Risk, Uncertainty and Investment Decision-Making in the Upstream Oil and Gas Industry

Fiona Macmillan

MA Hons (University of Aberdeen)

October 2000

A thesis presented for the degree of Ph.D. at the University of Aberdeen

DECLARATION

This thesis, and the research underpinning it, is entirely my own work. It has not been submitted in any previous application for a degree. All quotations in the thesis have been distinguished by quotation marks, and the sources of information specifically acknowledged.

Signed:…………………………………………..

ACKNOWLEDGEMENTS

Whilst this thesis is entirely my own work, many others have contributed to it and shaped the end result in their own unique way and I would like to take this opportunity to recognise them.

First, thanks must go to my sponsor, CSIRO Australia (Commonwealth Scientific and Industrial Research Organisation), and supervisors for their enthusiasm, patience and commitment, especially Professor Graeme Simpson, whose confidence in me and in the value of my study never wavered even when I doubted it myself. Second, I would like to acknowledge the respondents and the companies that they represented. For their time, honesty and encouragement I am extremely grateful. Special thanks must go to Steven McColl of Conoco, Jon Gluyas of Lasmo, Pat Mackintosh of DNV (Det Norske Veritas) and Gillian Doyle of Wood Mackenzie for all their assistance. Last and most importantly, I would like to thank my husband, Mike, my parents and my friends - especially Gill, Vanessa and Natalie, for their love, support and unshakeable belief in me and in all that I do. Without them, there would be no thesis.

ABSTRACT

The research presented in this thesis is rooted within the existing decision theory and oil industry literatures. It contributes to one of the current debates in these literatures by providing evidence that in the operators in the U.K. upstream oil and gas industry there is a link between the use of decision analysis in investment appraisal decision-making by organisations and good business performance.

It is commonly acknowledged that decision analysis is not as widely used by organisations as was predicted at its conception (for example, Schuyler, 1997). One reason for this is that no study to date has shown that use of decision analysis techniques and concepts can actually help individuals or organisations to fulfil their objectives. Despite over four decades of research undertaken developing decision analysis tools, understanding the behavioural and psychological aspects of decision-making, and applying decision analysis in practice, no research has been able to show conclusively what works and what does not (Clemen, 1999).

The current study begins to fill this gap by using qualitative methods to establish the following. Firstly, the research identifies which decision analysis techniques are applicable for investment decision-making in the oil industry, and thereby produces a description of current capability. Secondly, the study ascertains which decision analysis tools oil and gas companies actually choose to use for investment appraisal, and through this develops a model of current practice of capital investment decision-making. Lastly, using statistical analysis, it provides evidence that there is an association between the use of decision analysis in investment decision-making by companies and good organisational performance in the upstream oil and gas industry. Such research not only contributes to the current theoretical debate in the oil industry and decision theory literatures but also provides valuable insights to practitioners.

CONTENTS

LIST OF FIGURES

PAGE

LIST OF TABLES

Chapter One

Introduction

1.1 INTRODUCTION

The aim of this chapter is to introduce the research project and to outline the research themes that guide the study. The research presented in this thesis is rooted within the existing decision theory and oil industry literatures. It contributes to one of the current debates in these literatures by providing evidence that in the operators in the U.K. upstream oil and gas industry there is a link between the use of decision analysis in investment appraisal decision-making by organisations and good business performance.

1.2 BACKGROUND TO THE THESIS

Research into decision-making has become increasingly popular over the last forty years, and many published studies now exist (for example, Ford and Gioia, 2000; Gunn, 2000; Ekenberg, 2000; Milne and Chan; 1999; Nutt, 1999, 1997 and 1993; Burke and Miller, 1999; Papadakis, 1998; Dean and Sharfman, 1996; Quinn, 1980; Mintzberg *et al.*, 1976; Cyert and March, 1963). Whilst, these studies are useful for providing broad insights into the field of decision-making, very few have investigated investment decision-making in complex business environments where there is substantial risk and uncertainty and each investment decision requires significant capital expenditure without the prospect of revenues for many years.

Decision analysis (Raiffa, 1968; Howard, 1968; Raiffa and Schlaifer, 1961) is a label given to a normative, axiomatic approach to investment decision-making under conditions of risk and uncertainty (Goodwin and Wright, 1991). By using any one, or a combination, of decision analysis techniques, the decision-maker is provided with an indication of what their investment decision ought to be, based on logical argument (Clemen, 1999). Previous research into the usage of decision analysis by companies has typically been survey-based and produced evidence of a difference between the decision analysis techniques described in the literature, and the decision analysis tools which practitioners choose to use (for example see studies by Arnold and Hatzopoulous, 1999; Carr and Tomkins, 1998; Schuyler, 1997; Buckley *et al.*, 1996 Fletcher and Dromgoole, 1996; Shao and Shao, 1993; Kim *et al.*, 1984; Stanley and Block, 1983; Wicks Kelly and Philippatos, 1982; Bavishi, 1981; Oblak and Helm, 1980; Stonehill and Nathanson, 1968). It appears that whilst decision analysts describe a range of decision analysis techniques, some of which are very sophisticated, organisational decision-makers are choosing to utilise only the most simplistic tools and concepts in their investment decision-making (Atrill, 2000). However, the methodological approaches adopted by the researchers conducting these studies precluded them from providing any explanation into the reasons why some techniques fail to be implemented and others succeed (Clemen, 1999). Consequently, some writers, typically behavioural decision theorists such as Tocher (1976 and 1978 reprinted in French, 1989), have explained the results by arguing that decision-makers choose not to use decision analysis techniques because their use adds no value to organisations' investment decision-making processes since decision analysis does not aim to predict what decision-makers will do, only to suggest what they ought to do. Clemen (1999) offers another interpretation. He believes that at least one reason why decision analysis techniques and concepts are not widely used by organisations is that no study to date has provided evidence that organisations that use decision analysis tools perform better than those companies that do not. Despite over four decades of research undertaken developing decision analysis tools, understanding the behavioural and psychological aspects of investment decision-making and applying decision analysis to practical examples, no research has been able to show conclusively what works and what does not. Clemen (1999) believes that to rectify this situation, future studies into investment decision-making should investigate the relationship between organisational performance and the use of decision analysis techniques. If, as many decision analysts believe (for example, French, 1989), companies that use decision analysis in investment decision-making outperform those that do not, such research would contribute to the theoretical debate between the decision analysts and behaviouralists. The behavioural decision theorists would no longer be able to claim that there is no value in a theory that does not aim to predict what decision-makers will do. Such research would obviously also be valuable to practitioners.

