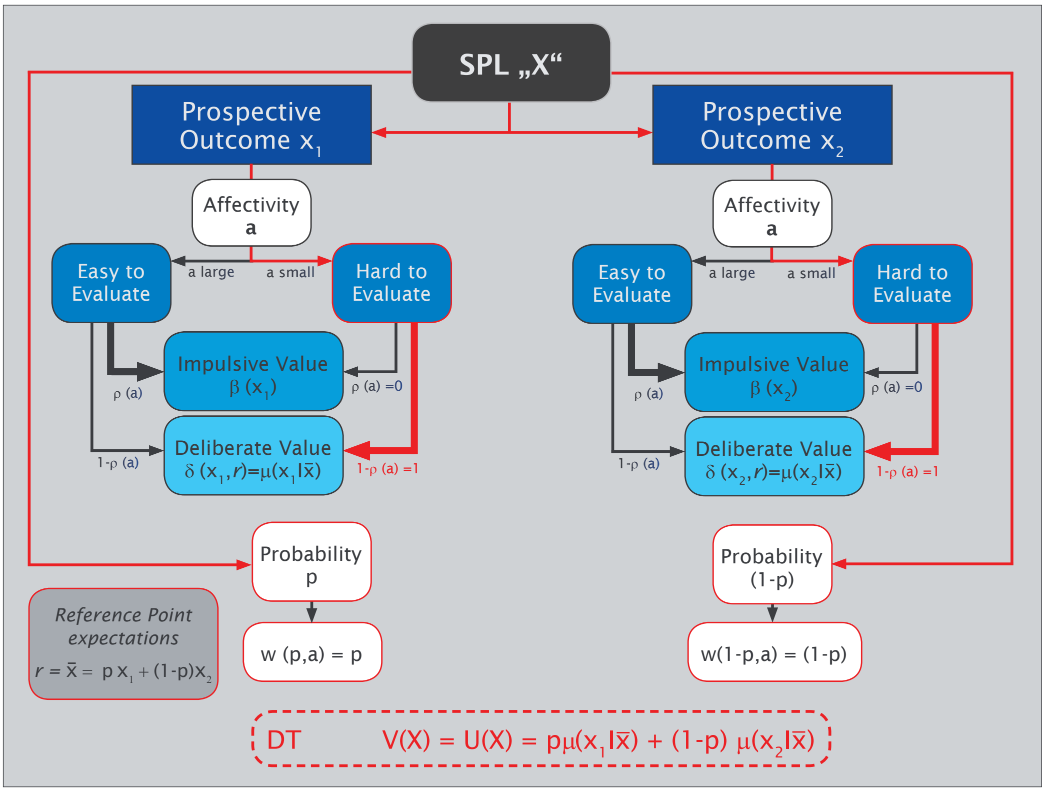

FIGURE 5.7: *Disappointment Theories as a Special Case in the ADMF*

risk aversion for expected risks. The choice between the following lotteries is approached to highlight the differences in context specific risk attitudes: $X : (-55,1)$ and $Y : (-100,0.5;0,0.5)$. RDP argues, that in surprise situations, expectations are fixed before the lottery is evaluated such that paying 55 Euros is evaluated as a loss. When the subject however knows that he will have to choose between these lotteries, his reference point is the expectation that he will have to pay, such that 55 Euros are not evaluated as a loss anymore. A subject will be even more risk averse if it is possible to commit for his decision long ahead before the outcomes are realized. In situations of large scale risk, u cannot be considered linearly such that the influence of v is close to be neglected. In the sense of RDP, this means that the SPL differs from the OL by the influence of the Risk Attitude and by the decision context. However, RDP also doesn't allow for any affectivity to be considered such that a subject's Affective

State is cold and he treats every Prospective Outcome as if it was hard-to-evaluate. RDP doesn't account for the weighting of probabilities. Thus, this leads to the fact that Lottery X's overall value $V(X)$ includes the Deliberate Value, with a reference Lottery Y. That is, with

$w(p,a) = p$, $\varrho(a) = 0$ and $\delta(x,r) = \mu(x|r) = u(x) + v(u(x) - u(r))$ this leads to

$$V(X) = U(X|Y) = \int\int \mu(x|r)dG(r)dH(z) \tag{5.8}$$

which can be interpreted as the Overall Value in the sense of RDP.

