Chapter 3
Requiem for subjective expected utility

Nor is the people's judgement always true
The most may err as grossly as the few.
(John Dryden, ca. 1670)

3.1 Introduction

An initial objective of the study was to evaluate the various theories of decision making to derive a theoretical model and associated empirical techniques that could be used to describe and predict choices made by wool producers. An important criterion in deciding if the model was appropriate was that it could describe and predict behaviour even if that behaviour could be regarded as 'irrational' by normative theories of decision making.

For around thirty years until the mid 1980s, expected utility theory (EU) has been the dominant paradigm in economics for choice under uncertainty. Although it was developed initially as normative theory, it has been used widely for descriptive and predictive purposes, and for prescriptive reasons[1]. In mainstream Western economics expected utility theory (EU) in its various forms has the status of a metatheory (Fischhoff, Goitein and Shapira 1983). In this climate, if the theory does not predict behaviour accurately, it is argued some factor has not been considered by the researcher, or the methods of elicitation of probabilities or utilities have been incorrectly applied. Its acceptance among Austra.ian agricultural economists as a prescriptive theory of decision making under risk (and perhaps also as a descriptive and predictive theory) probably owes much to an earlier review of the theory by Dillon (1971).

[1] Prescriptive is taken to mean 'How people should behave', descriptive 'How people do behave', and predictive 'What will be the result of their behaviour'.

Recently, particularly towards the end of the 1980s, many researchers in the field of choice under uncertainty have come to accept that EU theory and its most widely used form, subjective expected utility (SEU), have important weaknesses as descriptive, predictive and normative models (Schoemaker 1982; Fischhoff et al. 1983; Machina 1987; Munier 1988; Quiggin 1988). This chapter contains a discussion of the requirements for descriptive and predictive theories of behaviour, provides a brief introduction to EU theory and briefly summarises its weaknesses as a descriptive and predictive model of human behaviour.

3.2 What characteristics are required of descriptive and predictive theories?

Models are simplifications of reality that trade off simplicity, generality and power of use against complexity and error. Hence they cannot be expected to be accurate in all respects. Models should therefore be evaluated according to the purposes for which they are being used. For the purposes of this study expected utility theory is evaluated according to the requirements that should be met by a descriptive and a predictive model.

Perhaps the most common view of the requirements of a predictive theory follows the line expounded by Friedman (1953, p. 8) that a positive theory should be 'judged by the precision, scope, and conformity with experience of the predictions it yields.' He goes on to argue that such a theory should not be judged by the accuracy of the assumptions of the theory since a significant theory will often have assumptions that are wildly inaccurate descriptions of reality. He defends his position by means of the famous leaves on a tree and billiard player examples, which are used to argue that it is sufficient that the individual acts *as if* they were obeying the axioms of the theory. He adds the proviso that it is important to specify the circumstances under which the formula works.

Unfortunately, this approach can lead to problems when attempts are made to find evidence that falsifies the SEU hypothesis. As Schoemaker (1982) points out, it is always possible under such a situation to discount the validity of evidence against the theory by pointing to problems with the research method, or to factors that have not been allowed for or measured accurately. This argument is based on the demarcation criterion of Popper (1983 p. xix) which is that a 'statement (a theory, a conjecture) has the status of belonging to the empirical sciences if and only if it is falsifiable.'

There is also a more fundamental problem with the *as if* justification for positive theories; the 'black box' nature of the theory. If the axioms of the theory are not in any meaningful sense representative of the behaviour of decision makers, then it implies that the theory treats the behaviour *as if* it is derived from a 'black box', the inner workings of which are unobservable and unknowable. The problem with this is the user of the 'black box' can never be sure when the method is appropriate and when it is not; when it is likely to give accurate results and when it is not. In this context it is not possible to follow Friedman's proviso of specifying the circumstances under which the formula works.

To take a leaf out of Friedman's tree, the point can be illustrated with a story. Imagine a person who has bought his first car. He knows how to drive the car because he has taken lessons from a driving instructor. However, he knows nothing about the workings of the car except that it requires petrol every so often. In his experience the car is reliable; provided he keeps it supplied with petrol it gets him to wherever he wants to go. The car is behaving *as if* filling the car regularly with petrol is the only requirement for keeping it running reliably. Unfortunately, as those who know a little more about the inner workings of the 'black box' of the motor realise, at the very least cars also need to be supplied with oil and water. If this is not done, then the car will break down and will not be reliable, especially if driven for long periods or under harsh conditions. Even this is not the end of the problem, as fan belts and hoses are also likely to break at the most unexpected times unless they are checked and replaced when required. The list could go on. What is more important, the person who does not understand the workings of the 'black box' will not know why it has broken down and therefore cannot 'specify the circumstances under which the formula works' with any consistency.

Friedman's argument that a predictive model only needs to be able to predict is therefore only the minimum necessary requirement of an effective model. Violations of the underlying axioms may be disturbing as they imply the user cannot be sure when the model is likely to fail in its predictions. A detailed critique of the modernist methodology, to which Friedman's argument belongs, can be found in McCloskey (1983). Here it is argued this approach is not followed in the practice of economics, nor are many of its propositions accepted by philosophers or physical scientists from where it gained its original respectability.

Schoemaker (1982) suggests a descriptive model needs to meet much tougher guidelines than a predictive model and that the validity of the axioms and the manner in which information is processed are also important.

The arguments above suggest that while predictive ability is an important criterion for evaluating the SEU or any other model, the validity of their axioms is also important for their descriptive evaluation and may also be relevant for their predictive evaluation. Perhaps just as importantly, research that attempts to develop models with realistic axioms and predictive ability may be a worthwhile exercise.

3.3 Early developments in decision theory

In the 17th and 18th century early decision theorists were interested in solving problems relating to whether to believe in God and how the upperclass could make the most money out of their gambling pursuits. Their initial solutions to the problem were to use the concept of maximising the expected gain from a gamble (Machina 1987; Munier 1988).

It proved unsatisfactory because many people considered more than the expected gain when responding to gambles. Nicholas Bernoulli was the first to suggest an example that graphically illustrated the point, known as the *St. Petersburg Paradox* (Munier 1988). The paradox revolves around the finding that, in practice, people were only prepared to pay a small amount of money for a game that in theory had an infinite mathematical expectation. According to Munier (1988) several people (de Montmort, de Buffon and Daniel Bernoulli) arrived at similar solutions to the problem posed by the paradox. This was that people maximise the expected utility of the outcomes rather than the expectation of monetary gains. To explain the phenomenon Daniel Bernoulli (1738, p. 25) proposed a logarithmic utility function *U(w)* that implied diminishing marginal utility for wealth, or in his words 'the utility resulting from any small increase in wealth will be inversely proportional to the quantity of goods previously possessed'.

Schoemaker (1982) comments that, since Bernoulli did not suggest how to measure utility and did not argue why use of his expectation principle was rational, his theory was essentially descriptive rather than normative. The development of the expected utility principle as a normative model was left to von Neumann and Morgenstern (1944).

Mainstream nineteenth-century economists considered people possessed a cardinal measure of utility (Henderson and Quandt 1980). In the early part of the 20th century, following on from Pareto who suggested that cardinal utility was not needed to describe preferences between goods (Boadway and Bruce 1984), the economics profession began to accept ordinal utility concepts. Pareto's case against the need for a cardinal utility was strengthened by several authors, including Hicks and Allen (1934) who provided a justification for using only ordinal preferences in economic theory. The *coup de grace* delivered by Robbins (1938) declared that interpersonal utility comparisons were 'unscientific'.

The 'takeoff' phase for the EU paradigm was reached with the publication of the *Theory of Games and Economic Behavior* by von Neumann and Morgenstern (1944), although Ramsey (1931) quite independently had already outlined the arguments of which the later developments are variations. Von Neumann and Morgenstern developed an axiomatically-based proof in which preferences between gambles could be figured out from the expected utility of the gambles. This provided the basis for the analysis of economic behaviour under uncertainty that was to become the EU paradigm. It should be noted that they saw their theory as stating 'the mathematically complete principles which define "rational behaviour" for participants in a social economy ...' (von Neumann and Morgenstern 1953, p. 31). In other words, this was a prescriptive rather than a descriptive or predictive theory.

The assumptions inherent in the von Neumann-Morgenstern axioms imply the existence of numerical utilities for outcomes, whose expectations for lotteries provide a utility index that determines a preference ordering over lotteries. A person is hypothesised to possess a utility function *U(.)* defined on some outcome set *W*. Because of restriction on transformations, *U(w)* is considered a type of cardinal utility. The cardinal characteristics of the function relate only to describing behaviour under risk, and it makes no sense to add von Neumann-Morgenstern utilities (Ellsberg 1954). However, Schoemaker (1982, p. 533) points out 'it *implicitly* assumes that a neoclassical type of utility exists, otherwise it would not be possible psychologically to determine the certainty equivalence of a lottery.'

Unlike its most commonly used derivative, the SEU model, the von Neumann-Morgenstern utility model envisaged the use of objective probabilities. The debate over what constitutes a probability has a long history and a voluminous literature and it is not proposed to go into this debate here. Schoemaker (1982) outlines four major schools of probability that have received support. These are: the classical view of objective probability as number of elementary outcomes divided by total number of possible elementary outcomes; the modern axiomatic view of objective probability, the logical school; and the subjective or personal probability school.

In recent times, the most widely accepted view of probability has been that of the subjective or personal school. Its development was pioneered by Ramsey (1931), de Finetti (1972), and Savage (1954). Probability is viewed as the degree of belief a person has about a proposition. This view has the flexibility to account for repetitive events and unique events, an important advantage over the objective and logical views of probability. It also implies different people may disagree over the probability of an event. Although subjective probabilities are assumed to arise from personal strength of conviction about events, they are required to meet certain coherency requirements that make them mathematically indistinguishable from objective probabilities (Schoemaker 1982). These requirements include: probabilities must not lie outside the range zero to one; the probability of either of two or more mutually exclusive events occurring is the sum of their individual probabilities; and the probability of the universal set of events is one (Anderson, Dillon and Hardaker 1977). Ramsey (1931, p. 84) argues that if a person's belief system violated the laws of probability 'He could have a book made against him by a cunning better and would then stand to lose in any event.' This is the widely used 'Dutch book' test for coherence of probabilities.

3.4 Subjective expected utility theory

Savage (1954) extended the von Neumann and Morgenstern expected utility model to include a personal view of probabilities which forms the basis of the SEU model. This model has become the standard for problems of choice under risk both in its widespread usage and as an index by which competing models are judged.

3.4.1 Preference ordering using subjective expected utility theory

The SEU model purports to order risky prospects according to the preferences or attitudes of the decision maker. This ordering is achieved by a single-valued index for each prospect that derives from the decision maker's von Neumann-Morgenstern utilities and subjective distributions of the outcomes. As with von Neumann-Morgenstern utility a person is hypothesised to possess a utility function $U(.)$ defined on some outcome set W. Outcomes $w \in W$ may be interpreted as any type of outcome, but are generally construed in monetary terms as wealth or income[2]. A decision problem consists of a set of prospects (or action choices) $A_1, A_2, \dots, A_n$, and a related set of outcomes w_{ij} associated with the jth prospect in the ith state of nature. Each state of nature s_i has an associated subjective probability of occurrence $P(s_i)$. Each outcome w_{ij} is allocated a von Neumann-Morgenstern utility value $U(w_{ij})$. The subjective utility index for each prospect is obtained by summing the utility value for each outcome of that prospect weighted by its associated probability. This is expressed mathematically as:

[2] The meanings of the symbols in the notation are as follows: ε = element of; ∀ = for all; ≻ = preferred to; ~ = indifferent; ∃ = there exists.

$$\max_{j} EU(w) = \sum_{i=1}^{s} U(w_{ij})P(s_i), \quad j = 1, 2, \dots, n, \qquad 3.1$$

for discrete probabilities, or:

$$\max_{j} EU(w) = \int U(w_j)\, dF(w_j), \quad j = 1, 2, \dots, n, \qquad 3.2$$

for a continuous probability distribution. In other words the decision problem involves maximising the subjective expected utility of the prospects. The prospects are ranked by their expected utility index and the prospect with the highest index is rated the most preferred option.

3.4.2 Underlying axioms of subjective expected utility theory

The axioms underlying the SEU model consist of a series of behaviours which people are assumed to follow consistently. Although the axioms have been formulated in a few different ways they essentially require the same types of behaviour. If people conform then their choice behaviour under conditions of risk can be predicted by the model.

In more mathematical terms the axioms consist of a series of requirements of a person's preference and associated indifference relationships. A commonly used set of axioms for subjectively expected utility theory is outlined by Anderson et al. (1977).

1. Ordering. People can order prospects. That is, given any two risky prospects, A_1 and A_2, a decision maker either prefers A_1 to A_2, prefers A_2 to A_1, or is indifferent between them.

$$\forall A_1, A_2 \in Y, \quad either\ A_1 \succ A_2,\ A_2 \prec A_1,\ or\ A_1 \sim A_2. \qquad 3.3$$

2. Transitivity. Extends the idea of ordering to transitivity of orderings for three or more risky prospects. If a decision maker prefers A_1 to A_2 (or is indifferent between

them) and prefers A_2 to A_3 (or is indifferent between them), she will prefer A_1 to A_3 (or be indifferent between them).

$$\forall A_1, A_2, A_3, \in Y, \quad if\ A_1 \succ A_2,\ and\ A_2 \succ A_3,\ then\ A_1 \succ A_3. \qquad 3.4$$

3. Continuity. If a decision maker prefers A_1 to A_2 to A_3, then some subjective probability P will exist (between zero and one) such that the decision maker is indifferent between A_2 for certain and a risky choice of receiving A_1 with probability P and A_3 with probability (1-P). It implies that, if a decision maker is faced with a choice between a risky choice with a good and a bad outcome and a sure thing of intermediate outcome, there will exist a probability for the bad outcome (and complementary probability of the good outcome) for which she is indifferent between the risky prospect and the sure thing. If the probability of the bad outcome is increased she will prefer the sure thing and vice versa.

$$\begin{array}{c} \forall A_1, A_2, A_3 \in A,\ A_1 \succ A_2 \succ A_3 \\ \exists\ p \in [0,1],\ A_2 \sim [(A_1;p), (A_3; 1-p)]. \end{array} \qquad 3.5$$

4. Independence among choices. When A_1 is preferred to A_2, and A_3 is another risky prospect, then a risky choice $PA_1 + (1\text{-}P)A_3$ is preferred to another risky choice $PA_2 + (1\text{-}P)A_3$ for some probability P. In other words, adding a third risky prospect (with identical payoff and probability) to each of two prospects does not change the preference ordering between the prospects. No interaction occurs between the third prospect and the original prospects.

$$\begin{array}{c} \forall A_1, A_2, A_3 \in A,\ \ p \in [0,1] \\ A_1 \succ A_2 \Rightarrow (pA_1 + (1-p)A_3) \succ (pA_2 + (1-p)A_3). \end{array} \qquad 3.6$$

Another common form of the independence axiom is the 'sure thing principle' outlined by Savage (1954).