This type of study, however, has been slow to appear in the literature doubtless because of the threat they represent to the decision analysts (Clemen, 1999 pp23-24):

> "Asking whether decision analysis works is risky. What if the answer is negative? The contribution will clearly be scientifically valuable, but many

> individuals – consultants, academics, instructors – with a vested interest in decision analysis could lose standing clients, or even jobs."

The current study aims to remedy this situation by researching the use of decision analysis in investment appraisal decision-making by the major companies in the upstream oil and gas industry. The oil and gas industry epitomises investment decision-making under conditions of risk and uncertainty (Watson, 1998; Newendorp, 1996; Rose, 1987; Ikoku, 1984), and hence was one of the first industries to apply decision analysis (Grayson, 1960). The industry is often used as a laboratory for the development of new decision analysis tools and concepts (for example, Bailey *et al.*, in press; Galli *et al.*, 1999; Ball and Savage, 1999; Dixit and Pindyck, 1998 and 1994; Smith and McCardle, 1997) and it is recognised to lead all other industries, with the exception of the finance industry, in the extent to which it uses decision analysis (Schuyler, 1997). Clearly, then the oil industry provides a particularly useful context in which to establish whether a relationship exists between the use of decision analysis in investment appraisal by companies and business success. The study will focus on those major upstream oil and gas companies that are operators in the U.K.. Since most of the major oil companies that operate in the U.K. are global players in the oil industry, the findings will be indicative of investment decision-making in the worlds' major upstream oil and gas companies. The research questions that the thesis aims to answer and methodological approach followed are outlined in the following section.

1.3 RESEARCH QUESTIONS

1. Which techniques are the most appropriate for companies to utilise in their investment decision-making?

This question is motivated by the observation that there are many decision analysis techniques presented in the academic investment decision-making literature leading many practitioners to feel confused about which decision analysis techniques are most applicable for investment decisions (see Chapter 6 and studies by Schuyler (1997) and Fletcher and Dromgoole (1996)). Clearly, there is a need to identify which of the decision analysis techniques and concepts presented in the academic investment decision-making literature are the most appropriate for practitioners to use for investment decision-making. The current study undertakes such research in the upstream oil and gas industry.

The current study draws on the decision analysis and oil industry literatures to ascertain which decision analysis tools are the most appropriate for companies to use for investment decision-making. This involves firstly, identifying the whole range of techniques that are available and, secondly deciding which of these tools are the most appropriate for upstream investment decision-making. This demands careful consideration of factors such as the business environment of the upstream industry and the level and type of information used for investment decision-making in the industry. Through this process, the research identifies the decision analysis techniques that are particularly useful for upstream investment decision-making. This constitutes current capability. Then, drawing again on the investment appraisal and industry literatures, and also on insights gained at conferences and seminars, an approach to investment decision-making in the oil industry is presented that utilises the full spectrum of tools identified. Some decision analysts advocate using one decision analysis technique for investment appraisal (for example, Hammond, 1967). However, in reality, each tool has limitations (Lefley and Morgan, 1999) some that are inherent, others which are caused by a lack of information or specification in the literature. As such, the knowledge that the decision-maker can gain from the output of one tool is limited (Newendorp, 1996). Therefore, a combination of decision analysis techniques and concepts should be used to allow the decision-maker to gain maximum insight which, in turn, encourages more informed investment decision-making. Some oil industry analysts have recognised this and presented the collection of decision analysis tools that they believe constitute those that decision-makers ought to use for investment decision-making in the oil and gas industry (for example, Newendorp, 1996). However new techniques have only recently been applied to the industry (for example, Galli *et al.*, 1999; Dixit and Pindyck, 1998 and 1994; Ross, 1997; Smith and McCardle, 1997) and as such, these previously presented approaches now require modification.

2. **Which techniques do companies use to make investment decisions and how are they used in the investment decision-making process?**

This question is prompted by the observation highlighted in section 1.2 that very few previous studies into decision-making have investigated the use of decision analysis in investment appraisal decision-making by organisations. The current study examines the use of decision analysis in investment appraisal decision-making within the operating companies in the U.K. upstream oil and gas industry.

Data are collected by conducting semi-structured interviews in twenty-seven of the thirty-one companies who were operators in the U.K.'s upstream oil and gas industry in March 1998. The data is analysed in two stages; first against the core themes contained in the interview schedule (Appendix 1), which are informed by the literature analysed in Chapters 2 and 3, and the emergent themes identified in contemporaneous notes taken during the research process. Second, after this initial coding, the data is coded again. In this second level coding, the core themes are more highly developed and closely specified, and other emergent themes are included. This allows the researcher to develop a model of current practice in investment decision-making in the upstream oil and gas industry that is grounded in the data. The model provides insights into the use of decision analysis in investment appraisal decision-making organisations. In particular it permits identification of the techniques organisations do use and those that they do not, and, by drawing on the behavioural decision theory literature and the interview data, it is possible to suggest reasons for this.

3. Is there a relationship between using decision analysis techniques in investment appraisal decision-making and good organisational performance?

This question is motivated by the observation by Clemen (1999) discussed in section 1.2 that there is a need for researchers to explore the relationship between the use of decision analysis in investment appraisal decision-making by companies and organisational performance. The current study investigates whether such a relationship exists in the operating companies in the U.K. upstream oil and gas industry.

Very few other studies have attempted to value the usefulness to organisations of using decision analysis (Clemen, 1999). Some studies in behavioural decision theory have evaluated the effectiveness of individual decision analysis techniques (for example, Aldag and Power, 1986; John *et al.,* 1983; Humphreys and McFadden, 1980). However, such research has been criticised because the studies typically use hypothetical decision situations and there is evidence in the behavioural decision theory literature to suggest that people make different decisions under these circumstances than the decisions they would make if the situation were real (Slovic, 1995; Grether and Plott, 1979; Lichenstein and Slovic, 1971; Lindman, 1971).