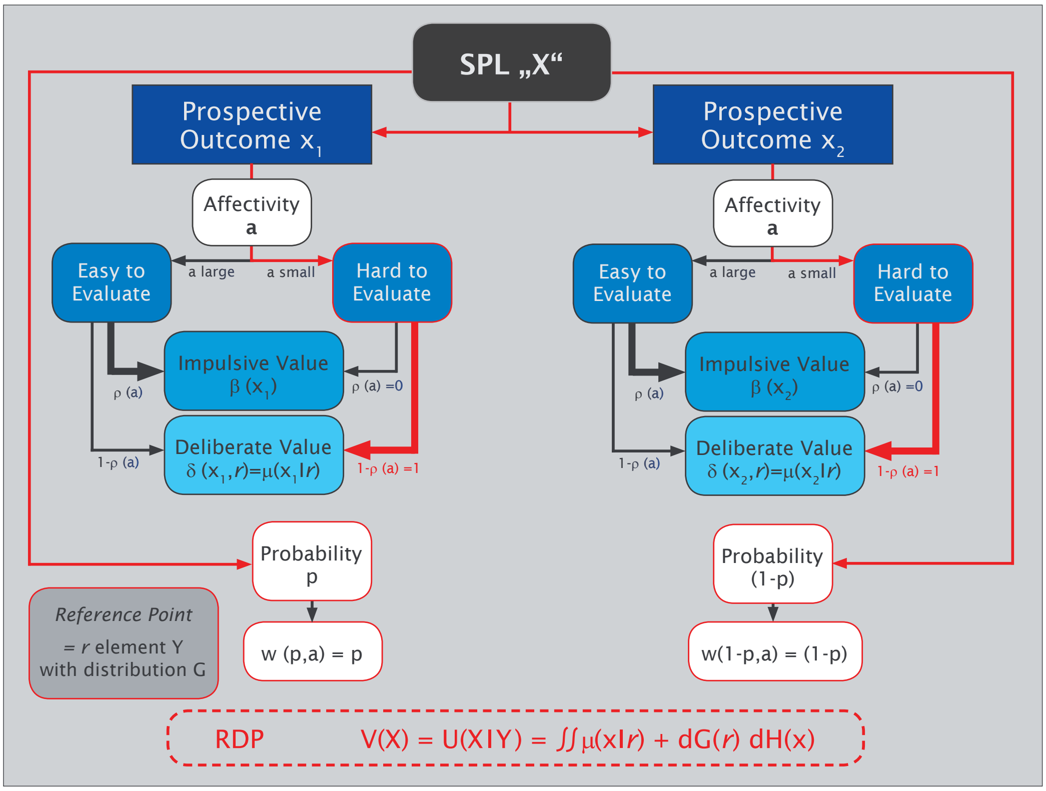

FIGURE 5.8: *Reference Dependent Preferences as a Special Case in the ADMF*

Figure 5.8 depicts the computation of $V(X)$in the sense of RDP graphically.

RDP approaches the differences of decision context that DT explicitly ignores in order to highlight the role of disappointment. However, if a subject is generally disappointment averse this implies that he will avoid situations with wide spread risk. This makes it a very intuitive approach of RDP to differentiate between large scale risk situations and modest scale risk situations as in large scale risk situations it is almost not possible to avoid disappointment. Large scale situations are most commonly associated with affective Prospective Outcomes which are easy-to-evaluate (T_1) such that $\varrho_{largescale}(a) > \varrho_{modestscale}(a)$. The strong influence of β on the Overall Value implies that a subject evaluates a Prospective Outcome without the need for a reference. Considering context specific Risk Attitudes reveals differences in risk aversion with respect to surprise risk and expected risk. The surprise payment of an insurance fee is evaluated as a real loss (T_1). This immediately elicits hope to avoid this loss such that the subject is in a hot positive Affective State (T_2). This leads to risk affinity (ST_2), (ST_3). If however, the subject is faced with such a decision and has time to contemplate, the situation is per definition less affective such that $\varrho_{surprise}(a) > \varrho_{expected}(a)$. The time to deliberate about paying an insurance fee reduces the intensity of hope such that the uncertainty about the future becomes dominant and induces a negative Affective State which leads to risk aversion (ST_2), (ST_3). If the realization of the lottery is far ahead of the time of choice such as for example in most insurance situations, uncertainty about the future is even more dominant such that the negative Affective State leads to more risk aversion. That is, differences in behavior in surprise risk situations and expected risk situations can be interpreted with the difference of real losses to relative losses as well as the characteristics of the decision. The surprise risk situation represents a hot decision, where System 1 is supposed to be dominant whereas the expected risk situation represents a cold decision, where System 2 is supposed to be dominant.