A decision maker who obeys these axioms can be considered to have a utility function $U(w)$ which reflects her preferences and associates a single real value with any risky prospect (Anderson et al. 1977).

3.4.3 Implications of subjective expected utility

A subjective expected utility function is unique up to a linear transformation and has the same cardinal characteristics as a von Neumann-Morgenstern utility function. That is, the scale of measurement for the function is arbitrary. Comparisons between individuals are therefore meaningless, as are comparisons that attempt to define one prospect as having a proportion of the utility of another prospect (Anderson et al. 1977).

An important implication of the SEU model is that a decision maker's attitude towards risk can be inferred from the shape of her utility function defined over gambles. A person with a concave utility function is said to have preferences that are risk averse while a person with a convex utility function is said to be risk preferring. A linear utility function implies risk neutrality. Both theoretical and empirical studies have suggested that some decision makers may have both convex and concave segments in their utility function (e.g., Friedman and Savage, 1948; Kahneman and Tversky, 1979; Anderson et al. 1977).

Given that a decision maker's attitude to risk is reflected in the shape of her utility function, the obvious question is how to measure the degree of risk aversion/preference. Since the second derivative of the utility function ($U''(w)$) changes under a linear transformation, it is not suitable. Two measures of risk aversion, the coefficients of absolute and relative risk aversion, were developed by Pratt (1964) and Arrow (1965) that are invariant to a linear transformation.

The coefficient of absolute risk aversion $r_a(w)$ is defined by:

$$r_a(w) = -U''(w)/U'(w) \qquad 3.7$$

where $U'(w)$ and $U''(w)$ are the first and second derivatives of the utility of wealth function. The sign of the risk aversion coefficient, either positive, zero, or negative, shows whether the person is risk averse, risk neutral, or risk preferring. The size of the coefficient suggests the degree of risk aversion or preference. In principle a decision maker's utility function can show decreasing risk aversion ($r_a'(w) < 0$), constant risk aversion ($r_a(w)$ = k), or increasing risk aversion ($r_a'(w) > 0$). It is regarded as a local measure of aversion to risk since it evaluates risk attitudes at particular wealth levels. Global comparisons of risk aversion can only occur if one decision maker has a higher $r_a(w)$ than another for all w. Most people feel intuitively that $r_a(w)$ declines with increasing wealth (declining absolute risk aversion). In other words, an increase in wealth will increase a person's willingness to accept a bet. This has generally been supported empirically (Arrow 1965).

The coefficient of relative risk aversion $r_r(w)$ is also a local measure of aversion to risk, but as a proportion of wealth, so to that degree it is independent of the units in which wealth is measured. It is defined by:

$$r_r(w) = -wU''(w)/U'(w) \qquad 3.8$$

Although Arrow (1965) has argued that relative risk aversion should be an increasing function of w, he admits it is not as intuitively obvious as declining absolute risk aversion.

3.5 Problems with subjective expected utility theory as a descriptive and predictive theory

Subjective expected utility theory has been applied to a wide range of prescriptive, predictive and descriptive problems, both within and outside economics. Almost from the very beginning, however, doubts have been raised about the underlying axioms of both EU and SEU theory. The Allais paradox, as it is now referred to, was first demonstrated by Maurice Allais in 1952 at a conference on decision making. Problems with the reliability of probabilities were introduced early by Ellsberg (1961). Initially these problems had little effect on the popularity of the theory. In the last decade, however, there has been increasing research interest in the implications of violations in the axioms, and other problems with the theory's predictive ability, for the validity of EU and SEU as predictive, descriptive and normative theories of decision making under uncertainty. Surveys of the research can be found in Schoemaker (1982), Fischhoff et al. (1983), Machina (1987), Munier

(1988), Quiggin (1988) and Luce (1992). Violations of many axioms of the theory have been recorded. As well, evidence has been found that the theory does not describe the procedures people use in making decisions, nor does it predict people's behaviour accurately except in a few simple situations. Some even regard key axioms of the theory as inappropriate in prescriptive situations.

Many leading developers of the theory consider it should be applied to prescriptive rather than descriptive or predictive problems because it performs poorly for the latter purposes. Savage (1954, p. 97) argued that its main use was as a prescriptive theory, while suggesting that it might be used for descriptive purposes where the departures from its assumptions were not too serious. Von Winterfeldt and Edwards (1986) support this view arguing that SEU does only a 'mediocre job' when used to predict choice among bets, although they believe that nothing else does much better. The prescriptive view of its use appears to have been advocated by von Neumann and Morgenstern (1953), as mentioned earlier in 3.3. Raiffa (1961) also did not regard the SEU model as a descriptive or predictive model. He goes on to point out: 'If most people behaved in a manner roughly consistent with Savage's theory then the theory would gain stature as a descriptive theory but would lose a good deal of its normative importance ... but as it is, we need to do a lot of teaching' (Raiffa 1961, p. 690-1).

As this thesis is concerned with descriptive and predictive analysis of the wool industry, discussion in the remainder of this chapter will focus on problems that have arisen with SEU theory for these uses. Initially, discussion focuses on violations of the axioms, followed by failures of prediction and finally problems with the descriptive validity of the model. Considerable overlap occurs between these categories both in the design of experiments and the implications of their findings, but each is important to the decision to reject SEU as a predictive and descriptive model of behaviour.

Included in the discussion is literature published after the final choice of methodology for this study was made. While the latest research has clarified some issues, several new problems have been raised. The conclusions reached initially by the author have not been greatly altered by the new findings. If anything, they have been reinforced.

3.6 Violations of SEU axioms

Most of the findings that have cast doubt on axioms of SEU theory have concentrated on violations of the independence and transitivity axioms. Some recent research has also found evidence of violations of the reduction of compound lotteries axiom. In line with many developments of SEU theory, this axiom was not presented earlier, although it is implicitly assumed. Simply, it is that people are indifferent between between any compound lottery (i.e. a two-stage or multiple-stage lottery) and a single stage lottery that is probabilistically equivalent.

3.7 Violations of the independence axiom - the Allais paradox

The most widely quoted violation of the independence axiom is the Allais paradox or 'certainty effect'. Although there have been many formulations of the Allais paradox, the presentation according to Allais (1979a) is shown here. Consider choosing between the following gambles.

First, for Bet 1 choose between:

Option 1. $1,000,000 with probability 1.0; and

Option 2. $5,000,000 with probability 0.1,
$1,000,000 with probability 0.89,
$0 with probability 0.01.

Next for Bet 2 choose between:

Option 3. $5,000,000 with probability 0.1,
$0 with probability 0.9; and

Option 4. $1,000,000 with probability 0.11,
$0 with probability 0.89.

In a wide range of experiments using variations on this formulation, researchers have found that the most common answer to the problem is for subjects to choose Option 1 over Option 2 in Bet 1 and Option 3 over Option 4 in Bet 2 (Allais 1953; Slovic and Tversky 1974; MacCrimmon and Larsson 1979). These choices violate the axioms of SEU and, in particular, the independence axiom. Even Savage gave the most common answer when first presented with the problem. He subsequently recanted on his original answer to the problem, suggesting it was due to framing problems (Savage 1954), although Pope (1986) maintains that his argument implies irrational behaviour. Despite his rethink, Savage still admitted an intuitive attraction to his original decision.

It is readily apparent, at least to those who shy away from Option 1, that the critical feature of the paradox is the 0.01 probability of receiving nothing with Option 2. The independence axiom (as stated in 3.4.2) implies that if two risky choices have an identical probability and payoff branch, the levels of payoff and probability should not affect choice between the two, that is, probability and payoff are independent. In practice what is happening is that people give a greater importance to security of outcome rather than 'utility' when they have a choice between a certain outcome and a risky outcome.

Initially these results were criticised because it was thought people would correct themselves once it was pointed out their response was wrong according to 'rational' behaviour as outlined by SEU theory. However, it has generally been found that when people are presented with both sides of the argument no significant net swing occurs towards obeying the independence axiom (MacCrimmon 1968; Slovic and Tversky 1974). Anyhow, this argument is irrelevant as a defence of SEU as a descriptive or predictive theory since, in practice, decision makers are not suddenly presented with arguments telling them to revise their decision every time they fail to obey the 'rational' axioms.

3.7.1 The common-consequence and common-ratio effects

While the original Allais paradox was demonstrated for large amounts of money, similar, although diminishing responses are found in less extreme situations.

Machina (1987) refers to the Allais paradox as a special case of a class of violations known as the 'common-consequence effect'. Using variations of this formulation several authors (MacCrimmon 1968; Kahneman and Tversky 1979; MacCrimmon and Larsson 1979) have shown violations of the independence axiom.

A further class of violations of the independence axiom, also related to an earlier example by Allais (1953), is the 'common-ratio' effect. The 'Bergen Paradox' of Hagen (1979) and some effects found by Kahneman and Tversky (1979) fall into this category (Machina 1989). Further violations of this type have recently been demonstrated (Loomes 1991; MacDonald, Kagel and Battalio 1991; MacDonald, Huth and Taube 1992). These violations reflect negatively on the theory as a descriptive model since people obviously do not use probabilities and outcomes in the manner prescribed, and as a predictive theory, since in many different situations the theory is not predicting people's behaviour.

More recently, research has focussed on mapping indifference curves and testing the hypothesis of 'fanning out' of preferences in the unit triangle (Camerer 1989; Prelec 1990; Bar-Shira 1992; Harless 1992b) following the introduction of this concept by Machina (1982). Some evidence was found of both 'fanning in' and 'fanning out' of preferences (Prelec 1990; Harless 1992b), both of which imply violations of the independence axiom, but also create problems for models of such preferences. On the other hand, Bar-Shira (1992) provides evidence that violations of the independence axiom of this type are less likely to occur in real-life than under experimental conditions.

Recent experimental evidence (Carlin 1992; Luce 1992) raises doubts that the evidence of violations of the SEU theory outlined above were due solely to violations of the independence axiom. Instead, it appears people consistently violate the reduction axiom and that this is part of the reason for their violation of the independence axiom.

3.8 Violations of transitivity

Decision makers have been found to violate transitivity over risky prospects and through the preference reversal phenomenon (Edwards 1954; MacCrimmon 1968; Tversky 1969; Lichtenstein and Slovic 1971; Grether and Plott 1979; Loomes, Starmer and Sugden 1991). Preference reversals occur when subjects are asked to choose between pairs of lotteries and then are asked to state the lowest price for which they would be willing to sell their right to participate in each lottery. Many respondents give a lower price for the preferred lottery, which appears inconsistent.

Karni and Safra (1987) and Segal (1988) argue the method of obtaining the selling price for the lotteries in most of these studies is not equal to the certainty equivalent if the axioms of EU theory (respectively the independence and reduction axioms) are violated. Here preference reversals may not involve a violation of transitivity. However, Loomes et al. (1991), in a study designed to overcome some shortcomings of the previous research, still found systematic violations of transitivity.

Recent reviews of the literature on transitivity can be found in Fishburn (1991) and Luce (1992). While it appears that transitivity of orderings of risky prospects is a principle that most people would want to obey, they do not always do so, or even want to do so (Fishburn 1991). A principal reason could be the simplifying heuristics used to make decisions. From a descriptive viewpoint this means the SEU theory is inadequate. However, from a predictive viewpoint it is likely to be less of a problem, except in situations where systematic violations of transitivity occur.

3.9 Violations of the reduction axiom

Although the reduction of compound lotteries axiom has not been always spelt out explicitly in the various formulations of SEU, it has been implicitly assumed in many applications and tests of the theory. Recent studies conducted by Segal (1990), Schoemaker (1991), Starmer and Sugden (1991), and Carlin (1992) suggest many decision makers do not conform to its tenets. Although they cast doubt on some reasons suggested for violations of SEU found by the earlier studies, these findings do not support the descriptive or predictive validity of SEU.

3.10 Predictive failures of SEU

In several important fields SEU theory gives inaccurate predictions about people's behaviours. These include situations where there is ambiguity about probabilities and outcomes, in situations of unique rather than repeated probabilities, gambling and insurance decisions, and where the framing or context of the decision produces different results. One factor leading to errors of prediction for some of these decisions might be difficulty with measurement of utility functions. The next section contains a brief discussion of these issues.

3.11 Ambiguity

An enduring debate in the literature on SEU theory is over how to define risk and uncertainty and whether differences exist between these two terms. It dates from Knight (1921) who is generally interpreted as defining risk as a situation in which decision makers act as if they have in mind well-defined probabilities on possible outcomes, while uncertainty is a situation where they do not. In other words, in situations of risk there is a known or knowable probability distribution, and uncertainty exists where it is not possible to specify knowable probabilities (Friedman 1962).

Many current decision theorists deny any distinction between the two because it would imply decision makers could not choose consistently among lotteries in situations of 'uncertainty' (LeRoy and Singell 1987). They would agree with Dillon (1962, p. 24) that 'some information or intuitive feelings are always available so that the most reasonable approach is a subjective probability one.' Subjectivists would also argue that objective probabilities are in practice necessarily subjective so that the objective-subjective distinction attributed to Knight (e.g., Menz 1976) is inappropriate (Menz 1976; Anderson et al. 1977).

A fundamental assumption of SEU theory is that all a decision maker's beliefs about the states of the world in a given situation can be represented by a unique subjective probability distribution defined over the states. The implication of this is that if a person assigns the same probability to the occurrence of two states of the world, then the person can have no other feelings about differences in reliability of these two probabilities.

3.11.1 The reliability of probabilities and the Ellsberg paradox

The question of reliability of probabilities and whether this influences choice is, however, a separate (although related) argument to the one about the risk-uncertainty distinction. In deriving his axioms Savage (1954 pp. 57-8) showed that he was aware of the problem of unreliability of probabilities when he said:

> There seem to be some probability relations about which we feel relatively "sure" as compared with others. When our opinions, as reflected in real or envisaged action, are inconsistent, we sacrifice the unsure opinions to the sure ones.

However, he did not have a solution to it, and was not particularly concerned since he saw the theory as normative.

The most famous illustration of 'vague' probabilities is the Ellsberg paradox (Ellsberg 1961) which showed that people have an aversion to 'vague' probabilities. Apart from its implication for the validity of the independence axiom, the paradox raises doubts about how effectively subjective probabilities capture the underlying psychological aspects of uncertainty. It demonstrates differences exist between exact probabilities and 'vague' probabilities and that 'vague' probabilities derived from choices between gambles are not coherent.