Clemen and Kwit (2000) investigated the existence of a relationship between use of decision analysis and organisational performance in Kodak. The researchers used depth interviews and documentary analysis to inform their research. This methodological approach permitted the researchers to value the "soft" effects on the organisation's performance of utilising decision analysis techniques and concepts. However, whilst their research provides useful insights, as the authors themselves acknowledge, the focus on one organisation meant that the results could not be generalised to a larger sample. The current study differs from this since it attempts to establish whether there is a relationship in the operating companies in the U.K. oil industry between using decision analysis in investment decision-making and business success. Therefore, by implication, the research involves numerous companies and this prohibits use of the type of time-consuming qualitative methodology implemented by Clemen and Kwit (2000).

Instead, the current study uses the indication of current capability and current practice, gained from answering the first and second research questions, to rank the operating companies according to the number of decision analysis techniques they use for investment appraisal. The research then assumes that any value added to the company from using a decision analysis approach, including any "soft" benefits, ultimately affects the bottom-line. This means that it is therefore possible to use publicly available financial measures and other criteria indicative of performance in the upstream oil and gas industry, to indicate business success. The existence of a relationship between organisational performance and use of decision analysis in investment appraisal decision-making in the oil industry is then analysed statistically.

The remainder of the thesis concentrates on answering these research questions. Each chapter is outlined in the following section.

1.4 OUTLINE OF THESIS

The literature review in Chapter 2 draws on the academic literature on investment decision-making to highlight the gaps in the existing literature that the research questions presented above are drawn from. It is structured so that attention is focussed on the source of each of the research questions in turn.

Chapter 3 draws on the oil industry literature to provide a brief description of the context of the current study that highlights the main challenges facing the oil industry in the 21st century. Since the current study is located in the U.K., the effects of these global changes on the U.K. oil industry are examined. This indicates the growing complexity of the industry's business environment and highlights why it is such a useful environment in which to study the use of decision analysis in investment decision-making.

Chapter 4 outlines the methodology adopted in the research. The current study utilises qualitative methods for data collection and a combination of mechanisms for data analysis. The qualitative method of semi-structure interviewing is used for the investigation of companies' investment decision-making processes and non-parametric statistical analysis is employed to investigate the relationship between the use of decision analysis in investment appraisal decision-making and organisational performance. Each type of analysis is evaluated in terms of their appropriateness for the study of investment decision-making.

Whilst Chapter 5 primarily draws on secondary data sources, it is presented as a significant contribution to this thesis, since it first identifies the decision analysis techniques available for upstream oil and gas industry investment decision-making, and also presents a new approach to investment decision-making in the industry which utilises this spectrum of tools.

Chapter 6 presents the first set of findings from the research interviews. It draws on the interview data to provide a model current practice in investment decision-making in the upstream oil and gas industry. In particular, the decision analysis techniques that upstream organisations actually use are presented. When this is compared with the indication of current capability ascertained in Chapter 5, the findings confirm the trend observed in previous quantitative research studies that there is a gap between current theory in investment appraisal and current practice. However, unlike these survey-based studies, where the research methodology used prohibited further investigation of such issues, the current study uses insights from the semi-structured interviews, together with behavioural decision theory literature, to suggest why this might be the case.

Chapter 7 uses the data presented in Chapters 5 and 6 to produce a ranking of the companies according to their usage of decision analysis techniques in investment appraisal decision-making. The assumption that any value added to the company from using a decision analysis approach will ultimately affect the organisation's bottom-line is justified. This assumption is then used to investigate the relationship between the ranking of organisations by their use of decision analysis in investment appraisal decision-making and business success statistically by using criteria that are indicative of organisational performance.

The final chapter, Chapter 8, brings together the information gathered for the thesis and provides the answers to the research questions posed in Chapter 1. It sets out the conclusions that can be drawn from the research. In particular, the implications of the results to the theoretical debate between the decision analysts and behavioural decision theorists are highlighted. The limitations of the research presented in this thesis are discussed and this leads into the identification of areas for future research that arise from the current study.

Chapter 2

Literature Review

2.1 Introduction

This chapter presents the literature review for the current study. It draws on the existing academic literature on investment decision-making to highlight the gaps in this literature that the research questions presented in Chapter 1 are drawn from. The literature review is structured so that attention is focussed on the source of each of the three research questions in turn.

2.2 Risk and uncertainty

The first section of the literature review emphasises the centrality of risk and uncertainty to investment decision-making by focusing on the following three questions:

1. How does the academic investment decision-making literature conceptualise risk and uncertainty?
2. How do investment decision-makers conceptualise risk and uncertainty?
3. How do these decision-makers cope with risk and uncertainty in investment decision-making?

Investigating the methods of coping with risk and uncertainty adopted by investment decision-makers highlights the role of quantitative techniques. This leads into identification of the need for a study that ascertains which of the tools and techniques that are presented in the decision theory literature are most appropriate for investment appraisal. This is the first research question that this thesis aims to answer.

Consider the first question proposed above. Risk and uncertainty are inherent in all decision-making (Bailey *et al.*, in press, Hammond *et al.*, 1999; Harrison, 1995; Goodwin and Wright, 1991; Morgan and Henrion, 1990) and hence receive considerable attention in the academic investment decision-making literature (for example, Atrill, 2000; Buckley, 2000; Murtha, 1997; Borsch and Mossin; 1968). This prominence is well deserved. Ubiquitous in realistic settings, risk and uncertainty constitute a major obstacle to effective capital investment decision-making (Simpson *et al.*, 2000 and 1999; Lamb *et al.*, 1999; Ball and Savage, 1999; Watson; 1998; Rose, 1987; Murtha, 1997; Newendorp, 1996; Oransanu and Connolly, 1993; McCaskey, 1986; Brunsson, 1985; Corbin, 1980; Thompson, 1967).