Table 5.1 summarizes the Subjective Transformations as supposed by each economic theory, describing the economic interpretation of these Subjective Transformations and the affective implications in the sense of the ADMF.

The ADMF expands the economic theories in two points. First, all the discussed

TABLE 5.1: *Affective Interpretation of the Subjective Transformation within Decision Making under Risk*

(EUT = Expected Utility Theory, PT = Prospect Theory, RT = Regret Theory, DT = Disappointment Theory, RDP = Reference Dependent Theory)

Theory	**Subjective Transformation**	**Economic Interpretation**	**Affective Interpretation**
EUT	u	shape of u reflects a subject's static risk attitude	neither (T_1), (T_2), (T_3) trigger the affective state: cold. Only subjective transformation:(ST_3)
PT	v, π	slope of v: losses loom larger than gains; shape of v: content specific risk attitude; shape of π: specific pattern of prob. weighting	aversive emotions are more intense than positive: (T_1); positive affective state: risk affinity, negative affective state: risk aversion (ST_2), (ST_3); hope and fear are triggered when probabilities are evaluated with respect to the prospective outcomes which leads to subjective probability weighting (T_1), (T_2), (ST_1)
RT	v	v reflects a general regret aversion such that subjects minimize expected regret	swap the possibility of experiencing regret (pain) against hope (pleasure): minimizing expected regret goes along with maintaining the hope for winning-> Lotto: (T_1): Jackpot very desirable (T_2): Hope for winning Affective state hot positive (ST_1): probs are overweighted (ST_2), (ST_3): risk affinity
DT	$v)$	v reflects a general disappointment aversion	The only way to avoid disappointment is to keep expectations realistic which goes along with a general aversion to any large scale risk.
RDP	u, v	u: context insensitive utility v: context sensitive utility large scale risk: risk attitude not context specific modest scale risks: risk attitude context specific with more risk aversion when risk is expected than surprise risk. When expected, more risk aversion with commitment long after choice than commitment soon after choice	large scale risk goes along with affective prospective outcomes which are easy-to-evaluate $(T_1)(\varrho_{largescale}(a) > \varrho_{modestscale}(a))$; strong influence of β on the overall value implies that a subject evaluates a prospective outcome without the need for a reference. surprise payment of an insurance fee is evaluated as a real loss (T_1). Hope to avoid this loss is the dominant emotion in this situation (positive affective state) and leads to risk affinity (ST_2), (ST_3). Time to deliberate about paying an insurance fee reduces affectivity of hope such that uncertainty about the future induces a negative affective state which leads to risk aversion (ST_2). If realization is far ahead of the time of choice uncertainty is more dominant such that the negative affective state leads to more risk aversion. Main difference: surprise risk is a hot decision, expected risk is a colder decision where paying the fee isn't evaluated as a real loss $\varrho_{surprise}(a) > \varrho_{expected}(a)$.

theories are based on different assumptions about the underlying SPL, yet neither theory specifies to any extent how the objective input of a decision is transformed into something subjectively perceived. EUT neither allows for content nor context but the expected utility. However, the shape of a subject's utility function is determined by the subject's risk attitude. EUT implies a static risk attitude for every subject, given by nature. The other theories, which all base their decisions on a reference dependent evaluation open up for some context sensitivity. PT transforms probabilities into subjective probability weights, yet without any further specification. Further, PT also implies a subjective utility function, determined by a specific pattern of risk attitude. RT and DT consider expected emotions to be relevant in the evaluation of a lottery, so that one could believe that these theories approach some affective component. However, in order to concentrate on effects due to disappointment or regret, utilities are modeled linearly such that mixed risk attitudes are only determined by an aversion towards disappointment/regret, which is implied by the subjective shape of v. That is, RT and DT also imply a subjective utility function, depending on the decision context, without further specifying it. RDP goes even one step further and considers some context sensitivity with respect to a subject's risk attitude. Yet, RDP also doesn't make any implications on the reasons why risk attitude changes in some situations, besides the induced shift of the reference point. The ADMF approaches these points by implementing another dimension: affectivity. Thus, the ADMF offers an explanation for some assumptions of economic literature which are not further specified. The Subjective Transformation explains *how* the specific shape of u and v is derived and *how* a subjective probability weight is added to the probability distribution.