Ellsberg argued this paradox occurred because of the differences in information that were available. He called this the *ambiguity* of the information, which he defined as 'a quality depending on the amount, type, reliability and 'unanimity' of information, and giving rise to one's degree of 'confidence' in an estimate of relative likelihoods.' (Ellsberg 1961, p. 657). Ellsberg also tested the effect of decreasing ambiguity, which tended to reduce aversion, but the observed pattern of choices remained essentially the same.

Despite Ellsberg's paradox, several authors (Raiffa 1961; Roberts 1963; Menz 1976) did not accept the concept of ambiguity of probabilities. It is relevant though, that one of their chief objections was its implications for SEU theory as a normative theory, not as a descriptive or predictive theory (e.g., see Raiffa 1961, p. 690). Menz (1976) suggests the use of diffuse priors to account for ambiguity, but unfortunately this does not answer the Ellsberg paradox.

Despite the *doubting Thomases* the Ellsberg paradox has been extensively tested and found to apply to a wide range of people including naive subjects, experts, theoreticians and even practitioners of decision analysis (Raiffa 1961; Gärdenfors and Sahlin 1982; Einhorn and Hogarth 1985; Hogarth and Kunreuther 1985; Curley and Yates 1989; von Winterfeldt and Edwards 1986; Viscusi and Magat 1992; for a recent review see Camerer and Weber 1992). Decision makers have also been resistant to reversing their decisions even when the 'rationality' of the SEU axioms and the implications of their responses are pointed out to them.

A further development in this area has been an attempt to distinguish between risk, uncertainty and ignorance (Gärdenfors and Sahlin 1982; Einhorn and Hogarth 1985). Einhorn and Hogarth (1986) define ambiguity as an intermediate state between risk (where information is reliable and all but one distribution is ruled out) and ignorance (where no information exists and no distributions are ruled out). This definition of ambiguity fits in with the view expressed by Ellsberg (1961, pp. 660-1) who said:

> Ambiguity is a subjective variable, but it should be possible to identify 'objectively' some situations likely to present high ambiguity, by noting situations where available information is scanty or obviously unreliable or highly conflicting; or where expressed expectations of different individuals differ widely; or where expressed confidence in estimates tends to be low.

While ambiguity avoidance has been emphasised in the discussion above, Einhorn and Hogarth (1988) and Hogarth and Kunreuther (1989) have shown that in certain cases people may shift from ambiguity avoidance to ambiguity preference. This shift is related to the subjective probability of occurrence of an outcome and whether it involves a loss or gain. Heath and Tversky (1990, p. 72) investigated this problem further and suggested that a possible reason for the difference is that 'people prefer to bet in areas where they feel competent and they avoid betting in domains where they feel ignorant.'

Another finding that has implications for descriptive and predictive models of decision making is that, particularly on the gain side, aversion to uncertainty or ambiguity may be independent of attitude to risk (Cohen, Jaffray and Said 1987; Schoemaker 1991).

3.11.2 Outcome uncertainty

The Ellsberg paradox highlighted the distinction between risk (where probabilities are known) and ambiguity or uncertainty (where probabilities are ambiguous or unknown). In the real world, however, another class of problem is outcome uncertainty (i.e., uncertainty about w_{ij} in the terminology used for defining SEU) (Zeckhauser 1986; Clementson 1988; Bogetoft and Pruzan 1991). This can arise because of a failure to define or consider a prospect or action choice (an A_j) or a state of nature (an s_i). Even when the action choices are well known the possible states of the world may be unknown. As an example consider the situation of a wool producer looking five years into the future from around 1986 when things were rosy. Though he may have been able to make some prediction about the boom in prices of the late 80s, what chance would he have had of considering a world in which at around the same time: the Soviet Union had disintegrated, the world economy was in a prolonged recession, the Chinese processing industry collapsed, he was in the midst of a drought, and, partly due to setting the Reserve Price too high, the Reserve Price Scheme had folded leaving a large stockpile? Would the wool producer have even considered a period of prolonged and very low prices that has been the result?

The discussion above indicates that while the jury may still be out on the question of the importance of ambiguity to a normative model of decision behaviour, it is certainly an important determinant of people's unaided behaviour. Because SEU theory does not acknowledge that uncertainty about uncertainty exists, it has no way of dealing with the empirical and intuitive evidence that it is important in descriptive and predictive models, a fact recognised by both Savage (1954) and Raiffa (1961).

3.12 Unique versus repeated decisions

A more recent development in the debate over EU maximisation has been raised by Lopes (1981) who questioned the appropriateness of expected value and expected utility maximisation for unique short-run decisions. She suggested that for short-run decisions the probability of coming out ahead (which implies considering the median outcome) could reasonably be considered, rather than, or in addition to, the long-run expectation (which implies considering the mean outcome). Her argument is based on consideration of the St. Petersburg Paradox, consideration of one-off gambles, and a proof that no one who wants to maximise utility can agree to a sequence of bets if each of the single bets is unacceptable. Lopes (1981, p. 380) argues that 'In evaluating gambles such as these [the St. Petersburg Paradox], we do not consider the large amounts that we are prodigiously unlikely to get but, rather, consider the amounts that we are likely to get most of the time.' She goes further to argue that although there is no consideration of the long-run in the von Neumann and Morgenstern (1944) utility theory, people never really combine values and probabilities except in the long run.

Tversky and Bar-Hillel (1983) provided a coherent rejection of her arguments from a normative viewpoint; however, this did not settle the debate. In 1988 an informal conference was held at Leiden University in the Netherlands to discuss the issue of 'Models and Methods for Unique versus Repeated Decision Making' (Beach, Vlek and Wagenaar 1988).

Support for the Lopes position comes from Keren and Wagenaar (1987) who summarise the debate and suggest that differences between the two arguments occur because Lopes (1981) is criticising SEU from a descriptive viewpoint while Tversky and Bar-Hillel (1983) are defending it from a normative viewpoint. Experiments conducted by Keren and Wagenaar (1987) looked at the consequences of unique and repeated gambles on the *certainty effect* and *possibility effect* violations of SEU theory. Their results support the contention that many decision makers perceive and respond to unique and repeated gambles differently. Under unique conditions the *certainty effect* and the *possibility effect* violations were predominant. In contrast, under repeated conditions, most subjects expressed preferences that were consistent with SEU theory.

While a final verdict has not been reached on the implication of unique versus repeated decisions for normative theory, it appears that the distinction has some relevance for descriptive and predictive theories. It is generally the big decisions that have the major influence on farming and have the most potential for adverse effects (Malcolm 1992). People appear to treat a unique decision differently from a repeatable decision and SEU theory appears more applicable to repeatable than unique situations. Since most big decisions are unique, it seems a descriptive and predictive theory needs to consider this factor.

3.13 Problems with gambling and insurance

It is generally assumed in SEU theory that people are risk averse for both gains and losses, that is, they have a totally concave von Neumann-Morgenstern utility function of wealth (Anderson et al. 1977). This creates a problem given the widespread observation that people simultaneously buy lottery tickets and insurance. It implies preference for large gains and aversion to large losses or, if these observations are to be explained, concave and convex segments of the utility function.

Apart from explanations that introduce factors other than the monetary value, various shapes have been suggested for utility functions to account for the phenomenon. An S-shaped utility function with a concave section at lower income levels around present wealth (i.e., locally risk averse), and convex for higher income levels (i.e., locally risk preferring), was suggested by Friedman and Savage (1948). Unfortunately, a utility function with this shape implies unbounded utility which has also been shown to create problems for EU theory (Arrow 1974; Samuelson 1977). However, Friedman and Savage (1948) had already suggested a function that overcame this problem - a function with a further concave segment at very high income levels.

Problems with the revised Friedman-Savage functional form were quickly raised by Markowitz (1952) who instead hypothesised horizontal shifts in the utility function with changes in wealth. Machina (1982) quotes several studies supporting this hypothesis, suggesting outcomes are evaluated as gains and losses, not final wealth states. The traditional economic assumption of utility as a function of wealth, or *asset integration*, was tested by Binswanger (1981, p. 888) using actual gambles made by farmers in India. He concluded asset integration 'is inconsistent with the experimental evidence reported, . . . decision makers apparently do not evaluate utilities of final wealth states but of changes in wealth, that is, utilities of gains and losses.'

Von Winterfeldt and Edwards (1986) provide an interesting insight into the problem of where the reference point or status quo is in evaluation of prospects, which relates to the question of utility over gains and losses. They suggest considering the problem as different transaction flows and that attitudes to risk and the status quo will depend upon which income stream the problem involves. In their case, they describe four transaction flows: a) quick cash stream; b) capital assets stream; c) income and fixed expenditure stream; and d) play money stream. Without going into the idea in detail, the basic principle is that similar 'SEU risks' will be treated differently depending upon the stream in which they are perceived to occur.

Apart from the paradox of insurance and gambling, a range of evidence about people's behaviour in purchasing insurance, derived from hypothetical and practical experience, has raised doubts about the descriptive and predictive power of the SEU model (Eisner and Strotz 1961; Pashigan, Schkade and Menefee 1966; Slovic, Fischhoff, Lichtenstein, Corrigan, and Coombs 1977; Kahneman and Tversky 1979). In some situations people show a preference for buying insurance for high-probability, low-loss events over low-probability, high-loss events, whereas, for example, actuarially unfair flight insurance will be purchased (which is a low-probability, high-loss occurrence). Particular difficulties are experienced in dealing with low-probability, high-loss events. Preferences expressed by consumers for packages of insurance and other relatively expensive forms of insurance with low-deductions are also inconsistent with SEU predictions.

Although various excuses can be made for some problems the SEU model has in predicting insurance and gambling problems, they appear to exist in a variety of situations, many of which are real-life situations.

3.14 Framing and context effects

Additional problems arise for SEU theory from complexities that arise due to the context of a decision, or how the decision is framed. Framing and context is taken here to mean the way in which the decision problem is formulated. It includes the norms, habits, and expectancies of the decision maker, and the way information is presented including the script, verbal labels, social dimensions, information displays and response modes of the decision problem. Since SEU theory assumes decision makers to be indifferent to variation in representation of the same choice problem (Tversky and Kahneman 1986), it cannot account for differences in behaviour that arise in these situations.

Several studies have shown people will respond in systematically different ways to logically equivalent problems when they are framed differently or involve different contexts. An illustration of the effect of context is given by Schoemaker (1982) where losses framed as insurance problems induced greater risk aversion than losses framed as gambles. A similar effect has been displayed by other authors (Tversky and Kahneman 1981; McNeil, Pauker, Sox, and Tversky 1982) in which the same medical survival problem was presented from two different frames of reference, one in which the number who will survive was emphasised, the other in which emphasis was on the number who will die. Presentations that appeared to show that an option would save lives had increased appeal. Even when the inconsistencies in their answers were pointed out, many remained attracted to their original answer.

It has also been shown that the framing of a problem can also lead to violations of such principles as dominance when the problem is presented in a format that requires the decision maker to put the information together to detect the dominance. An example of this was presented by Tversky and Kahneman (1981), which showed that when the complexity of the decision increases people will not necessarily obey axioms that they would otherwise accept. It is also bolsters the contention that in such situations people use simplifying rules that can lead to biases from SEU predictions.

Interaction also occurs between the framing of a decision and the reference point used by individuals to evaluate the problem. Markowitz (1952) initiated the debate over reference point effects when he suggested decision makers assess outcomes from a neutral reference income and their reaction to gambles is influenced by the reference point they use to assess the outcomes. This he saw as depending on whether they had assimilated any recent gains or losses. Kahneman and Tversky (1979), in developing their prospect theory, have provided evidence that people assess outcomes as gains and losses from a neutral reference point, often the status quo. As well people were found to have value functions that were generally concave for gains and convex for losses and steeper for losses than gains.

Further evidence of the interaction of the framing and context of a decision and the reference point effect can be found in articles by Tversky and Kahneman (1986), Tversky, Slovic and Kahneman (1990), Carlin (1992), Harless (1992a) and McDaniels (1992) for a wide range of issues and under a range of conditions. Evidence was found of assimilation of gains and losses, susceptibility of decision makers to manipulation of the reference point and framing of the problem, and failure of procedure invariance. People's decisions were influenced by the way decision problems were formulated and the way information was presented. This influence led to results that were inimical to the predictions of SEU theory. Indeed Tversky, Slovic and Kahneman (1990, p. 215) believe the framing effects and procedure invariance failures 'pose a greater problem for rational choice models than the failure of specific axioms'.

3.15 Utility measurement problems

Perhaps the most convincing argument that SEU theory has problems as a descriptive and predictive theory arises in texts on using SEU for prescriptive purposes (Anderson et al. 1977; von Winterfeldt and Edwards 1986). This is not surprising since, if SEU is needed as a prescriptive theory, by definition it must have some problems as a predictive or descriptive theory. The contradiction over its application is common in the agricultural economics profession. Some have advocated applying the theory to help farmers make better decisions, implying they do not maximise SEU without assistance. Simultaneously, other economists use the theory to predict (and describe) the same farmers' behaviour, implying they maximise SEU without assistance.

A particular problem arises with the elicitation of utility functions for prescriptive or predictive applications. To quote Anderson et al. (1977, p. 69):

> Experience has shown that manipulation of probabilities while keeping consequences fixed is not very satisfactory because of the difficulties people have in mentally grappling with probabilities other than those involving only a single decimal digit. In addition, some people exhibit preference for particular probability values.

Several gambling-based methods have been suggested and used to elicit utility functions including the von Neumann-Morgenstern method, the Modified von Neumann-Morgenstern method (also known as the Equally Likely Certainty Equivalent method), and the Ramsey model (also known as the Equally Likely Risky Outcomes method). The first of these uses variable probabilities, while the latter two use fixed probabilities (Officer and Halter 1968; Anderson et al. 1977; von Winterfeldt and Edwards 1986).

Two weaknesses were found with the von Neumann-Morgenstern method (Officer and Halter 1968). First, preferences of some subjects were not linear in the probabilities because they had preferences for particular probabilities, had difficulties with the idea of probability, or probability weights were involved a la Allais or Ellsberg. Second, since the method involves a choice between a gamble and a certain outcome, people who had a strong aversion to gambling per se were biased towards the certain effect. Both the Modified von Neumann-Morgenstern method and the Ramsey method overcome the probability weighting problems by using 'ethically neutral' probabilities of 0.5. The latter method overcomes the gamble aversion problem by comparing two gambles rather than a gamble and a certain return.

Experimental evidence from Butler and Loomes (1988) provides support for the notion that people do not find it easy to provide 'certainty equivalent' valuations for simple gambles. Evidence of probability weighting has been found in a wide range of studies from experimental gambling situations (McCord and de Neufville 1983; Lattimore, Baker and Witte 1992) to real gambles (Kachelmeier and Shehata 1992). In general, preferences were not linear in the probabilities. Results were consistent with the hypothesis of probability weighting and the weightings differed between gain and loss outcomes. The evidence suggests overweighting of 'small' probabilities, and there is some suggestion of underweighting of 'large' probabilities.