AUTHORS	TERM	CONCEPTUALISATION
1. Anderson *et al.* (1981)	Uncertainty	A situation in which one has no knowledge about which of several states of nature has occurred or will occur
2. Anderson *et al.* (1981)	Uncertainty	A situation in which one knows only the probability of which several possible states of nature has occurred or will occur
3. Anderson *et al.* (1981)	Risk	Same as (1)
4. Anderson *et al.* (1981)	Risk	Same as (2)
5. Humphreys and Berkley (1985)	Uncertainty	The inability to assert with certainty one or more of the following: (a) act-event sequences; (b) event-event sequences; (c) value of consequences; (d) appropriate decision process; (e) future preferences and actions; (f) one's ability to affect future events
6. Lathrop and Watson (1982)	Risk	Potential for deleterious consequences
7. Lathrop and Watson (1982)	Uncertainty	Lack of information available concerning what the impact of an event might be
8. MacCrimmon and Wehrung (1986)	Uncertainty	Exposure to the chance of loss in a choice situation
9. Harrison (1995)	Risk	A common state or condition in decision-making characterised by the possession of incomplete information regarding a probabilistic outcome.
10. Harrison (1995)	Uncertainty	An uncommon state of nature characterised by the absence of any information related to a desired outcome.
11. Spradlin (1997)	Risk	The possibility of an undesirable result
12. Holmes (1998)	Risk	A situation which refers to a state where the decision-maker has sufficient information to determine the probability of each outcome occurring.
13. Holmes (1998)	Uncertainty	A situation where the decision-maker can identify each possible outcome, but does not have the information necessary to determine the probabilities of each of the possibilities.

Table 2.1: *Conceptualisations of risk and uncertainty (source: adapted from Lipshitz and Strauss, 1997)*

However, despite this prominence, there is much confusion in the academic investment decision-making literature over the definitions of risk and uncertainty. Table 2.1 presents a sample of the definitions of risk and uncertainty given by some of the contributors to the capital investment decision-making literature. The table clearly illustrates conceptual proliferation in the academic investment decision-making literature. This has led Argote (1982 p420) to assert:

> "…there are almost as many definitions of risk and uncertainty as there are treatments of the subject."

A comment echoed by Yates and Stone (1982 p1):

> "…if we were to read 10 different articles or books on risk, we should not be surprised to see it described in 10 different ways."

To answer the first question proposed above of how the academic investment decision-making literature conceptualises risk and uncertainty then, it is clear that whilst it is widely acknowledged in this literature that risk and uncertainty are inherent in capital investment decision-making, there is no conceptual basis for agreement of the definitions of risk and uncertainty.

The second question that this section aims to address, how investment decision-makers conceptualise risk and uncertainty, has received relatively little attention in the empirical literature on investment decision-making (Lipshitz and Strauss, 1997). However, there is evidence in this literature which suggests that the conceptualisation of risk and uncertainty adopted by a decision-maker affects the method of coping that the decision-maker adopts (Lipshitz and Strauss, 1997). Milliken (1987) found that decision-makers encountering diverse risks and uncertainties respond differently. The existence of contingent coping is a recurrent theme in the academic decision-making literature (for example, Gans, 1999). Cyert and March (1963 p119) proposed that:

> "…[organisations] achieve a reasonably manageable decision situation by avoiding planning where plans depend on prediction of uncertain future events and by emphasising planning where the plans can be made self confirming through some control device."

Grandori (1984) specified which of five decision-making methods should be selected given the magnitude of risk and uncertainty caused by a lack of information. Thompson (1967) specified which of four decision-making approaches should be selected given the amount of risk and uncertainty. Butler (1991) later adapted this model.

To answer the section question of how investment decision-makers conceptualise risk and uncertainty then, the empirical investment decision-making literature offers many hypotheses and scant empirical evidence regarding how decision-makers conceptualise risk and uncertainty (Lipshitz and Strauss, 1997). However, it does indicate that the definitions of risk and uncertainty that are adopted by decision-makers affect the model or mechanism they use to handle risk and uncertainty (Lipshitz and Strauss, 1997; Butler, 1991; Grandori, 1984; Thompson, 1967).

The last question that this section aims to address, how decision-makers cope with risk and uncertainty, follows from this and has received considerable attention in the investment decision-making literature (for example, Clemen and Kwit, 2000; Clemen, 1999; Gans, 1999; Galli *et al.*, 1999; Lipshitz and Strauss, 1997; Murtha, 1997; Newendorp, 1996; Raiffa, 1968; Raiffa and Schlaifer, 1961). According to Smithson (1989 p153) the prescription for coping with risk and uncertainty advocated in much of the capital investment decision-making literature is:

> "First, reduce ignorance as much as possible by gaining full information and understanding…Secondly attain as much control or predictability as possible by learning and responding appropriately to the environment…Finally, wherever ignorance is irreducible, treat uncertainty statistically."

Thompson (1967) suggests that organisations constrain the variability of their internal environments by instituting standard operating procedures and reduce the variability of external environments by incorporating critical elements into the organisation (that is, by acquisition or by negotiating long-term contractual arrangements). Similarly, Allaire and Firsitrotu (1989) list several "power responses" used by organisations to cope with environmental uncertainty including shaping and controlling external events, passing risk on to others and disciplinary competition. However, the standard procedure for coping with risk and uncertainty advocated in the investment decision-making literature is outlined in the section of this literature referred to as decision theory (Clemen and Kwit, 2000; Clemen, 1999; Goodwin and Wright, 1991; French, 1989; Raiffa, 1968; Howard, 1968; Raiffa and Schlaifer, 1961).

In the decision theory literature, the process decision-makers are advised to adopt for coping with risk and uncertainty involves three steps known as R.Q.P. (Lipshitz and Strauss, 1997). The first stage involves the decision-maker *reducing* the risk and uncertainty by, for example, conducting a thorough information search (Kaye, 1995; Dawes, 1988; Janis and Mann, 1977; Galbraith, 1973). The decision-maker then *quantifies* the residue that cannot be reduced in the second step. Finally, the result is *plugged* into a formal scheme that incorporates risk and uncertainty as a factor in the selection of a preferred course of action (Newendorp, 1996; Smithson, 1989; Hogarth, 1987; Cohen *et al.*, 1985; Raiffa, 1968). Each step will now be discussed further. This will highlight the role of quantitative techniques and introduce the concept of decision analysis. The section will conclude by identifying the need for a study that ascertains which of the many decision analysis tools and concepts described in the decision theory literature are the most appropriate for investment decision-making. This is the first research question that this thesis aims to address.