Second, RT, DT and RDP imply similar modified utility functions, which are all based on the assumption that a subject has an absolute value of a Prospective Outcome which is somehow modified by its comparison to a reference point: $\mu = u + v$. For the sake of simplicity, RT and DT usually assume $u(x) = x$. That is, they do not analyze the different impact of u and v on μ. They rather highlight the impact of v as the regret/rejoice function or the disappointment/elation function respectively. RDP however approaches the different impact of u and v. Köszegi and Rabin (2007) state:

> "[...]we investigate attitudes toward large-scale risk, where consumption utility cannot be assumed to be linear. We show that under reasonable conditions, the reference point has only a minor impact on how a person evaluates very large gambles. A person is therefore prone to exhibit risk aversion reflecting diminishing marginal utility of wealth independently of the environment."(Köszegi and Rabin (2007), p. 1049)

They approach a subject's context sensitivity only within different situations of risk: modest-scale risk and large-scale risk. They show that, as discussed in section 4.3.1, subjects are only context sensitive when the situations are modest in risk. Whenever the risk is very large, they find that risk attitudes mostly coincide with classically predicted risk attitudes. Thus, as discussed above, Risk Attitude is the only subjective factor to be considered in order to explain different behavior to different context. The ADMF however approaches this from the perspective of the affectivity of a Prospective Outcome. As large scale risk situations mostly go along with high Prospective Outcomes, the ADMF offers an explanation *why* a subject is more context sensitive in modest-scale risk situations than in large scale risk situations as modeled within RDP. The more affective a decision situation, the more impact has β due to its weighting by $\varrho(a)$. Further, the differences in risk attitudes considering surprise risk and expected risk go along with the parallel processing of System 1 and System 2 as modeled within the ADMF. A surprise risk situation as supposed by RDP is characterized by a hot decision where System 1 is dominant. An expected risk situation is characterized by a cold decision where System 2 is dominant (always keeping in mind that these systems process parallel).

Thus, the ADMF comprises situations in which a decision is purely cold in its characteristics such that only System 2 is active, as discussed in the sense of EUT. However, as pointed out above where the economic theories are interpreted in the sense of the ADMF, most decisions are parallel in their characteristics. Then one system is dominant. The dominance strongly depends on the subject's individual properties such as experience, cognitive abilities and welfare. There are also examples of situations in which a decision is based on a purely affective evaluation. Contrary to the purely cognitive evaluation as depicted in the sense of the economic theories, these examples comprise a situation in which the subject is highly emotional and aroused and decides unconsciously according to an affective impulse. Such a situation can be described as a Fight-or-Flight decision as for example the encounter with a wild animal. It is not rational to deliberate about how the Prospective Outcomes are distributed. It is a life-saving human property to intuitively know when to run in the face of danger. Yet, there might be economic situations in which it is useful for a subject to take the advantage of this ability. Consider for example a stock exchange trader or a manager. They sometimes have to decide very fast without the possibility to think deliberately. It is very useful to rely on the intuition for what is advantageous or not as processed by System 1.

In this chapter I combined a utility-maximization approach with the intuitive appeal that subjects make some Subjective Transformations of the objectively given facts with respect to a decision situation. I developed an Affective Framework of Decision Making under Risk which generates a wide range of explanations for the necessary, but not further specified, assumptions within each of the economic theories. The ADMF gives rise to the following questions:

- How can the specific properties of a utility function be derived from the affectivity of a decision situation?
- How can a subject's context sensitivity, that is the impact of the reference dependent component of utility be derived from the affectivity of a decision situation?

Part III

Conclusion

Chapter 6

Conclusion and Future Research

The objective of this thesis is to understand how the cognitive-affective interplay in the sense of the Dual-Processing-Theory influences decision making under risk. Since the middle of the last century, economists have observed that subjects do not decide as predicted by EUT. Therefore, economic research has focused on some psychological components as key to understanding decision behavior under risk in greater depth. However, the idea that there is an affective processing prior to a cognitive evaluation of a decision, in the sense of the Dual-Processing-Theory, has not been approached by economics yet. This thesis therefore establishes a solid foundation on which further economical research on the cognitive-affective interplay can be based. The central result, the Affective Decision Making Framework, enables economists to analyze the role of affect in economic decision making under risk and experimentalists to discuss affective decision making under risk using a standardized concept. The application of this standardized concept sheds light on the influence of affect on the Subjective Transformation of utility functions and probabilities as well as on the Context Sensitivity of a decision situation. It illustrates the importance to include affect into the question of how utility is derived form a prospective outcome, the probability distribution and the risk attitude. The affectivity of a prospective outcome reflects the impact of the absolute component and the relative component of the utility function such that the affectivity of a prospective outcome determines the reference dependency of a decision. The analysis of the affectivity furthermore determines the subjective probability weighting and gives rise to the determinants of a subject's risk attitude.