Problems may also arise with gamble-based methods for utility elicitation (von Winterfeldt and Edwards 1986), in particular with the Modified von Neumann-Morgenstern method, because they could be susceptible to anchoring and adjustment biases of the type discussed in 3.18.3.

Another problem that arises is the reflection effect (Kahneman and Tversky 1979). This is the hypothesis that when gains are replaced by losses the preference between negative prospects is the negative image of the preference between positive prospects. Anderson et al. (1977), who had already experienced this problem, suggested that at times initial responses to their utility elicitation procedures will reveal a convex shape for losses. They suggest such a result is wrong from a normative viewpoint and that the interviewer should try to obtain the more 'correct' concave shape by rewording the questions asked.

More recent research has not clarified this issue with Battalio, Kagel and Jiranyakul (1990) and Lattimore et al. (1992) giving only qualified support to the reflection hypothesis. On the other hand, Cohen et al. (1987) found no correlation between subjects' attitudes on the gain side and their attitudes on the loss side. None of this evidence suggests people were likely to conform with the SEU hypothesis. Rather, the picture was that transformation of probabilities seemed highly significant, particularly for small probabilities, and asset integration was not common.

The von Winterfeldt and Edwards (1986) transaction streams may provide some explanation for the confusion that exists with the reflection effect. Decision makers' responses to questions aimed at eliciting their utility functions will be influenced by how they code the questions in terms of their income streams and their attitude to risk for these streams, including the effect of reference point. The idea of risk-taking for relatively small losses in the capital and income streams, but being influenced by quasi-ruin effects for large losses, is intuitively appealing. However, even within a particular stream other factors, such as attitude towards particular types of insurance, may further complicate the problem.

3.16 Descriptive problems with SEU

The violations of axioms and failures to predict discussed earlier in this chapter are also symptoms of problems with SEU as a descriptive model of behaviour. Further confirmation comes from psychological criticisms of the theory and research which shows that decision makers do not behave as Bayesians when dealing with probabilities.

3.17 Psychological critique of SEU theory

Much of the initial evidence against SEU theory came about through the work of those who perceived weakness in SEU theory from a psychological perspective. This section makes use of this evidence and other psychological criticisms to expand the case against SEU theory as a descriptive model. Key points to be discussed include evidence about: information processing limitations, information processing distortions, and aversions that influence the manner in which people make judgments and choices.

3.17.1 Information processing limitations

Research in this area owes much to the work of Simon (1955) who expounded the view that the concept of global rationality needed to be replaced by what he called 'bounded' rationality. In this view decision makers would wish to be rational, but lack the mental capacity to follow the axioms of SEU theory.

As Simon (1990) points out, human short-term memory can handle only a few bits of information at a time and has limited recognition and processing speeds. These constraints, plus limitations on availability of information, mean decision makers are forced to simplify problems and to focus on certain aspects of a problem, while virtually ignoring others. To simplify decisions people not only simplify the problem by using approximations and ignoring some information; they use simplified decision rules (e.g., Larichev, Moshkovich and Rebrik 1988). Various simplifying rules are used which may lead to different solutions, some of which may be inferior choices (Arthur 1991). As a result, behaviour of people has often departed widely from the projections of SEU theory in all but the simplest of situations (Simon 1978).

One simplification is to consider a single dimension of a problem at a time, and to compare alternatives on this basis rather than assigning an alternative a particular utility level (Schoemaker 1982). Another finding is that people use one or more decision rules depending upon the complexity of the problem. Payne (1976) and Janis and Mann (1977) have provided evidence that people use a variety of strategies to simplify decisions to manageable proportions with the choice of strategy depending upon the size and complexity of the problem.

Since most people can only process information sequentially and attention is a scarce resource, an important technique used to cut down on the continual flow of information is to selectively omit information (Resnikoff 1989). Information that is above an arousal threshold is passed on to a sensory evaluation centre that arranges storage in the brain (Mortensen 1972). Here further selection and attention depend upon an assessment of its pertinence as learned by experience following modification of the information by expectations and understanding. Information that creates the greatest amount of interest is selected for further attention. Such selective attention results in much information being ignored or even misinterpreted.

The isolation effect demonstrated by Kahneman and Tversky (1979) is an illustration that a simplification used by decision makers is to decompose a problem into similar and different components. Greatest attention is paid to the components that differentiate the alternatives. First-degree stochastic dominance violations can be induced by this simplification (Tversky and Kahneman 1981) and different decompositions can lead to different preferences. Other effects, which are probably due mainly to information processing limitations and simplifications, include evidence of improper estimates of probabilities in Bayesian inference tasks. This will be discussed in more detail in 3.18.

3.17.2 Information processing distortions

While it is no doubt true that information processing limitations lead to differences from the predictions of SEU theory, it does not necessarily follow that but for these limitations people would be expected utility maximisers. It is contended in this section, and the next on aversion distortions, that people's preferences divert from the predictions of SEU theory because there are instances in which they do not wish to follow the constraints of the theory even when they could overcome their computational limitations. Reasons for this include that people's behaviour is driven by a multiplicity of goals and constraints. It is not always apparent that departures from SEU are due to either information limitations, distortions of values, distortions of probabilities, or to the factors influencing the selection process.

Both Simon (1955) and Kahneman and Tversky (1979) have considered that alternatives are evaluated in terms of gains and losses from some reference point or aspiration level. Typically this aspiration level is the status quo, but it might also be a minimum level of survival, a hoped-for achievement level, or a future wealth position. The effect of reference point on choice between alternatives and attitude towards risk has already been discussed in 3.15, with the main conclusion being that gains are treated differently from losses by many decision makers. The reference point may be the status quo, but also may be some target or aspiration level. It may be more complex than this as Ritov and Baron (1992) suggest that when change is involved people prefer inaction to action, so that the reference point should be omission rather than the status quo. A further complication is that aspiration levels may change over time (Anand 1985; March 1988), sometimes discontinuously (Earl 1983). Lopes (1987) in her two-factor model of risky choice suggests aspiration is a situation variable influenced by the perceived opportunities and constraints.

Studies of decisions of business executives (MacCrimmon and Wehrung 1986; Shapira 1986) have found they focus on the difference between actual performance and a certain target or aspiration level rather than having fixed risk aversion tendencies. Other findings of these studies that pose problems for SEU as a descriptive and predictive model of decision making include: 1) uncertainty about positive outcomes was not treated as an important aspect of risk; 2) although probability was considered, the size of possible bad outcomes was considered more important and the worst outcome particularly important; 3) most were not interested in reducing risk to a single number; 4) most were more inclined to take risks when an organisation was failing to meet its targets than when the targets were secure; 5) managers tended to focus on one or two attributes of risky investments even when information was available on several important attributes; 6) managers tended to try to control or adjust to a risky situation rather than accept the probabilities and potential losses as fixed; 7) a manager's willingness to take risks in one situation was only weakly related to his willingness to take risks in similar situations, reflecting his desire to choose the time and place to accept risks.

March and Shapira (1987) suggest the empirical studies on risk-taking by managers have three implications for understanding their risk-taking behaviour. First, risk-taking is insensitive to probability estimates. Second, the context in which the risk is to be taken influences the risk preference (shades of von Winterfeldt and Edwards' transaction flows). Third, while taking risks is seen as desirable, gambling is not.

Other research has suggested that people are more likely to handle uncertainty by means of common verbal expressions and the rules of conversation associated with them rather than numerical probability (Zimmer 1983). He points out that mathematical probability theory did not develop until the seventeenth century, and then only in Europe, while verbal expressions to describe uncertainty are found in most languages and were used much earlier. Support for this view comes from Wright (1984) who compared the methods of conceptualising uncertainty of East Asians and Britons. He found Asians were more likely to use non-probabilistic thinking, and less probabilistic thinking than Britons. Although there were qualitative differences in how they dealt with uncertainty, he concluded neither was necessarily superior, but that 'the relative success of the two alternative ways of dealing with uncertainty depends on the prevailing external environmental conditions.' (p. 80).

3.17.3 Aversion distortions

Aversion distortions occur where decision makers refuse to follow the SEU axioms even when the reasons for following them are pointed out. They do not occur because of information processing limitations or distortions, but because the decision maker has an aversion to the implications of the axioms for the decision. Distortions that come under this heading include aversion (or sometimes preference) to ambiguity, aversion to ruin, the 'certainty' effect, the long run/short run question, and confirmation bias.

The ambiguity effect, the certainty effect and the unique versus repeated decision problems have already been discussed extensively in this chapter, so they will not be repeated here. Confirmation bias, which is the tendency of a person to ignore or discount information that does not fit their current viewpoint (Smithson 1989) is another example of behaviour that occurs because decision makers are not SEU maximisers. A corollary of this is the tendency to search and attend to information that confirms current thinking. An important effect of confirmation bias is to maintain the status quo. The key point to be made about these behaviours is that they are instances of situations where decision makers disobey the SEU axioms because the results derived from SEU theory do not agree with their preferences.

3.18 Use of probabilities by decision makers

SEU theory assumes decision makers act in a particular situation as if they have a unique subjective probability distribution defined over states of the world, and that this probability distribution is coherent. By coherence it is meant that their probabilistic beliefs fulfil the laws of probability theory including Bayes law for updating probabilities. Bayes theorem makes use of conditional probabilities and, in basic form, says the posterior probability of the *i*th state, given the *k*th forecast from some experiment, is equal to the product of the prior probability of the *i*th state and the likelihood probability of the *k*th forecast given the *i*th state, divided by the probability of the *k*th forecast (Anderson et al. 1977). This is illustrated algebraically below:

$$p(s_i|z_k) = \frac{p(s_i)p(z_k|s_i)}{\sum_i p(s_i)p(z_k|s_i)} = \frac{p(s_i)p(z_k|s_i)}{p(z_k)} \qquad 3.9$$

where: s_i is the *i*th state of nature
$p(s_i)$ is the prior probability of s_i occurring
z_k is the *k*th possible forecast from some experiment
$p(z_k|s_i)$ is the likelihood probability of z_k occurring given s_i
$p(s_i|z_k)$ is the posterior probability of s_i

It has become increasingly apparent that the assumption that people act as if they use probabilities in the manner prescribed by SEU theory when making unassisted decisions is, at the very least, dubious. The literature on the subject contains many statements like the following:

> In his evaluation of evidence, man is apparently not a conservative Bayesian: he is not a Bayesian at all. (Kahneman and Tversky 1972, p. 450)

> People systematically violate the principles of rational decision making when judging probabilities, making predictions, or otherwise attempting to cope with probabilistic tasks. (Slovic, Fischhoff and Lichtenstein 1976, p. 169)

> There is extensive evidence that when individuals have to estimate or revise probabilities for themselves they will make systematic mistakes in doing so. (Machina 1987, p. 147)

In this section some support for these statements is discussed. Although apparently people can generally express their beliefs about the likelihood of a state of nature occurring, several studies have shown (Tversky and Kahneman 1974; Schoemaker 1991; Grether 1992) that when people have to estimate or revise probabilities for themselves in anything but a simple decision making environment, they employ a limited number of rules. The simplifying heuristics or rules enable decision makers to cope in situations where their cognitive restrictions do not enable them to process the available information accurately. Although these rules save on time and effort and may at times lead to valid and accurate solutions, in some situations they may lead to systematic biases. Evidence is presented for the judgmental heuristics of representativeness, availability and anchoring (Tversky and Kahneman 1974), which can lead to large, persistent and serious biases from the predictions the SEU model (Slovic, Fischhoff and Lichtenstein 1977).

3.18.1 Judgment by representativeness

Decision makers are often required to make assessments about the probability that object A belongs to set B or that process B generates event A. In making these assessments people often rely on the representativeness heuristic, and evaluate based on the degree to which the characteristics of A are similar to, or representative of, B (Tversky and Kahneman 1974; Grether 1992). When this occurs, errors in assessing probabilities may occur because there is the chance that people may neglect other important factors.

The representativeness bias has been hypothesised to be caused by: insensitivity to prior probabilities (see Kahneman and Tversky 1973; Carroll and Siegler 1977; Bar-Hillel 1980); insensitivity to sample size (see Edwards 1968; Slovic and Lichtenstein 1971; Kahneman and Tversky 1972); misconception of chance (see Tversky and Kahneman 1971; Kahneman and Tversky 1972); insensitivity to predictability combined with an illusion of validity; and misconceptions of regression (see Kahneman and Tversky 1973; Jennings, Amabile and Ross 1982).

3.18.2 Judgment by availability

This refers to situations in which people judge the probability of an event by the number of occurrences of a similar event they can recall. While recall of the number of times an event has occurred may often be a valid clue to its probability, it can be influenced by other factors that lead to systematic biases. Evidence has been found for this type of bias in probabilities due to factors such as ease of recall of an occurrence, ease of construction of a particular scenario, and the ease of association of two occurrences (Tversky and Kahneman 1973; Tversky and Kahneman 1974; Fischhoff, Slovic and Lichtenstein 1978).

3.18.3 Adjustment and anchoring

When decision makers need to make an estimate, one strategy is to anchor on some, generally obvious, initial value and adjust this up or down, if this is considered necessary, to accommodate additional information. This method often leads to adjustments that are inexact and insufficient. Tversky and Kahneman (1974) discuss several biases that occur when using this method including: insufficient adjustment; biases in evaluation of conjunctive and disjunctive events (see Bar-Hillel 1973; Tversky and Kahneman 1973); anchoring in the assessment of subjective probability distributions (see Lichtenstein, Fischhoff and Phillips 1977). There is some evidence that conservative adjustment may not be due to biased processing procedures, but could be due to overload when people are forced to use numbers for computation (Zimmer 1983).

3.18.4 Overconfidence

As a broad generalisation, it can be argued that the studies of the use of heuristics for the formation of probabilities suggest the most common error of calibration is one of overconfidence (Slovic, Fischhoff and Lichtenstein 1977; von Winterfeldt and Edwards 1986; Norris and Kramer 1990). People often believe their probability assessments are more accurate than is the case. For instance, confirmation bias may be due partly to people's desire to have their opinions confirmed and avoid having to face the chance of having to admit they may have been wrong. Information that causes them to reconstrue their view of the world causes anxiety and discomfort; a view jointly held by personal construct theory (Kelly 1955) and cognitive dissonance theory (Festinger 1957).

Overconfidence is also due to the simplifying rules used. Sometimes people even participate in bets based on their judgments that would not be regarded as 'rational' according to SEU theory (Fischhoff et al. 1983). It is hypothesised that the reason this occurs is the environment does not provide the information in a way that leads to learning about the errors associated with use of the heuristics (Tversky and Kahneman 1974; Slovic, Fischhoff and Lichtenstein 1977).