Strategies for reducing risk and uncertainty include collecting additional information before making a decision (Kaye, 1995; Dawes, 1988; Galbraith, 1973; Janis and Mann, 1977); or deferring decisions until additional information becomes available and it is possible to reduce risk and uncertainty by extrapolating from the available evidence (Lipshitz and Strauss, 1997). A typical method of extrapolation is to use statistical techniques to predict future states from information on present or past events (Butler, 1991; Allaire and Firsirtou, 1989; Bernstein and Silbert, 1984; Wildavski, 1988; Thompson, 1967). Another mechanism of extrapolation is assumption-based reasoning (Lipshitz and Strauss, 1997). Filling gaps in firm knowledge by making assumptions that go beyond, while being constrained by, what is more firmly known which are subject to retraction when, and if, they conflict with new evidence, or with lines of reasoning supported by other assumptions (Cohen, 1989). Using assumption-based reasoning, experienced decision-makers can act quickly and efficiently within their domain of expertise with very little information (Lipshitz and Ben Shaul, 1997). Scenario planning, imagining possible future developments in script-like fashion (Schoemaker, 1995), is another strategy of reducing risk and uncertainty that combines prediction and assumption-based reasoning. Finally, risk and uncertainty can also be reduced by improving predictability through shortening time horizons (preferring short-term to long-term goals, and short-term feedback to long range planning, Cyert and March, 1963), by selling risks to other parties (Hirst and Schweitzer, 1990), and by selecting one of the many possible interpretations of equivocal information (Weick, 1979).

It is important to recognise, however, that reducing risk and uncertainty by collecting information can be problematic since often the information is ambiguous or misleading to the point of being worthless (Hammond *et al*, 1999; Morgan and Henrion, 1990; Feldman and March, 1981; Grandori, 1984; Wohstetter, 1962). Moreover, there is evidence to suggest that collecting information does not help the decision quality when the level of environmental uncertainty is very high (Fredrickson and Mitchell, 1984). This leads some to adopt an entirely different approach to reducing risk and uncertainty by controlling the sources of variability that decrease predictability. For example, as discussed above, according to Allaire and Firsitrotu (1989), some organisations use "power responses" (Lipshitz and Strauss, 1997).

It is the second stage of the R.Q.P. heuristic that much of the decision theory literature discusses (for example, Clemen and Kwit, 2000; Hammond *et al.*, 1999; Clemen, 1999; Thomas and Samson, 1986; Keeney, 1979; Kaufman and Thomas, 1977; Raiffa, 1968). Decision analysis (Raiffa, 1968; Howard, 1968; Raiffa and Schlaifer, 1961) is a normative discipline within decision theory consisting of various techniques and concepts that provide a comprehensive way to evaluate and compare the degree of risk and uncertainty associated with investment choices (Newendorp, 1996). Traditional methods of analysing decision options involve only cash flow considerations, such as computation of an average rate of return (Newendorp, 1996). The new dimension that is added to the decision process with decision analysis is the quantitative consideration of risk and uncertainty (Clemen and Kwit, 2000; Clemen, 1999; Newendorp, 1996; Goodwin and Wright, 1991; Morgan and Henrion, 1990; French, 1989; Raiffa, 1968; Howard, 1968; Raiffa and Schlaifer, 1961). In Chapter 5, all aspects of decision analysis will be discussed in detail and specific techniques will be reviewed. However, for the purposes of gaining an overview of the approach, the standard decision analysis can be summarised as a series of steps (Simpson *et al.*, 1999; Lamb *et al.*, 1999; Newendorp, 1996; Goodwin and Wright, 1991; Morgan and Henrion, 1990; French, 1989; Thomas and Samson, 1986):

1. Define possible outcomes that could occur for each of the available decision choices, or alternatives.
2. Evaluate the profit or loss (or any other measure of value or worth) for each outcome.
3. Determine or estimate the probability of occurrence of each possible outcome.
4. Compute a weighted average profit (or measure of value) for each decision choice, where weighting factors are the respective probabilities of occurrence of each outcome. This weighted-average profit is called the expected value of the decision alternative, and is often the comparative criterion used to accept or reject the alternative. Another measure that can be used to compare decision alternatives is the expected preference/utility value of the decision alternative. This is a decision criterion that attempts to take into account the decision-maker's attitudes and feelings about money using preference or utility functions. In either case, the decision rule is to choose the decision alternative with highest expected preference/utility value. This is the third and final stage of the R.Q.P. heuristic.

The new parts of this standard decision analysis approach are steps 3 and 4 (Newendorp, 1996). The analyst is required to associate specific probabilities to the possible outcomes. Since this basic approach was proposed, the experience gained by academics and consultants has stimulated changes designed to make the decision analysis approach more flexible to the needs of managers (for example, Hammond *et al.*, 1999; Thomas and Samson, 1986; Keeney, 1979; Kaufman and Thomas, 1977).

Recently, as computing power has increased, the dimension of simulation has been added to the standard decision analysis approach (Newendorp, 1996). Risk analysis based on Monte Carlo simulation is a method by which the risk and uncertainty encompassing the main projected variables in a decision problem are described using probability distributions. Randomly sampling within the distributions many, perhaps thousands, of times, it is possible to build up successive scenarios. The output of a risk analysis is not a single value, but a probability distribution of all expected returns.

The prospective investor is then provided with a complete risk-return profile of the project showing the possible outcomes that could result from the decision to stake money on this investment (Newendorp, 1996).

More recently, preference, portfolio and option theories have been attracting some attention in the decision theory literatures (for example, Bailey *et al.*, in press; Simpson *et al.*, 2000; Simpson *et al.*¸ 1999; Galli *et al.*, 1999; Hammond *et al.*, 1999; Smith and McCardle, 1997; Ross, 1997). Each of these techniques will be discussed in Chapter 5. The plethora of techniques that are presented in the academic decision theory literature for the quantification of risk and uncertainty has confused practitioners (see Section 6.3 of Chapter 6 and studies by Schuyler (1997) and Fletcher and Dromgoole (1996)). Most decision-makers report uncertainty about what each tool aims to do, the differences between techniques and are unclear about when certain tools should and should not be used (Section 6.3 of Chapter 6). Clearly then, there is a need to identify which of the decision analysis techniques and concepts presented in the academic decision theory literature, are the most appropriate for investment decision-making. The current study aims to do this by answering the first research question which was posed in Chapter 1.