Chapter 2 addresses the interdisciplinary approach of this thesis and motivates the promising role of affect in economic decision making from the perspective of psychology and neuroscience. The main result of Chapter 2 is that Psychology as well as Neuroscience reveal that decisions are based on two systems, an affective as well as a cognitive system and that a subject's affective state serves as a mediator to control for the activation of affective or cognitive processing. Yet, it concludes that there is little consensus how the cognitive-affective interplay can be analyzed with respect to economic decision making under risk. The literature review in Chapter 3 discusses the most common economic theories of decision making under risk with respect to the observation that subjects do not decide as predicted by EUT. These theories include psychological components, such as anticipated regret and expectations into the subjective utility function. The discussion from Chapter 2 however reveals that such emotional components as regret, disappointment or other expectations cannot be equated to the cognitive-affective interplay in the sense of the Dual-Processing Theory. Instead, Chapter 2 reveals that affective reactions in the sense of the Dual-Processing Theory elicit immediate emotions. The psychological and neuroscientific literature review of Chapter 3 discusses how the cognitive-affective interplay with respect to decision making under risk is approached by these disciplines and identifies the appropriate concepts which are useful for the further analysis of affect in economic decision making under risk. The main result of the discussion within Chapter 2 and Chapter 3 is the understanding that affect, being the counterpart of cognition, is mediated by a subject's affective state. However, there is no consensus of how its influence within the economic decision making process can be analyzed in a structured way. This result motivates the further structure of analysis.

Chapter 4 analyzes the relevant components of decision making under risk from the perspective of economics, psychology and neuroscience. The objective is to understand how prospective outcomes, the probability distribution and the risk attitude can be evaluated on the basis of the cognitive-affective interplay. The main results of the discussion within Chapter 4 are first, that there are several characteristics of prospective outcomes which allow to classify them as easy-to-evaluate or hard-to-evaluate. This classification implies different context sensitivity within the evaluation. An easy-to-evaluate prospective outcome does not need any context to be evaluated whereas a hard-to-evaluate prospective outcome needs a reference. Second, the subjective probability weighting is strongly influenced by the affectivity of the decision situation which implies that an affective situation leads to a stronger pronounced inverted s-shaped probability weighting function whereas a non-affective situation leads to more linear probability weighting. The stronger pronounced overweighting and underweighting of probabilities is related to the immediate emotions hope and fear. The correlation between the affectivity of the decision situation, mostly elicited by the characteristics of the prospective outcomes, and the subjective probability weighting refers to the intensity with which hope and fear are perceived. The desire for a prospective outcome intensifies the hope to receive it, if probabilities are low (overweighting) or the fear not to win it, if probabilities are high (underweighting). The dislike for a prospective outcome intensifies the fear of losing if probabilities are small (underweighting) and the hope to avoid the loss if probabilities are high (overweighting). Third, the analysis of risk attitude reveals the content and context specificity of risk attitude. Subjects either react risk neutral, risk averse or risk seeking to the presence of risk. This manifests in mixed risk attitudes within different situations. Within EUT, it is assumed that risk attitude is a static individual property, expressed by the shape of its utility function. A Subject's behavior, however, shows that risk attitude is a context and content specific variable. PT, RT and DT allow for mixed risk attitudes which depend on the decision content. RDP even reveals how risk attitude is context specific. Psychology and Neuroscience specify the role of affect influencing a subject's risk attitude. Psychological research reveals different factors influencing a subject's risk attitude. These factors can be classified in three categories:

relation to the decision task, no relation to the decision task and individual properties, whereof factors with relation to the decision task can be further categorized as context specific and content specific. All these factors, to some extent, change a subject's affective state and thus influence his risk attitude. Neuroscientific research underlines these psychological results and suggests that there are two different systems in the brain processing positive and negative affective states. NAcc is responsive to positive emotions such as pleasure and happiness. There is evidence that subjects decide more risk seeking if they are happy. aINS is responsive to negative emotions such as fear and anger. Subjects decide more risk averse if they are scared. Thus, a positive affective state leads to more risk affinity whereas a negative affective state leads to more risk aversion.