3.18.5 Poor calibration and incoherence of subjective probabilities

Decision makers have been found in general to be 'oversensitive' to changes in the probabilities of low-probability outlying events and to overemphasise small probabilities and underemphasise high probabilities (Machina 1982; Lattimore et al. 1992). Another interesting finding is that decision makers may use more exact categories of probability on the gain side, but use only coarse categories of belief on the loss side (Cohen et al. 1987). These involve violations of the SEU axioms and combined with the evidence of violations of Bayes theorem suggest the probabilistic beliefs of many individuals are not coherent. The overwhelming evidence on calibration is that decision makers' subjective probability distributions tend to be too tight and assessment of extreme fractiles is especially prone to bias (Lichtenstein, Fischhoff and Phillips 1982). In addition Schoemaker (1991) indicated they have problems evaluating continuous probability distributions.

Perhaps what this evidence is saying is that many people do not use subjective probabilities in their decision making process when they are not asked to do so and, furthermore, do not even act as if they are doing so. It does not necessarily follow that in all situations the biases which occur as a result will be found in market behaviour (Camerer 1989), although this appears to depend on characteristics of particular markets. Wright concluded that 'some people may be non-probabilistic thinkers, tending to see the world in terms of certainty or total uncertainty' (Wright 1984, p. 79). Whether we believe that decision makers are not very good at using probabilities in their decision making processes, or that they do not use them at all, it appears there are serious problems with the use of theories incorporating subjective probabilities to describe and to predict behaviour.

3.19 Status of subjective expected utility as a descriptive and predictive theory

It should be apparent, following the discussion presented in this chapter, that few individuals follow the tenets of SEU theory in a broad spectrum of their decisions under uncertainty. While it may explain behaviour in a few simple situations, its performance is patchy in the more complex everyday decision making environment. The next point is to consider the performance of SEU as a descriptive and a predictive model using the criteria outlined at the beginning of this chapter. These include: validity of the axioms, relevance of assumptions about information processing, as well as predictive ability.

Several types of evidence have been presented in this chapter to show that SEU performs poorly as a descriptive model of people's behaviour. This is not surprising as its developers never meant it to be a descriptive model. First, widespread violations of the underlying axioms of the model have been displayed. Second, people do not consider the broad range of options, nor do they always attempt to maximise utility as suggested by the theory. Third, many do not use numerical probabilities to handle uncertainty, and of those who do, many do not use them to derive a single value index for a prospect based on the weighted value of the outcomes. Fourth, it does not include the other factors that people consider, such as the quality of information and the context in which the decision is made.

Assessing the performance of SEU as a predictive model is more complicated because of the following arguments used in its defence: the *as if* argument; that divergences from the model occur because of errors in its use by the researcher; that poor prediction may not matter for the aggregate; and the need for alternate models to exist which do a better job of prediction.

Apparently, widespread violations of the axioms occur on an individual basis and often these biases are systematic and consistent. Then, as was argued earlier in the chapter, it is not valid to use the *as if* argument, since one could not have confidence that the 'black box' would produce consistent results and one would not be sure when it was likely to 'break down'. Schoemaker (1982) has also argued the *as if* analogy is not valid since: people are not experts in economic matters; learning from the environment is not always simple; and it is difficult to assess the optimality of people's behaviour without an accurate measure of their utility function, their perception of the problem and what rationality criteria they are using.

When systematic biases occur (e.g., aversion to ambiguity), the aggregation argument may also be suspect. A systematic bias in the aggregate result is likely. The evidence presented in the section on insurance shows some of these individual biases pass through to the aggregate, with certain types of insurance being 'under purchased' and other types being 'over purchased'. Aggregated models based on suspect individual assumptions will have particular problems when the situation being studied is changing rapidly. While the aggregated model may 'predict' the historical situation well, it will perform poorly in predicting the future, since the model does not capture the underlying causes of behaviour, and these will be changing.

While it is becoming increasingly apparent SEU does not perform well as a predictive model, no one model has arisen which has received widespread acceptance as an alternative. From this viewpoint, SEU has not been successfully pushed aside; however, it is recognised that in certain situations other models overcome some of its weaknesses. These models will be discussed in more detail in the next chapter.

3.20 Reaction of expected utility supporters

Several approaches have been used by defenders of SEU theory to maintain its validity in response to research that has found various anomalies in its predictions. These have included, first, arguments that there are biases in the research that has identified the anomalies and second, increasingly, in more recent times suggested modifications to the theory to accommodate the anomalies.

The biases in the research arguments take several forms including: failure to consider the cognitive costs of being rational; failure to allow for the internal representation of the person; and the artificial nature of the experiments which produces different results from the real world. Many of these issues have been addressed in recent research that was discussed earlier in the chapter.

In the last ten years, many researchers who support the general thrust of EU theory have accepted the need for modification of the SEU model. This has resulted in a plethora of models that attempt to account for the main violations of the theory by relaxing the initial axioms (e.g., Handa 1977; Bell 1982; Loomes and Sugden 1982; Machina 1982; Quiggin 1982; Fishburn 1983; Yaari 1987; Tversky and Kahneman 1992). By far the most common approach has been to change the independence axiom, since this seems the axiom that has the most problems and the least support from decision makers. In the next chapter the characteristics, strengths and weaknesses of a selection of these models are discussed.

Chapter 4
What utility theory shall replace SEU?

> No doubt it is refreshing to find economists conferring greater analytical powers on their subjects than they claim for themselves; but it is not necessarily a good research strategy. (Loasby 1986, p. 41)

4.1 Introduction

With the waning of support for SEU as the theory to explain and predict behaviour under uncertainty, the search for alternative models has intensified. Some of these alternatives have remained within the EU framework, while others are outside its domain to varying degrees. A few models that had previously been passed over are being reexamined and reformulated, while others are reworkings of the SEU axioms. In this chapter the aim is to scrutinise some alternative models from the perspective of their practical use in describing and predicting the production and marketing behaviour of woolgrowers.

Given the complexity of the decision making environment in the wool industry, information processing limitations are likely to mean that most woolgrowers use various simplifying strategies to make decisions. While some major decisions of a similar type may be repeated from year to year (e.g., sale time of wool), to a certain extent these are also unique decisions, since if the result of a decision bankrupts a woolgrower, there is unlikely to be a second chance. Similarly, woolgrowers are influenced by a variety of goals when making their decisions, which means that in two seemingly similar situations from an SEU perspective, totally different behaviours may result. The evidence that managers choose the time and opportunity to take a 'risk' (MacCrimmon and Wehrung 1986; Shapira 1986) is relevant here.

The emphasis in this chapter is on the extensions or alternatives to SEU theory which attempt to overcome some of its deficiencies outlined in the previous chapter. These include: theories that weaken or remove the independence axiom (e.g., generalised utility, anticipated utility); theories that weaken or remove the dominance and/or transitivity axioms (e.g., prospect and regret theories); and theories that deal with the ambiguity problem (e.g., venture theory and second-order probabilities). The Newbery-Stiglitz framework is also considered, although this is basically an extension of the traditional SEU model.

4.2 Non-expected utility theories

The evidence of 'probability weighting' which resulted in preferences that could not be explained by the 'linear' expected utility form led to the development of various 'nonlinear' or non-expected utility functional forms that attempted to account for this (Machina 1989). These theories evaluate preferences over lotteries using the value of a function derived from a single value assigned to each outcome. Some forms exhibit preferences that retain transitivity and stochastic dominance and these will be called generalised utility theories (Quiggin and Fisher 1989), while others allow violations of stochastic dominance and/or transitivity. A comparison of the functional forms of the von Neumann-Morgenstern, SEU and some non-expected utility models is given in Table 4.1, along with the names of researchers involved with their development. This provides an overview of the range of alternatives developed, each of which, to greater or lesser degree, can accommodate some violations of the SEU model.

An early development of SEU by Edwards (1955) replaced subjective probability with a decision-weighted subjective probability (see functional form in Table 4.1), and used an interval-scaled utility measured under uncertainty instead of a von Neumann-Morgenstern utility measure. While it explains some violations of SEU, it also allows violations of dominance (Quiggin 1986). Karmaker (1978, 1979) replaced the decision weights with normalised decision weights of the form:

$$w^*(p_i) = w(p_i) / \sum_j w(p_i), \qquad 4.1$$

in an attempt to overcome the dominance problem.

Table 4.1

Examples of non-expected utility models compared with von Neumann-Morgenstern and subjective expected utility models

$\sum p_i u(x_i)$	von Neumann & Morgenstern (1944)
$\sum f(p_i)u(x_i)$	SEU
$\sum \pi(p_i)v(x_i)$	Edwards (1955)
$\dfrac{\sum u(x_i)w(p_i)}{\sum w(p_i)}$	Karmaker (1978)
$\sum w(p_i)v(x_i)$	Kahneman and Tversky (1979)
$\sum_i u(x_i)[q(\sum_{j=1}^{i} p_j) - q(\sum_{j=1}^{i-1} p_j)]$	Quiggin (1982)
$\dfrac{\sum u(x_i)w(p_i)}{\sum \tau(x_i)p_i}$	Chew (1983) Fishburn (1983)
$\sum_i h(x_i, \sum_{j=1}^{i} p_j)[w(\sum_{j=1}^{i} p_j) - g(\sum_{j=1}^{i-1} p_j)]$	Segal (1984) Green and Jullien (1988)
$\sum v(x_i)p_i + [\sum \tau(x_i)p_i]^2$	Machina (1982)

Note:
x_i = wealth, income or gains and losses
$u(x_i)$ = utility constructed from gambles
$v(x_i)$ = value of outcome i.
$f(p_i)$ = subjective probability
$\pi(p_i)$ = transformation of subjective probability, not degree of belief, but satisfies $\sum\pi(p_i)=1$.
$w(p_i)$ = decision weight does not satisfy rules of mathematical probability

Source: Adapted from Schoemaker (1982) and Machina (1987, 1989)

While the theory can explain some problems, including the Allais paradox and the common-ratio effect, it entails violations of dominance (Quiggin 1982). The major weakness of this model is that it allocates the same decision weight to any outcomes with the same probability, irrespective of whether the outcomes are 'extreme' or 'intermediate' (Quiggin 1982). It allows violations of dominance and means that a minor modification to the Allais paradox can be made which produces behaviour that cannot be explained by the theory. The reason for this is that the Allais paradox and its associated violations arise because the 'weighted probability' effect occurs with low-probability extreme outcomes but not with low-probability intermediate outcomes.

In more recent times an abundance of theories has arisen which maintain stochastic dominance and transitivity of preferences, but generally relax the independence axiom. A variety of approaches have been used to categorise these models (e.g., Quiggin and Fisher 1989; Gul 1991; Bernasconi 1992; Luce 1992). In this review those which relax the independence axiom but maintain stochastic dominance and transitivity will be discussed in the next section (4.3) on generalised utility theories. Other theories that are more descriptive in nature and to various degrees allow violations of dominance and/or transitivity are discussed in 4.4.

4.3 Generalised utility theories

While a broad range of generalised utility models has been postulated, only two of these, Machina's generalised utility model and Quiggin's anticipated utility model will be discussed in any detail in this thesis.

4.3.1 Machina's generalised expected utility model

As the most commonly found and persistent violations of SEU theory were of the independence axiom, Machina (1982) attempted to retain the basis of EU theory by dropping the independence axiom. He replaced it with an assumption of 'smoothness' in the preference ranking over alternative probability distributions over ultimate wealth. His derivation is complex, highly mathematical and not at all intuitive.

Machina's model (Machina 1982) assumes outcomes defined over wealth, with a choice set of all probability distribution functions *F(·)*. Preferences over the choice set are complete, transitive, and can be represented by a real-valued preference functional *V(·)*. *V(·)* is a Fréchet differentiable functional of *F(·)* (i.e., 'smooth in the probabilities').

From these assumptions he shows a change in the distribution from *F(·)* to some 'very close' F*(·) will change the value of preference functional *V(·)* by:

$$\int U(x;F)(dF^*(x) - dF(x)), \qquad 4.2$$

which is the change in the expected value *U(x;F)* with respect to the distributions. Hence the function *U(x;F)* is the 'local utility function' around *F(·)*. That is, in the neighbourhood of each distribution $F_0(\cdot)$ the individual acts in the same manner as would an expected utility maximiser with utility function $U(x;F_0)$. When *U(x;F)* is independent of *F(·)*, or in other words all the local utility functions are identical, the individual behaves in the same manner as an SEU maximiser (Quiggin 1986).

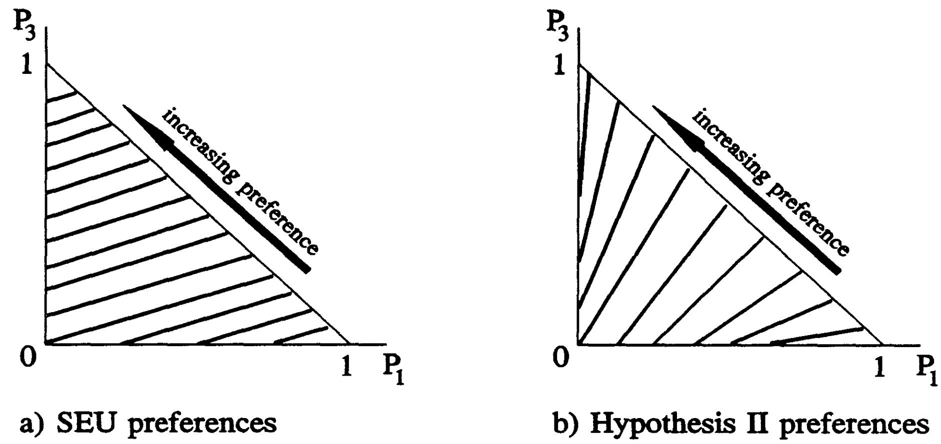
Since the derivation above only applies to differential changes in *F(·)*, Machina extends the analysis to the global situation by placing certain global properties on the local utility functions that imply the same global property for the preference function *V(·)*. Using these principles, and by making two hypotheses about the shape of the individual preference functional, Machina (1982) claims his model can explain most of the violations of the SEU model. The hypotheses are:

> I The local utility functions should exhibit decreasing risk aversion in the sense that the 'generalised Arrow-Pratt term' should be a nonincreasing function of *x*.
>
> II Moving from one probability distribution in D[0,M] to another which stochastically dominates it entails a local utility function which is more concave at each *x*.
> (Machina 1983, p. 282).

Hypothesis II implies the indifference curves 'fan out' in a unit triangle diagram (Figure 4.1), with the curves getting steeper towards the northwest. The unit triangle can be used to represent lotteries over fixed outcomes ($w_1 < w_2 < w_3$) and variable probabilities (p_1, p_2, p_3) such that $\Sigma p_i = 1$.