The focus in this chapter now turns to the motivation for the second research question proposed in Chapter 1. In exploring this question the researcher aims to ascertain which techniques companies actually use to quantify risk and uncertainty in investment appraisal and to understand how the results from the techniques are plugged into the organisational investment appraisal decision-making process. The following section draws on the academic investment decision-making literature to analyse the recent studies of current practice in investment decision-making. In doing so, it identifies the gap in the existing literature that by answering the second research question and producing a description of current practice in investment appraisal in the operators in the U.K. upstream oil and gas industry, this study aims to fill.

2.3 CURRENT PRACTICE IN INVESTMENT APPRAISAL DECISION-MAKING

The fundamental concepts used in decision analysis were formulated over two hundred years ago. Yet the application of these concepts in the general business sector did not become apparent until the late 1950s and early 1960s (for example, Grayson, 1960), and it has only been within the last five to ten years that it has seriously been applied to investment decision-making in practice (for example, see Section 6.3 of Chapter 6 and studies by Schuyler (1997) and Fletcher and Dromgoole (1996)). Furthermore, it is widely acknowledged that current practice in the techniques used for investment appraisal decision-making in practice in all industries trails some way behind current decision theory (for example, Atrill, 2000; Arnold and Hatzopouous, 1999; Schuyler, 1997). This has been established via empirical research which has tended to focus on whether, when and which decision analysis techniques are used by organisations (for example see studies by Arnold and Hatzopoulous, 1999; Carr and Tomkins, 1998; Schuyler, 1997; Buckley *et al.*, 1996 Fletcher and Dromgoole, 1996; Shao and Shao, 1993; Kim *et al.*, 1984; Stanley and Block, 1983; Wicks Kelly and Philippatos, 1982; Bavishi, 1981; Oblak and Helm, 1980; Stonehill and Nathanson, 1968). These studies have typically used survey techniques to produce statistical results indicating the percentage of organisations using decision analysis techniques (for example, Schuyler, 1997). As will be discussed in more detail in Chapter 4, utilising survey techniques for data collection has precluded the researchers from conducting an investigation of why companies endorse the use of some techniques and yet fail to implement others and, more importantly, it prevents the identification of the decision analysis techniques which perform best (that is, where the predicted outcome from the technique is close to the actual outcome) (Clemen, 1999). As will be seen in section 3.4, the failure of these earlier studies to investigate such issues has contributed to the divide between the behavioural decision theorists and decision analysts, and to the gulf between current practice and current capability in decision analysis highlighted above (Clemen, 1999). Evidently then, since the empirical research conducted to date has limitations, there is a need for a study to establish common practice in investment appraisal. This is the second research question that this thesis aims to address.

The current study will use a qualitative methodology. This will allow the researcher not only to establish which decision analysis techniques companies are currently using, but also to investigate other, “softer” issues. For example, if the study confirms the earlier empirical studies that there is difference between the techniques described in the academic investment decision-making literature (which will be identified by answering the first research question proposed in Chapter 1) and those which companies choose to use, it will explore this issue. Furthermore, since previous research has suggested that the relationship between the conceptualisation of risk and uncertainty in the organisation and the techniques or method of coping with risk and uncertainty adopted by decision-makers (see section 2.2), this will also be investigated. The researcher will then be able to offer insights into how the results from the decision analysis techniques are integrated into the organisational investment decision-making process.

Attention is now focussed on the source of the third research question which aims to establish whether there is a relationship between the use of decision analysis techniques by organisations and organisational performance. The next section examines the evolution of the decision theory literature from classical decision theory through to the potentially useful technology of decision analysis and the more recent contributions of behavioural decision theory. The current debates in the decision theory literature are then reviewed and this indicates the need for a study that investigates the relationship between use of decision analysis in investment appraisal decision-making and organisational performance. In section 2.5, a hypothesis is advanced for empirical testing.

2.4 THE EVOLUTION OF DECISION THEORY

Consider first the status of systematic reasoning about human action. With stylistic changes the following, written by Laplace in 1812, could represent an optimistic view of decision analysis today (Howard, 1988 p679):

> "By this theory, we learn to appreciate precisely what a sound mind feels through a kind of intuition often without realising it. The theory leaves nothing arbitrary in choosing opinions or in making decisions, and we can always select, with the help of this theory, the most advantageous choice on our own. It is a refreshing supplement to the ignorance and feebleness of the human mind.
>
> If we consider the analytic methods brought out by this theory, the truth of its basic principles, the fine and delicate logic called for in solving problems, the establishments of public utility that rest on this theory, and its extension in the past and future by its application to the most important problems of natural philosophy and moral science, and if we observe that even when dealing with

> things that cannot be subjected to this calculus, the theory gives the surest insight that can guide us in our judgement and teaches us to keep ourselves from the illusions that often mislead us, we will then realise that there is no other science that is more worthy of our meditation."

The possibility of effective, systematic reasoning about human action has been appreciated for over two hundred years. Laplace's predecessor, Bayes, showed in 1763 that probability had epistemological power that transcended its aleatory uses (Howard, 1988). In the early 1700s, Bernoulli captured attitudes towards risk taking in mathematical form. In his *Ars Conjectandi* (1713), Jacob Bernoulli proposed an alternative to the objectivist view that probability is a physical concept such as a limiting frequency or a ratio of physically described possibilities. He suggested that probability is a "degree of confidence" - later writers use degree of belief - that an individual attaches to an uncertain event, and that this degree depends on the individual's knowledge and can vary from individual to individual. Similarly, Laplace himself stated in *A Philosophical Essay of Probabilities* (1812), that probability is but the "expression of man's ignorance" and probability calculus is relevant to "the most important questions of life" and not just to repetitive games of chance as previously thought. In addition, Augustus De Morgan in his *Formal Logic* (1847) argued that:

> "By degree of probability we really mean, or ought to mean, degree of belief…" (Raiffa, 1968 p275)