These results are approached in Chapter 5. The objective of Chapter 5 is to understand how affective decision making under risk can be analyzed in a standardized formal decision making framework which is the central result of this thesis. The ADMF reflects the human decision making process adequately such that it enables the interpretation and analysis of affective elements of a decision under risk. This framework should give researchers a deeper understanding of the interactions involved in the evaluation of a lottery and helps to describe behavior within a decision under risk in a structured way. The evaluation sequence in the ADMF is characterized by three steps.

First, the Triggers of the Affective State are identified. Here, immediate integral emotions are elicited with the representation of the Prospective Outcomes as well as the Probability Distribution. Further, immediate incidental emotions can change a subject's Mood, which also influences the Affective State.

Second, based on the Affective State, the Subjective Transformation of the Objective Lottery (OL) into the Subjectively Perceived Lottery (SPL) is specified. The Subjective Transformation of an OL into a SPL can formally be expressed as a function F which maps an OL and particular Subjective Perception (SP) onto a SPL. SP is a set of affective information which includes the Affectivity a, the properties of the Impulsive

Value Function β, the properties of the Deliberate Value Function δ, the properties of the Weighting Function w and the Reference Point r. This affective information can then be used to compute the Overall Value in the next step.

Third, the Affective State triggers the Processing System which finally computes the Overall Value of the SPL. The Overall Value is composed of two components: the Impulsive Value $\beta(x)$ and the Deliberate Value $\delta(x,r)$. The impact of each component on the Overall Value is determined by $\varrho(a)$. The more affective a Prospective Outcome is, the more impact has the Impulsive Value on the Overall Value. This implies a subject's context insensitivity for affective Prospective Outcomes. The less affective a Prospective Outcome is, the more impact has the Deliberate Value on the Overall Value. This implies context sensitivity for non-affective Prospective Outcomes. The sum of the Impulsive Value and the Deliberate Value is weighted with the Weighting Function $w(p,a)$ which is more pronounced in its inverted s-shape when the Prospective Outcome is affective and it is close to be linear if the Prospective Outcome is non-affective. Based on the foundations developed in Chapter 5, the economic theories of decision making under risk are discussed with respect to the ADMF. The objective of this discussion is to understand first, how can the specific properties of a utility function be derived from the affectivity of a decision situation and second, how can a subject's context sensitivity, that is the impact of the reference dependent component of utility, be derived from the affectivity of a decision situation?

This research provides a structured method to identify affective components of decision making and a methodology for conducting lab experiments focusing on affect and its implications in a systematic way. It contributes to the existing literature in the following points.

From the economic perspective, the ADMF is mostly related to the model of Reference Dependent Preferences by Köszegi and Rabin (2006, 2007). Yet, it expands this model by two major points. First, the ADMF gives rise to the question of why subjects show different risk attitudes within large scale risk and modest scale risk situation and second, the ADMF gives rise to the question why subjects show different context sensitivity, expressed by absolute or reference dependent evaluation of a Prospective Outcome.

While designing an experiment, the ADMF enables researchers to consider all steps of decision making and their affective incidences. Identifying all triggers of a decision and the possibility to analyze their implications on behavior makes affective processing within decision making under risk clearer and future discussion more productive. Thus, this structured approach to identify and discuss the cognitive-affective interplay within decision making under risk will benefit affective decision making research in general. The discussion of the economic theories shows how applying the ADMF can lead to new insights into the cognitive-affective interplay and decision behavior.

However, it is evident that the ADMF has some limitations which imply interesting questions for future research.

First, the hypotheses derived from the ADMF within the different steps of decision making need to be empirically tested, with the methods of experimental economics as well with psychophysiological methods. So far, the whole discussion is rather hypothetical, although with solid foundations from psychology and neuroscience.

Second, the ADMF might be presented and discussed as a fully formalized model. Especially, the Impulsive Value Function and the Deliberate Value Function lack further specification with respect to their differentiability, shape and slope. This thesis presents a first idea of how affect could be modeled within a utility maximizing theory, yet further formalization would go far behind the scope of this thesis.

Third, the discussion within this thesis is restricted to one-shot decisions, as most of the considered models only consider one-shot decisions. However, this framework may be extended such that sequential choice, intertemporal choice, social choice and strategic choice can also be analyzed by means of the ADMF.

In summary, this thesis contributes an important method for identifying and interpreting the cognitive-affective interplay in the decision making process and its role in decision behavior. It provides a substantial basis for future research of the cognitive-affective interplay within decision making.

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