Figure 4.1

Comparison of SEU and Hypothesis II preferences in unit triangle



'Fanning out' of the indifference curves as implied by hypothesis II is claimed to explain violations of the independence axiom such as the common-consequence, common-ratio and utility evaluation effects. Combining hypotheses I and II is also claimed to imply behaviour that would be consistent with coexistence of gambling and insurance, invariance of preferences to initial wealth, the St. Petersburg paradox and boundedness of utility. Machina (1983, p. 293) saw his model as offering a 'theoretically powerful and empirically supported generalisation of the expected utility model.'

While Machina's theory has impressed many researchers with its mathematical sophistication and elegance (e.g., Arrow 1983; Hoen 1988), it has been criticised on both theoretical and empirical grounds. Theoretical criticisms of the model were made by Pope (1985) and Allais (1988a) because it is impossible to directly test either the model or hypothesis II. In addition, Allais claims that hypotheses I and II cannot be formulated in the discrete case and considers the theory 'is a pure mathematical concept devoid of any psychological or empirical reality' in the continuous case (Allais 1988a, p. 345). Furthermore, on the basis that the assumption of local linearity cannot be tested, Pope (1985) suggests the theory cannot explain any of the observed violations of SEU theory.

More recently doubts have been raised about the predictive potential of the model, with several studies (Battalio et al. 1990; Prelec 1990; Loomes 1991; MacDonald et al. 1991; Schoemaker 1991; MacDonald et al. 1992) finding behaviours inconsistent with the 'fanning out' specification for preferences of hypothesis II. Asset integration is assumed by the model (Machina 1982, p. 308) and evidence against this (e.g., Binswanger 1981; Battalio et al. 1990) also undermines confidence in its predictive and descriptive value.

Whatever its theoretical and predictive inadequacies, perhaps the most telling criticism from a purely practical viewpoint is that local utility functions are difficult to interpret and extremely difficult to estimate (Quiggin 1986; Quiggin and Fisher 1989). An important negative of Machina's model for the research in this thesis is, in Allais' (1984, p. 51) words, it 'does not seem to lend itself easily to empirical research.' To the author's knowledge the approach has not been applied to an empirical problem, nor has anyone suggested how it might be. Another equally important negative is it does not describe the procedures people use in making their decisions: it is not a descriptive model.

Karni (1989) extends Machina's generalised expected utility model to the multivariate case. He shows that some results found for expected utility theory are valid in the new framework when the appropriate restrictions are applied to Machina's 'local' utility functions. Given the complications and problems associated with Machina's uni-variate model, it is not proposed to consider this further.

4.3.2 Anticipated utility theory or rank-dependent expected utility

Quiggin (1982) developed anticipated utility theory (or rank-dependent expected utility (RDEU) as it and its derivatives are commonly called) initially as an attempt to explain the phenomenon of simultaneous gambling and insurance. In one sense the theory is a special case of Machina's theory, since it weakens the independence axiom, but in another sense it is not as it does not meet the smoothness condition (Quiggin 1986). The aim of the model was to find a way of allowing for the observations of probability weighting of outlying low probability events, while overcoming the problems of dominance and transitivity of preferences associated with the models proposed by Edwards (1955) and Karmaker (1978).

Anticipated utility starts by assuming basically the same axioms as SEU theory (i.e., it assumes complete, reflexive and transitive preferences along with dominance and continuity rules), plus a weakened version of the independence axiom (Quiggin 1982). It also implicitly assumes the reduction of compound lotteries axiom. By assuming all the random variables are comonotonic (Schmeidler 1989), Quiggin can assume that the set of states of the world Ω can be ordered from worst to best.

In the discrete case Quiggin (1982, 1986) assumes the outcomes are ordered from worst to best, that is, $\boldsymbol{w} = \{w_1, w_2, \ldots, w_n\}$, where $w_1 \preceq w_2 \preceq \ldots \preceq w_n$ and $\boldsymbol{p} = \{p_1, p_2, \ldots, p_n\}$, where p_i is the probability of outcome w_i. From this the anticipated utility function is defined to be:

$$V(w;p) = \Sigma_i U(w_i) h_i(p), \qquad 4.3$$

where $U(\cdot)$ is a von Neumann-Morgenstern type utility function. The decision weight $h_i(p)$ depends on all the elements of $\boldsymbol{p}$ and not just on p_i, and for which $\Sigma_i h_i(p) = 1$. The decision weights are derived as follows:

$$h_i(p) = f(\sum_{j=1}^{i} p_j) - f(\sum_{j=1}^{i-1} p_j), \qquad 4.4$$

where f is a probability weighting function $f:[0,1] \rightarrow [0,1]$ which is continuous, monotonically increasing and $f(0)=0$, $f(1)=1$. Therefore the model can be written as:

$$V(w;p) = \sum_i U(x_i)[f(\sum_{j=1}^{i} p_j) - f(\sum_{j=1}^{i-1} p_j)]. \qquad 4.5$$

Anticipated utility can also be extended to the continuous case.

An important implication of this model, which distinguishes it from earlier probability weighting models is that two outcomes with the same probability may have different decision weights. This occurs because the idea of ordering the outcomes allows low-probability extreme outcomes to be treated differently from outcomes with the same probability but intermediate outcomes (Quiggin 1986).

Anticipated utility can explain many violations of SEU theory. However, for some of them different assumptions about the probability weighting function *f* are required. Quiggin (1982, 1986, 1987) has considered alternative conditions to place on the probability weighting functions *f*. His initial model forced $f(½) = ½$ but, in response to the criticism of Segal (1987a) that this was unduly restrictive, supported the following condition:

> (A**) There exists p^o such that *f* is concave on $[0,p^o]$ and convex on $[p^o,1]$.
> (Quiggin 1987, p. 642)

The condition implies an S shaped preference pattern with concave and convex segments. Quiggin (1987) defends this condition using the argument that many experiments and observed behaviour show people often overweight low-probability extreme events. A similar weighting function has been proposed by Karni and Safra (1990) which they claim is consistent with the 'preference reversal' phenomenon. Tversky and Kahneman (1992) also propose a similar functional form for their cumulative prospect theory and provide some experimental evidence of its relevance.

The weighting function A** is consistent with simultaneous gambling and insurance, although it could discourage insurance against high probability events (Quiggin 1986). It also provides an explanation for problems that arise in construction of utility functions when different probabilities are used.

Segal (1987a, 1987b) and Yaari (1986, 1987), however, provide some evidence to support the contention of a concave *f*. Segal (1987a) redefines the weighting function as $g(p) = 1 - f(1-p)$ which implies $g(p)$ is convex when $f(p)$ is concave. He shows a convex $g(p)$ to be consistent and A** to be inconsistent with the Generalised Allais Paradox, while both are inconsistent with the Generalised Common-Ratio Effect. Quiggin (1987) admits these problems, but discounts the evidence of the Generalised Common-Ratio Effect because it does not receive widespread support. He uses the arguments given above, plus its ability to explain the reflection effect, and evidence from a survey of risk attitudes among Australian farmers, to support A**.

Anticipated utility is not viewed as a normative model by Quiggin, but as a predictive model that can be used to represent preferences. From this viewpoint, one problem with the model is the decision weighting function *h(p)* is independent of outcomes. That is, for a particular individual the weighting attached to an extreme outcome will be the same for large extreme outcomes as for small extreme outcomes. For example, the Allais paradox is relevant for a range of magnitudes of outcomes, but the effect is smaller with smaller outcomes.

The anticipated utility model was not designed to deal with ambiguity and the Ellsberg paradox (Quiggin 1986). The decision weighting function would be the same in both cases as the only difference between the two situations is the difference in information, and there is no opportunity for differential weights to be applied. Therefore the model cannot explain situations such as the demand for flight insurance versus life insurance, or the lack of demand for flood insurance found in the study by Kunreuther, Ginsberg, Miller (1978). It should be noted, though, Segal (1987b) uses anticipated utility to develop a model of choice under ambiguity by proposing a two-stage model of choice that abandons the reduction of compound lotteries axiom. However, it is not dependent upon anticipated utility for its effect, but could have been combined with other generalised utility models.

Recent assessments of the predictive ability of RDEU using the convex weighting function *g(p)* of Segal (1987a) have not been particularly encouraging. Battalio et al. (1990) observed violations of EU theory not predicted by RDEU and failures of choices over gambles to exhibit asset integration. For predictions in the interior of the unit triangle (rather than on the border), Harless (1992b) found RDEU with concave *g(p)* produced the best results, but conversely, RDEU with convex *g(p)* proved no better than chance. On the boundary of the triangle, RDEU with convex *g(p)* performed poorly, as did RDEU with convex *g(p)*. Loomes (1991) found RDEU did not explain the violations of independence found in his experiment. However, the experimental design involves a matrix presentation (Harless 1992a) which produces results that are not found with other formats. It also appears concave *g(p)* was used to test RDEU rather than convex *g(p)* argued for by Segal (1987a). Much of the evidence was also not consistent with the original weighting function proposed by Quiggin (1982) which set $f(½) = ½$. In an experiment which examined people's preferences for information Schoemaker (1991) found little benefit from using RDEU with convex $g(p)$. Part of the problem was put down to violations of the reduction axiom.

The experiments above suggest problems with the predictive ability of anticipated utility using the concave probability weighting function $f(p)$ supported by Segal (1987a). They do not test the A** form suggested by Quiggin (1987), although there seems growing support for the notion that decision makers overweight low probabilities and underweight high probabilities.

Evidence of systematic violations of first-order stochastic dominance preference (an assumption of RDEU) reported by Loomes, Starmer and Sugden (1992), and violations of quasiconvexity (required for risk aversion in RDEU) reported by Prelec (1990) also raise doubts about the predictive and descriptive validity of anticipated utility and rank-dependent expected utility models.

Allais (1988b) makes some criticisms of the anticipated utility theory. His basic criticism is the anticipated utility model contains two measures of risk: the utility function, which is a von Neumann-Morgenstern type function and therefore measures declining marginal utility of wealth and attitude to risk; and the decision-weighting function that also includes an attitude towards risk. He is also critical of the axioms of anticipated utility theory that he views as '*neither very appealing nor convincing ... utterly artificial*' and the proofs as making an 'excessive use of mathematics' Allais (1988b, p. 269-70). In that sense he views the theory as not corresponding well with psychological interpretations of behaviour.

Anticipated utility can explain many violations of SEU theory. However, for some of them different assumptions about the probability weighting function f are required. These functions are sometimes incompatible with each other and, combined with violations of the reduction axiom, ambiguity effects, context effects and failures of asset integration, suggest problems for anticipated utility as a predictive and descriptive model of behaviour.

4.3.3 Other non-expected utility theories

Other forms of generalised utility theories have been developed, but these will not be discussed in detail here. The functional forms of 'weighted utility' developed by Chew (1983) and Fishburn (1983) and a generalisation of the anticipated utility type models (sometimes called the rank-linear utility models) developed by Segal (1984) and Green and Jullien (1988), can be seen in Table 4.1. Dual theory (Yaari 1987) considers the consequences of utility being linear in wealth instead of probabilities. It treats probabilities similarly to anticipated utility, and attitude towards risk is represented by distortion of the probabilities, not curvature of the utility function. Unfortunately, it has its own paradoxes and is not empirically viable (Yaari 1987).

Recently Gul (1991) (with a theory of disappointment aversion) and Neilsen (1992) (with a mixed-fan hypothesis) have proposed approaches overcoming some problems with the generalised utility theories. Their proposals involve accommodating preferences which 'fan out' in the southeast corner of the unit triangle and 'fan in' for the northwest corner.

Becker and Sarin (1987), with lottery-dependent utility, and Karni (1992), with probability-dependent outcome valuation, have suggested approaches in which the utility or valuation of outcomes depends on the lottery or probabilities to which they are attached. An evaluation of lottery-dependent utility by Daniels and Keller (1990) found the model did not outperform expected utility theory.

4.4 Relaxation of dominance and/or transitivity

An alternative approach to overcoming the problems associated with the violations of SEU theory has been to adjust the assumptions associated with dominance and transitivity of preferences. Two such theories which follow this approach are prospect theory and regret theory. These theories are essentially descriptive and predictive theories and make no normative claims.

4.4.1 Prospect theory

Developed by Kahneman and Tversky (1979), prospect theory was not designed to be used normatively. Instead, its purpose was to explain and predict individual decisions under risk. It divides the decision process into two stages: an initial editing stage, and a subsequent evaluation stage. Decision makers use the editing stage to simplify the decision through reduction of the number of options and organisation of the information into simpler forms. One method of reducing options is to eliminate dominated prospects. Several other operations are assumed which enable decision makers to handle the information using their limited processing capacity (e.g., rounding probabilities, discarding common constituents and combining the probabilities of identical outcomes).

After the editing stage, the reduced number of simplified options is evaluated using the following equation:

$$V = \sum w(p_i)v(x_i), \tag{4.6}$$

where V = value of the option, $w(p_i)$ = decision weight on outcome i, $v(x_i)$ = value of outcome i. The option with the highest value is selected.

Values of outcomes, while similar to utility measures, are defined over changes in wealth, or welfare, around the reference point decided in the editing stage. Kahneman and Tversky (1979) hypothesise people are risk averse for gains and risk seekers for losses (which implies a concave function above the reference point and convex below). As well, the value function is assumed to be steeper for losses than gains.

While the decision weights are related to subjective probabilities, they do not follow the probability axioms and are not measures of degrees of belief. They hypothesise 'overweighting' of low probabilities, 'underweighting' of higher probabilities and discontinuities at probabilities close to zero and one, implying these are ignored. For the whole distribution they presume subcertainty which they define as:

$$\sum_{i=1}^{n} \pi(p_i) < 1. \qquad 4.7$$

The combination of decision weights and a value function defined over changes in wealth around a reference point allows predictions consistent with many violations of SEU theory including the certainty effect and framing and context effects. Kahneman and Tversky (1979) suggest the Ellsberg paradox may also be accommodated in prospect theory by adjustments to the decision weights.

Evidence against asset integration (e.g., Battalio et al. 1990; Kachelmeier and Shehata 1992) supports this aspect of prospect theory. There is also evidence that gains are treated differently from losses (e.g., Battalio et al. 1990; Prelec 1990; Schoemaker 1990), but although the reflection effect occurs with aggregated data, considerable variation occurs on an individual basis.

A further problem with the value function is that as losses increase people become averse to risk, especially as they approach the region of ruin; a point that Tversky and Kahneman (1986) recognise. This suggests the value function for losses will initially be convex but later become concave. Kahneman and Tversky do not say at what stage this will occur or how it should be handled.