The resurgence of the field in modern times began with statistical decision theory and a new appreciation of the Bayesian perspective (Howard, 1988) which seeks to introduce intuitive judgements and feelings directly into the formal analysis (Raiffa, 1968). In his *A Treatise on Probability* (1921) Keynes took the position that a probability expresses the rational degree of belief that should hold logically between a set of propositions (taken as given hypotheses) and another proposition (taken as the conclusion) (Raiffa, 1968). Jeffreys (1939) and Jaynes (1956), who worked in the field of physics rather than in mathematics and statistics, provided an all encompassing view of probability, not as an artefact, but as a basic way of reasoning about life, just as had Laplace. Jeffreys (1939) and Jaynes (1956) developed very clear ways of relating probabilities to what you know about the world around you, ways that provide dramatic insights when applied to molecular processes that interest many physicists. However, Jaynes (1956) also showed that these ideas pay off handsomely when applied to inference problems in our macroscopic world (Howard, 1988). Frank Ramsey was the first to express an operational theory of action based on the dual intertwining notions of judgmental probability and utility. In his essay, *Truth and Probability* (1926) Ramsey adopted what is now termed the subjective or decision theoretic point of view. To Ramsey, probability is not the expression of a logical, rational, or necessary degree of belief, the view held by Keynes and Jeffreys, but rather an expression of a subjective degree of belief interpreted as operationally meaningful in terms of willingness to act (Raiffa, 1968). De Finetti in his essay, *Foresight: Its Logical Laws, Its Subjective Sources* originally published in 1937, like Ramsey, assessed a person's degree of belief by examining his overt betting behaviour. By insisting that a series of bets be internally consistent or coherent such that a shrewd operator cannot make a sure profit or "book" regardless of which uncertain event occurs, De Finetti demonstrated that a person's degrees of belief – his subjective probability assignments – must satisfy the usual laws of probability (Raiffa, 1968). Von Neumann and Morgenstern developed the modern probabilistic theory of utility in their second edition of *Theory of Games and Economic Behaviour* published in 1947. These authors, however, deal exclusively, with the canonical probabilities; that is, where each outcome is "equally likely". Evidently, they were unaware of the work of Ramsey (Raiffa, 1968 p276). Abraham Wald formulated the basic problem of statistics as a problem of action. Wald (1964) analysed the general problem in terms of a normal form analysis (Raiffa, 1968 p277) and the problem he states reduces to selecting a best strategy for statistical experimentation and action when the true state of the world is unknown. Wald was primarily concerned with characterising those strategies for experimentation and action that are admissible or efficient for wide classes of prototypical statistical problems. Although Wald's accomplishments were truly impressive, statistical practitioners were left in a quandary because Wald's decision theory did not single out a best strategy but a family of admissible strategies, and in many important statistical problems this family is embarrassingly rich in possibilities. The practitioner wanted to know where to go from where Wald left off. How should he choose a course of action from the set of admissible contenders? The feeling of Wald and some of his associates was that while this is an important problem, it is not really a problem for mathematical statistics; they felt that there just is no scientific way to make this final choice (Raiffa, 1968 p277). However, they were in the minority.

In the early 1950s, there were many proposals suggesting how a decision-maker should objectively choose a best strategy from the admissible class. No sooner did someone suggest a guiding principle of choice, however, than someone else offered a simple concrete example showing that this principle was counterintuitive in some circumstances and therefore the proposed principle could not serve as the long sought key (Raiffa, 1968). In 1954, Savage laid the foundations of modern Bayesian decision theory. In particular he showed that utilities and subjective probabilities could model the preferences and beliefs of an idealised rational decision-maker facing a choice between uncertain prospects. At least, they should do, if you accept Savage's axiomatic definition of rationality (French, 1984). Building on Savage's work, decision analysis was developed in the 1960s by Howard Raiffa (Raiffa, 1968; Raiffa and Schlaifer, 1961) and Ronald Howard (1968), and represents an evolution of decision theory from an abstract mathematical discipline to a potentially useful technology (foreword by Phillips in Goodwin and Wright, 1991).

Simplistically, decision analysis seeks to introduce intuitive judgements and feelings directly into the formal analysis of a decision problem (Raiffa, 1968). Its purpose is to help the decision-maker understand where the balance of their beliefs and preferences lies and so guide them towards a better informed decision (French, 1989 p18). The decision analysis approach is distinctive because, for each decision, it requires inputs such as executive judgement, experience and attitudes, along with the "hard data". The decision problem is then decomposed into a set of smaller problems. After each smaller problem has been dealt with separately, decision analysis provides a formal mechanism for integrating the results so that a course of action can be provisionally selected (Goodwin and Wright, 1991 p3). This has been referred to as the "divide and conquer" orientation of decision analysis (Raiffa, 1968).

Decompositional approaches to decision-making have been shown to be superior to holistic methods in most of the available research (for example, Kleinmuntz *et al.*, 1996; Hora *et al.*, 1993; MacGregor and Lichenstein, 1991; MacGregor *et al.*, 1988; Armstrong *et al.*, 1975). Fischer (1977) argues that decompositional approaches assist in the definition of the decision problem, allow the decision-maker to consider a larger number of attributes than is possible holistically and encourage the use of sensitivity analysis. Holistic evaluations, he believes, are made on a limited number of attributes, contain considerable random error and, moreover, are extremely difficult when there are fifty or more possible outcomes. Kleinmuntz (1990) shares this perspective. He suggests that the consistency of holistic judgements will deteriorate as the number of possible outcomes increases because of the limits on human information processing capabilities. Whereas he argues, systematic decomposition relaxes the information processing demands on the decision-maker reducing the amount of potential error in human judgement. Furthermore, since decompositional methods provide an "audit trail" it is possible to use them to produce a defensible rationale for choosing a particular option. Clearly this can be important when decisions have to be justified to senior staff, colleagues, outside agencies, partners, the general public, or even to oneself (Goodwin and Wright, 1991).