As has been discussed earlier, 'overweighting' of low probabilities may be quite common (Kachelmeier and Shehata 1992; Tversky and Kahneman 1992), although 'underweighting' of high probabilities is not always as apparent. In addition some doubt exists about the assumption of subcertainty (Battalio et al. 1990).

A major criticism of prospect theory has been that it allows violations of stochastic dominance (Machina 1982; Quiggin 1986), a fact not disputed by Kahneman and Tversky (1979) and Tversky and Kahneman (1992), and overcome in their updated version of prospect theory known as cumulative prospect theory (Tversky and Kahneman 1992). They suggest direct violations of dominance in prospect theory will be eliminated in the editing phase, but admit indirect examples of dominance may occur. Quiggin (1986) points out the editing phase may introduce systematic intransitivities and discontinuities. Tversky and Kahneman (1986), however, provide evidence that people often violate stochastic dominance in non-transparent situations as predicted by their model. They argue a descriptive model needs to be able to take account of such violations rather than ignoring them or assuming them away.

While prospect theory overcomes some weaknesses of SEU as a descriptive and predictive model, it has some of its own limitations as a predictive model because of problems with measurement of the value function and decision weights (Musser and Musser 1984). This occurs because Kahneman and Tversky (1979, p. 284) suggest these should be measured from 'choices between specified prospects rather than on bids or other production tasks.' This requires far more detailed questioning. Since framing effects have also been shown to have an important impact on responses and violations of procedure invariance have been displayed (Tversky et al. 1990), they could also create problems in the formulation and interpretation of questions in real world situations. Therefore prospect theory may be used to generate hypotheses that can be tested empirically, but is less useful for making numerical predictions about the likely consequences of particular changes.

Studies of the performance of prospect theory have not shown it produces predictions that are consistently followed by decision makers. It was found to perform better than most other models on the gain side, but to perform poorly on the loss side (Schoemaker 1991). Harless (1992b) found it performed poorly for decisions inside the unit triangle, although it was more reliable for decisions on or close to the boundary of the triangle. Perhaps one of its most important failings as both a descriptive and predictive model of decision making is that it is difficult to use in real life situations that involve many outcomes (Tversky and Kahneman 1992).

4.4.2 Cumulative prospect theory or rank- and sign-dependent linear utility

To overcome problems identified for prospect theory, some features of prospect theory and rank-dependent linear utility have been combined to form a new theory (Luce and Fishburn 1991; Tversky and Kahneman 1992). Tversky and Kahneman (1992) refer to their version as cumulative prospect theory, while Luce and Fishburn

(1991) and Luce (1992) have called this general category of models rank- and sign-dependent linear utility (RSDLU).

The main features of these new models are, first, a value function defined in terms of gains or losses from a reference point, as in prospect theory and, second, instead of a separable decision weight, a rank-dependent weighting function is used which is different for gains and losses. Tversky and Kahneman (1992) indicate their new model can be extended to continuous distributions and can handle uncertain and also risky prospects. It also assumes a S-shaped value function and an inverse S-shaped weighting function. Because of the cumulative weighting function, the model satisfies stochastic dominance and therefore is not able to explain these violations when they occur in non-transparent presentations.

While Luce (1992, p. 24) considers RSDLU 'the best alternative to SEU', Tversky and Kahneman (1992, p. 317) are pessimistic about its descriptive ability because of the decision rules which people use and 'because their application depends on the formulation of the problem, the method of elicitation, and the context of choice.'

4.4.3 Regret theory

A theory that incorporates the utility of the final asset position, as well as the feeling of regret or disappointment that arises when the result of a decision is known, has been developed independently by Bell (1982), Fishburn (1982) and Loomes and Sugden (1982). Bell (1982) and Loomes and Sugden (1982) provide intuitive explanations for their model which they call 'regret' theory, while Fishburn's (1982) 'measurable utility' theory was developed from an axiomatic base that restricts decisions to the special case of statistically independent prospects (Quiggin 1986).

The Loomes and Sugden development assumes a Bernoullian cardinal utility function $C()$, not a von Neumann-Morgenstern cardinal utility function, which evaluates consequences through the pleasure/pain associated with each result when these are measured without them being the result of individual choices. Choices are made over actions A_i (rather than prospects), with consequences depending on the states of the world S_j. The probability of the jth state is p_j and the consequence if this state occurs and the *i*th action was taken is x_{ij}, which has a basic utility of c_{ij}. They further assume that, when a result occurs under uncertainty, additional effects result which modify the choiceless utility. People take this into account when making their decisions.

Loomes and Sugden (1987) outline their theory for paired choices between actions such as A_i and A_k. If an individual chooses A_i and state S_j occurs, a function $\Psi(x_{ij}, x_{kj})$ is derived which measures the modified utility of obtaining x_{ij} and missing out on x_{kj}, minus the modified utility of obtaining x_{kj} and missing out on x_{ij}. It is defined as:

$$\Psi(x_{ij}, x_{kj}) = c_{ij} - c_{kj} + R(c_{ij}, c_{kj}) - R(c_{kj}, c_{ij}), \qquad 4.8$$

where *R (.,.)* is the regret/rejoice function. Choice between the two options is made by maximising the expectation of the modified utility function $\Psi(x_{ij}, x_{kj})$ using the decision rule - A_i is preferred to A_k if:

$$\sum p_j \Psi(x_{ij}, x_{kj}) > 0. \qquad 4.9$$

To enable regret theory to make predictions that account for most of the violations of SEU theory a few restrictions are placed on $\Psi(.,.)$, the most important being convexity (Loomes and Sugden 1987). Using these restrictions, explanations are provided that are consistent with the common-ratio effect, the common-consequence effect, the coincidence of gambling and insurance and the preference reversal effect. It is also able to generate the fanning out of indifference curves property in the unit triangle. Note that the regret model gives equivalent predictions to the SEU model when $R(x_{ij}, x_{kj}) = 0$. The effect of regret theory is to drop the transitivity axiom and maintain the independence axiom, in contrast to the generalised utility models discussed earlier which relax the independence axiom while maintaining the other axioms.

A major criticism of regret theory is the assumption of intransitivity of preferences, despite the defences offered by Loomes and Sugden (1982). Quiggin (1986) suggests their defence against the 'money pump' argument is not valid in more complex scenarios. As was discussed in 3.8, transitivity of prospects is not a principle that decision makers always follow and may not necessarily be a problem for descriptive theories, especially in complex scenarios. Indeed, Fishburn (1991) argues that its position as a normative principle is tenuous.

What is more important, Quiggin (1986, p. 71) develops a proof to show 'regret theory involves pervasive violations of dominance.' Using this finding he suggests examples that imply people following the precepts of regret theory would behave irrationally. Quiggin (1986) admits his examples of violations of dominance require prospects which are not independent. Since some key predictions of regret theory rely on independence of prospects, his criticism may not be as significant as he implies. In addition, apparently some people systematically violate stochastic dominance, which is consistent with regret theory (Loomes et al. 1992).

Another important problem is that if the prospects are not statistically independent, indifference curves predicted by regret theory do not fan out and therefore are not consistent with the common-consequence effect (Munier 1988). An instance of this is the version of the Allais paradox given by Kahneman and Tversky (1979, pp. 265-6) where the prospects are not statistically independent. Regret theory gives the same predictions as SEU theory and in contrast to the responses given by most people. Loomes and Sugden (1982) admit their theory has difficulties with this type of problem, but argue this form of violation is less prevalent than others.

Since regret theory assumes the independence axiom, violations of the independence axiom (e.g., Loomes 1991) sometimes appear to involve results that are not consistent with regret theory.

Another problem for the theory is that the regret effects seem to occur when presented in the matrix format used by Loomes and Sugden but not in other presentations of state-contingent consequences (Battalio et al. 1990; Tversky et al. 1990; Harless 1992a). Other violations of SEU predictions that are not accounted for by regret theory include the 'framing' effects of Tversky and Kahneman (1981, 1986) and the translation effects of Payne, Laughhunn and Crum (1980). These results imply a particular reliance on the framing of the problem that is not assumed by regret theory and therefore denote susceptibility to framing and context biases.

Perhaps the most telling criticism of regret theory from the viewpoint of this thesis has been made by Hoen (1988, p. 1119) who sees it as 'excessively complex' and its problem as a descriptive theory is that it 'makes demands on human cognition in excess of those of the expected utility theory.' This means it is unlikely to be very descriptive of the manner in which people make decisions under uncertainty. Intuitively, the idea that people consider the regret/rejoicing associated with their decisions has some appeal. Regret theory, however, attaches this to the basic framework of probabilities and comparison of alternatives associated with SEU theory. As was indicated in chapter 3, people do not just violate the axioms because they do not accept them, they also do so because they use simplifying heuristics. Regret theory implies that they not only consider the utility of each alternative, but that they also consider the effect of other alternatives in terms or regret/rejoicing on each alternative - a complex procedure for everyday decision making.

4.5 The Allais theory

While the Allais paradox has been widely quoted by researchers and theorists in the field of decision making as suggesting deficiencies with SEU theory, the Allais theory of decision making has been virtually ignored. This is despite the initial responses to the Allais paradox at the Paris conference of 1952, including those of Savage, suggesting problems with the von Neumann-Morgenstern utility index and therefore for EU theory. Both Machina (1982) and Quiggin (1982, 1986), for example, ignore the theory when developing their theories although they critique other developments in the area. In the last decade a debate emerged between the 'American school' based on developments of EU theory, and the 'French school' around Allais' theory and criticisms of von Neumann-Morgenstern utility. For an analysis of the differences between the two schools see Lopes (1988).

The position taken by Allais has been succinctly outlined by Hagen (1979, p. 17):

> (1) the assumption of a cardinal utility (psychological value) in the classical sense, (2) that games are valued under the influence of this utility and of a possible subjective deformation of probabilities, (3) that the valuation of games depend not only of [*sic*] the expected values of the utility, but on the whole shape of the probability distribution over utility, (4) that rationality implies consideration of objective probabilities when they exist and observance of the axiom of absolute preference, (5) that if the psychology of a person is at the same time rational and conforms with the neo-Bernoullian formulation, the index of [*sic*] which the expectation is maximised is necessarily identical with the cardinal utility in the classical sense.

A key difference of Allais' theory from the generalisations of SEU is the existence of a cardinal utility function that he regards to be 'invariant from one subject to the next both at a given moment and over time, at least as a first approximation' (Allais 1986, p. 83). This is cardinal utility in the classical mould that exists independently of risky choice, unlike the von Neumann-Morgenstern index.

Perhaps the main accent in the Allais theory is on risk being related to the dispersion of psychological values, that is, the shape of the probability distribution of the cardinal measures of utility (Allais 1979b, Lopes 1988). In other words, Allais' view is that in some risky situations people may concentrate on a few key gains and losses. These become more important in deciding behaviour than mathematical expected gain (or loss), any subjective distortion of probabilities, or any subjective distortion of monetary values. This is the basis of his criticism that SEU theory is irrelevant in many instances to an isolated decision (Allais 1979b, p.490, original italics): '*the asymptotic validity of the neo-Bernoullian* [SEU] *formulation when the probability of ruin remains fairly low* cannot in general warrant its validity in the case of a single gain.'

Not surprisingly, most of the criticisms of the Allais model have come from supporters of the SEU paradigm defending their theory from the heresy; what may become referred to as their 'last gasp' appears in Allais and Hagen (1979). Here notables such as Morgenstern, Finetti and Marschak, and others, defend SEU or criticise the Allais model. For this study the major question to be considered is whether Allais' theory is a useful descriptive or predictive model.

The first point is that Allais (1979a, p. 27) views his theory as a positive theory since he calls it 'a positive theory of choice'. He appears interested in ensuring his model is based in psychological reality and can predict behaviour, but its overall thrust is normative in nature. For a start it is based on five basic axioms: 'Existence of a system of probabilities, existence of an ordered field of choice, axiom of absolute preference, axiom of composition, existence of an index of psychological value' (Allais 1979b, pp. 527-8). These axioms have much in common with the axioms of SEU theory, which are used to imply what should be regarded as 'rational' behaviour. For instance the axiom of absolute preference is a form of first-order stochastic dominance (Borch 1979). While most theories of risk include a form of this axiom, some evidence exists (e.g., Tversky and Kahneman 1986; Goldstein and Einhorn 1987; Pope 1990) that people will violate it in some situations.

From the point of view of satisficing and bounded rationality, the Allais model is as complex as the SEU model and does not deal with the question of simplifying heuristics. First, it implies people have a utility function and combine this with an assessment of probabilities, in a formal sense, to arrive at a ranking of all the prospects (Marschak 1979). This question was discussed in detail in 3.18 with the main conclusions being that: people may not make use of a utility function (if one exists); they often do not use probabilities; and, even if both are present, are unlikely to combine the two in anything but the simplest of situations. Second, the Allais model assumes the reduction of compound lotteries principle is correctly applied, but recent studies by Segal (1990), Schoemaker (1991), Starmer and Sugden (1991), and Carlin (1992) suggest otherwise.

Little empirical work has been conducted using the Allais model. Bernard (1984) questions whether the model is operational. Pope (1985) suggests one reason the model may not be operational is that the axiom of absolute preference is difficult to integrate with the other assumptions and that it should be dropped. Whether this is true, it is interesting that an excuse used by Allais for the delay in publishing the results of his 1952 and 1975 work is the time required for calculating the results (Allais 1979a), suggesting it is complex to carry out in its present form.

Given the axioms of the theory that imply rational, consistent behaviour and the assumptions it makes about people's processing abilities, it is unlikely the theory is completely descriptive of behaviour. While the flexibility of the model means it can account for at least some violations of SEU theory (e.g., the Allais paradox), it is likely to have problems predicting behaviours in more complex situations where framing effects and simplifying biases are prevalent. It is also unclear how the ambiguity problem would be treated with the Allais model. Given its structure, which makes no allowances for variation of probabilities to take account of ambiguity, and its similarity to the anticipated utility model, the Allais model would appear to suffer from the same deficiencies in this area as the anticipated utility model.

4.6 Models designed to accommodate the effects of ambiguity

The discussion in 3.11 about the Ellsberg paradox and other evidence for the effect of ambiguity on decisions suggest that ambiguity is an important determinant of people's unaided behaviour. Starting with Ellsberg (1961) several models have been developed which attempt to incorporate and explain ambiguity, or at the very least the Ellsberg paradox (Gärdenfors and Sahlin 1982; Einhorn and Hogarth 1986; Levi 1986; Segal 1987b; Schmeidler 1989; Chataneuf 1991; Luce and Fishburn 1991; Tversky and Kahneman 1992). A comprehensive review of these and other models can be found in Camerer and Webber (1992). They divide the models into four main groups: a) models which allow variation in utilities for ambiguous and unambiguous events; b) models which assume a single second-order probability distribution and relax the reduction axiom and use nonlinear weights for possible probabilities; c) models based on sets of probabilities, but not a unique distribution of probability over elements of the set; and d) models which avoid unique second-order probabilities or sets of probabilities entirely.

Most models in this group are not suited to practical, real-world situations, but two that have some potential are discussed in this review. The most widely applied is venture theory (Hogarth and Kunreuther 1985; Einhorn and Hogarth 1986; Hogarth and Einhorn 1988; Hogarth and Kunreuther 1989) belongs to group d) above. The theory proposed by Gärdenfors and Sahlin (1982), which belongs to group c), uses the idea of second order probabilities or probability of probabilities and will be discussed because of the controversy over this issue. Most of the other models belong to group d) and a detailed assessment of these can be found in Camerer and Weber (1992).

4.6.1 Venture theory

Venture theory was developed specifically as a descriptive model of choice behaviour under risk and uncertainty and has no pretensions to being a normative model (Hogarth and Einhorn 1988). It postulates a value function proposed by Kahneman and Tversky (1979) in their prospect theory and combines it with an anchoring and adjustment strategy for deriving decision weights from probabilities.

Hogarth and Einhorn (1988) use decision weights rather than probabilities. They believe the probability approach does not take account of people's concerns about the difference between short- and long-run probabilities, the effects of ambiguity about probability estimates, the influence of sign and size of outcomes, and the distinction between certainty and uncertainty. Decision weights are derived from an anchoring and adjustment strategy which starts by anchoring on an initial point estimate (p_A) and adjusting this to reflect the uncertainty and ambiguity of the situation. The final probability weight ($Z(p_A)$) is given by:

$$Z(p_A) = p_A + \theta(1 - p_A - p_A^{\beta}). \qquad 4.10$$

Upward adjustment is proportional to ($1-p_A$), the maximum upward adjustment. Downward adjustment is proportional to $p_A{}^{\beta}$, where β (≥ 0) represents the person's attitude towards ambiguity in the circumstances. The effects of simulating greater and smaller values than p_A are represented as proportions of these maximum adjustments using a proportionality constant θ. This model implies θ determines the size of the adjustment (e.g., $\theta = 0$ signifies no adjustment). On the other hand, β and p_A together determine the sign of the adjustment.

Venture theory can explain ambiguity avoidance (preference) when $p = 0.5$ in the Ellsberg paradox as due to underweighting (overweighting) (Einhorn and Hogarth

1986). A dynamic component can also be incorporated into the model by letting ν represent the amount of new information acquired in time t (Einhorn and Hogarth 1986). The shape of the decision weighting functions is similar to those hypothesised by Allais (1953), Karmaker (1978), Quiggin (1982) and Yaari (1987). However, because of axiomatic restrictions or underlying assumptions these theories are not able to deal with some situations covered by venture theory and, in particular, many are not suited to handling ambiguity.

The predictions of venture theory have been tested using experiments involving choice under uncertainty with known and ambiguous probabilities (Einhorn and Hogarth 1985; Einhorn and Hogarth 1986; Einhorn and Hogarth 1988; Hogarth and Einhorn 1988). Generally the results have supported the predictions. Further work has been carried out on the effect of risk and ambiguity on insurance decisions (Einhorn and Hogarth 1985; Hogarth and Kunreuther 1985; Hogarth and Kunreuther 1989). The findings that consumers and firms are averse to ambiguity, and that the level of aversion decreases as probabilities of losses increase, are consistent with the predictions of the model. It provides support for the contention that people use an anchoring and adjustment strategy when assessing risky and ambiguous decisions.

A contrary view comes from tests of the competence hypothesis conducted by Heath and Tversky (1990). An experiment measuring the percentage of subjects preferring a judgment bet over a lottery, for low, medium and high probabilities, gave the opposite result from that predicted by venture theory. Heath and Tversky (1990) also suggest that findings of preference for ambiguity to clarity, when the probability of winning is small or when the probability of losing is high, may be due to differences in belief rather than uncertainty preference.

A weakness of the model, recognised by Hogarth and Einhorn (1988), is that it can on occasion predict violations of dominance when choices are made. This occurs when $Z(p_A)$ is not restricted to being a positive monotonic function of p_A. It does not pose much a problem for a descriptive/predictive model, especially as experimental evidence of the preference reversal effect has shown people will violate dominance when the effect is not transparent.

A crucial limitation of the model for modelling farmer decisions is that it is restricted to binary type decisions where an event will or will not occur. This implies a point estimate of the occurrence of an event, whereas wool has a distribution of prices and a Reserve Price Scheme is likely to influence expectations about the shape of this probability distribution.

4.6.2 Second-order probabilities

The debate over the relevance of reliability (or unreliability) of subjective probabilities as a factor that may influence decision making has simmered for some time. While the idea of second order probabilities has generally been discounted (e.g., Menz 1976), the idea refuses to go away. Gärdenfors and Sahlin (1988) propose a model that extends the Bayesian framework to take account of second order probabilities.

The theory makes the normal assumptions about finite sets of actions and states of nature. If action A_i is chosen and state s_j occurs, the outcome w_{ij} results. Given a utility function $U(\cdot)$ the utility of w_{ij} is U_{ij}. A key assumption of the theory is that people will often be unwilling to take either side of a bet because of the uncertainty associated with their subjective probability of the event. A person's knowledge or beliefs about the states of nature are assumed to be represented by a set $\wp$ of probability measures that 'consists of all epistemically possible probability measures over the states of nature' (Gärdenfors and Sahlin 1988, p. 317). To this end each state of nature can be associated with a set $P(s_j)$ of probability values where $P(\cdot) \in \wp$. Since it is assumed not all beliefs about the states of nature are captured by $\wp(\cdot)$, a second order probability measure ρ is introduced as a measure of epistemic reliability. In other words ρ measures the degree of reliability attached to each of the probability distributions.

Three steps are required to decide using the model. First, the set of all epistemically possible probability measures $\wp$ is restricted by excluding those that are not 'sufficiently' reliable. To do this a desired level of reliability ρ_0 is established and the distributions P for which $\rho(P) < \rho_0$ are excluded. Second, the expected utility of each alternative A_i is calculated for each P remaining in the restricted set of distributions. Finally, the alternative actions are compared and the action is selected which has the largest minimal expected utility (called 'gamma minimax' by Levi (1986)). This rule becomes the classical maximin rule in the limiting case of decision making under situations of no information or 'ignorance' (Gärdenfors and Sahlin 1988). Alternatively, under full information only one probability distribution is possible and it becomes the SEU criterion.

Two main arguments have been used against second order probabilities: a) an uncertain first order probability should be replaced by a new point estimate that is a weighted average using second order probabilities as weights; and b) it can lead to infinite regress as could then take probabilities of probabilities of probabilities etc. (Ellsberg 1961; Menz 1976). Defences against these arguments have been offered by Sahlin (1983). A new point estimate obtained using the second order probabilities as weights yields a mean result that does not take account of the shape of the second order probability distribution. This argument is particularly appealing in cases like that of the Australian Wool Corporation's Reserve Price Scheme that yielded very unambiguous probabilities for the lower price ranges but much more ambiguous probabilities for higher prices. The main argument against the infinite regress problem is that there are diminishing benefits from higher than second order probabilities and anyhow people do not normally think in those terms. The other related approach is to consider the second order probabilities as 'measures of the quality of knowledge' (Sahlin 1983, p. 97) and therefore there is little need to go higher.

Other arguments have been made specifically against this model. Levi (1986) shows that the 'gamma minimax' solutions can lead to the choice of a dominated option. Decision makers have been found to consider other features of the probability distribution, apart from the minimum and the mean, which is incompatible with Gärdenfors and Sahlin's (1988) approach (Camerer and Weber 1992). Einhorn and Hogarth (1985) argue the model cannot account for the crossover from overweighting some probabilities to underweighting other probabilities, although they do not provide evidence for this assertion. The evidence from Heath and Tversky's (1990) study is also inconsistent with the predictions of the model.

From a pragmatic viewpoint this theory has some limitations as a descriptive and predictive model of decision making. Although Gärdenfors and Sahlin do not make plain whether they view their model as normative or descriptive, the complexity of the model and the number of calculations it assumes suggests the model is more normative in character. Although it is intuitively plausible that people consider second order probabilities in their decision making, it is highly unlikely the model describes their decision processes and it also appears to have some problems with prediction under some circumstances. Another problem is the model is geared to handling events that have single probabilities rather than probability distributions and it is not immediately obvious how it would be extended to the general case without leading to a further escalation in complexity.

4.6.3 Other theories

Other theories that purport to deal with ambiguity have been developed by Levi (1986), Gilboa (1987), Segal (1987b), Schmeidler (1989), Chataneuf (1991) and the recent developments of rank- and sign-dependent linear utility (see 4.4.2 earlier). For a discussion of these and other models see Camerer and Weber (1992). Levi sees his model as prescriptive. Gilboa and Schmeidler extend expected utility theory, Segal and Chataneuf extend anticipated utility, while the rank- and sign-dependent models are based on the principles underlying prospect and anticipated utility.

They are mathematical adaptations of earlier models designed specifically to account for the Ellsberg paradox. The recent hypothesis of ambiguity and missing information and the competence hypothesis are not covered by these theories (Camerer and Weber 1992). Although they are mathematically elegant and sophisticated it is not apparent how they might be applied to more practical problems. They have been developed to handle simple situations and therefore have difficulty with the real world which is dynamic and has multiple outcomes (Winkler 1991).

4.7 Newbery-Stiglitz framework

The Newbery-Stiglitz model of farmer response under conditions of risk (Newbery and Stiglitz 1981) and its extensions by Fraser (1984, 1986, 1988), while discussed in this chapter, are based firmly in SEU theory and are not extensions that take account of the issues raised in the previous chapter. They are discussed here because the model has been used recently to model supply response and welfare effects in Australia of wheat underwriting and the Reserve Price Scheme. Only the key assumptions of the model are discussed since its development is lengthy and complex.

A crucial assumption of the model is that the production of a single product is solely a function of labour (l). In the applications of the model by Fraser (1988, 1989) this is further restricted to a specific form where mean output $\bar{x} = l^m$ (Fraser 1988) with m in the range 0.5-1.0. Another important assumption is that utility is (additively) separable in income and leisure and that the farmer's objective is to maximise:

$$E[U(px)] - wl, \tag{4.11}$$

by choice of labour input. Here w is the (constant) marginal disutility of labour and $U(px)$ is the utility of the random income (with positive first derivative and non-positive second derivative) based on uncertain output x and uncertain price p. In modelling the effect of underwriting and buffer stock schemes, Fraser (1988, 1989) and Fraser and Murrell (1990) use the mean and variance of a Winsorised probability distribution of price, ignoring the skewness effect.

Since the model implicitly assumes farmers act as if they are using a von Neumann-Morgenstern utility function and that farmers use Winsorised probability distributions in assessing the effect of underwriting and reserve price schemes, many criticisms made against SEU theory as a predictive model can also be made against this model. First, the weighting of probability effects discussed by Allais (1953), Kahneman and Tversky (1979) and Quiggin (1986) may be relevant. Second, underwriting schemes and reserve price schemes reduce the ambiguity of some sections of the probability distribution of prices, especially the crucial lower end. This is likely to increase supply response above that implied by a model that does not allow for this factor. Third, the direction of skewness of a price distribution influences people's preferences for alternatives (see, for example, Lopes 1987) with *ceteris paribus* a positively skewed distribution being preferred. Fourth, several other factors may be important such as: probability biases, framing effects and the unique versus repeated decision effect.

Other criticisms of this model have been made by Quiggin and Fisher (1989) and Quiggin (1991). The major one is the labour supply assumption that implies 'the coefficient of relative risk aversion will be greater than unity if and only if the producer displays backward-bending labour supply' (Quiggin and Fisher 1989, p. 7). This could explain some seemingly perverse supply responses predicted by the model. A second criticism is that the assumption of labour as the sole input for production, with the only cost being disutility of effort, is inappropriate in the Australian context. Apart from the fact that labour does not have zero opportunity cost and is not necessarily a binding constraint, many other inputs are critical, not the least of which is capital.

Additional assumptions made in the model that are debatable include: producer's utility is (additively) separable in income and leisure; producer's expectations are rational in the sense that beliefs about expected price, the variance of price, the variance of the risk term and the covariance of price and the risk term are correct; and the value of disutility of effort w is inversely related to the producer's coefficient of relative risk aversion. The first of these may be defensible as an approximation in the range over which it is important. On the other hand the second requires phenomenal processing capacity by producers, while it is not even intuitively obvious why a lower disutility of effort would be associated with greater relative risk aversion. The combination of problems with the assumptions of the model and criticisms of the SEU theory raise considerable doubt about the relevance of predictions made using the model.

4.8 Relevance of utility theories for research problem

Various utility theories have been outlined in this chapter created to explain and predict behaviour under uncertainty while overcoming some problems with SEU theory. At this stage none of them has established supremacy over the others as a descriptive or predictive theory. Some of them do not appear operational at this stage of their development (e.g., Machina's generalised utility and Allais' cardinal utility). Prospect theory also seems difficult to operationalise in a complex decision-making environment. Others are exceedingly complex and are unlikely to be descriptive of production and marketing decisions made by wool growers (e.g., Machina's generalised utility, anticipated utility, regret theory, Allais' cardinal utility, venture theory and second order probabilities).

None of the current crop of theories accounts for all the violations of SEU (Camerer 1989), and it appears unlikely that any general algebraic model will (Loomes 1991; Schoemaker 1991). At this stage no consensus has been reached about which are the relevant axioms to include in a descriptive and/or predictive model of behaviour under uncertainty. Violations of transitivity, stochastic dominance, or reduction of compound lotteries are allowed in one or more of the models, with no agreement on which should be included. Although violations of axioms are a problem, perhaps the greatest problem for these models is the presence of framing and elicitation effects (Tversky et al. 1990) which arise because of the simplifying heuristics used by decision makers that seem task and context specific.

The decision making environment of the Australian wool grower is complex and uncertain. The information processing capacities of wool growers (and all other humans for that matter) are not sufficient to cope in this environment without the use of simplifying heuristics. Producers have to face the prospect of events that are totally unexpected (see discussion in 3.11.2), a totally different environment from problems involving guessing about balls in urns. The utility models developed so far fail to take account of these issues and therefore are likely to produce inappropriate results in the turbulent environment faced by wool producers. Judged by the criteria outlined in 3.2 they do not meet the requirements of this study for a predictive and descriptive model of wool-grower behaviour. They can also be criticised as 'black box' theories of behaviour. For these reasons it was decided not to use any of the utility models in this study. An alternative approach was sought.

In the next chapter theories that allow for 'bounded rationality' are introduced and a hierarchical decision theory is discussed which can be used to develop descriptive and predictive models of decisions.