Since its conception the role of decision analysis has changed. No longer is it seen as a method for producing optimal solutions to decision problems. As Keeney (1982) points out:

> "Decision analysis will not solve problems, nor is it intended to do so. Its purpose is to produce insight and promote creativity to help decision-makers make better decisions." (Goodwin and Wright, 1991 p4)

This changing perception of decision analysis is also emphasised by Phillips (1989):

> "…decision theory has now evolved from somewhat abstract mathematical discipline which when applied was used to help individual decision-makers arrive at optimal decisions, to a framework for thinking that enables different perspectives on a problem to be brought together with the result that new intuitions and higher level perspectives are generated." (Goodwin and Wright, 1991 p4)

However, whilst decision analysis does not produce an optimal solution to a problem, the results from the analysis can be regarded as "conditionally" prescriptive which means that the analysis will show the decision-maker what they should do, given the judgements that have been elicited from them during the course of the analysis. The fundamental assumption underlying this approach is that the decision-maker is rational (Goodwin and Wright, 1991). When a decision-maker acts rationally it means that they calculate deliberately, choose consistently, and maximise, for example, their expected preference/utility. Consistent choice rules out vacillating and erratic behaviour. If it is assumed that managerial decision-makers want to maximise, for example, their personal preferences, and that they perceive that this will happen through maximising the organisation's objectives, then it may also be assumed that such managers will pursue the maximisation of the organisation's performance in meeting its objectives (Harrison, 1995 p81). More simply, if managers are rewarded based on the organisation's performance and they behave rationally, they will try to maximise the outcome of their decisions for the organisation, to achieve the highest amount of personal utility.

For many years it was believed, implicitly or explicitly, that such normative theories of decision-making not only represent the "ought" but also the "is": the normative and descriptive facets were assumed to be one and the same (Keren, 1996). The unprecedented advancements in the physical sciences and information theory and the realisation of the enormous capabilities inherent in computing machines and information technology, strengthened and encouraged the belief in rational agents who were considered to be in full control of their thoughts and actions, and capable of following the normative desiderata. Decision failures were exclusively attributed to the perceptual-cognitive machine and could, it was assumed, be avoided by increasing mental effort and by appropriate training (Keren, 1996). Consequently, the presupposition that normative models (with, conceivably, some minor modifications) can concurrently serve descriptive accounts was introduced with little contention (Keren, 1996). For example, in a frequently quoted article, Peterson and Beach (1967 p29) concluded that:

> "In general, the results indicate that probability theory and statistics can be used as the basis of psychological models that integrate and account for human performance in a wide range of inferential tasks."

There was little attempt to explain human behaviour (Keren, 1996). Even the most transparent cases of discrepancy between human behaviour and normative models (for example, see the often referred to Allais' paradox outlined in Goodwin and Wright, 1991 pp83-85) did not change the dominating outlook (Keren, 1996). In 1954, Ward Edwards published his seminal paper "The Theory of Decision-Making" which marked the birth of behavioural decision theory. Since then, the past forty years have witnessed a gradual transition in which the descriptive facet has received growing attention (Keren, 1996).

Behavioural decision theory questioned the assumption of normative models that decisions are, and ought to be, made on solely rational grounds (Lipshitz and Strauss, 1997). Such an assumption means that non-cognitive factors such as emotions, motivations, or moral considerations should have no impact on the decision process unless they can be justified by rational means. Both causal observations as well as growing empirical evidence suggest that this assumption is irreconcilable with any tenable behavioural descriptive theory (Keren, 1996). Much of this research, under the heading of "heuristics and biases", has portrayed decision-makers as imperfect information processing systems that are prone to different types of error. The most pertinent of these studies can be grouped under the headings of probability and preference assessment and are discussed below.

- *Probability assessments* - As indicated above, decision analysis, and many other normative models in decision theory, rely on the use of probability for modelling the uncertainty surrounding future outcomes. Considerable work has been done on the assessment of subjective probabilities, although much of it has focused on the internal consistency of human assessment (Clemen, 1999). For example, articles in the volume by Kahneman, Slovic and Tversky (1982) emphasise how heuristic judgement processes lead to cognitive biases. For the most part, this work indicates ways that human judgement of subjective probability is inconsistent with probability laws and definitions (Clemen, 1999). This is a situation that is exacerbated in organisational decision-making since many judgements are generated by groups of experts (Clemen, 1999). Myers and Lamm (1975) report evidence that face-to-face intervention in groups working on probability judgements may lead to social pressures that are unrelated to group members' knowledge and abilities. Gustafson *et al.* (1973), Fischer (1975), Gough (1975) and Seaver (1978) all found in their experiments that interaction of any kind among experts led to increased overconfidence and, hence, worse calibration of group probability judgements. More recently, Argote, Seabrigh and Dyer (1986) found that groups use certain types of heuristics more than individuals, presumably leading to more biases (Clemen, 1999).

The situation outlined above is aggravated by the observation that whilst most people find it easiest to express probabilities qualitatively, using words and phrases such as “credible”, “likely” or “extremely improbable”, there is evidence that different people associate markedly different numerical probabilities with these phrases (for example, Budescu and Wallsten, 1995). It also appears that, for each person, the probabilities associated with each word or phrase varies with the semantic context in which it is used (Morgan and Henrion, 1990) and that verbal, numerical and different numerical expressions of identical uncertainties are processed differently (Gigerenzer, 1991; Zimmer, 1983). Hence, in most cases such words and phrases are unreliable as a response mode for probability assessment (Clemen, 1999). Given this, many writers have proposed encoding techniques. However, the results of the considerable number of empirical comparisons of various encoding techniques do not show great consistency, and the articles reviewed provide little consensus about which to recommend (Clemen, 1999). As Meehl (1978 p831) succinctly comments:

> “…there are many areas of both practical and theoretical inference in which nobody knows how to calculate a numerical probability value.”

The most unequivocal result of experimental studies of probability encoding has been that most assessors are poorly calibrated; in most cases they are overconfident, assigning probabilities that are nearer certainty than is warranted by their revealed knowledge (Morgan and Henrion, 1990). Such probability judgements, Lichenstein, Fischoff and Phillips (1982) found, are not likely to be close to the actual long run frequency of outcomes.

Some researchers have investigated whether using specific procedures can improve probability judgements. Stael val Holstein (1971a and 1971b) and Schafer and Borcherding (1973) provide evidence that short and simple training procedures can increase the accuracy (calibration) of assessed probability, although their empirical results do not indicate an overwhelming improvement in performance. Fischoff

(1982) discusses debiasing techniques intended to improve the quality of subjective performance assessments. Gigerenzer and Hoffrage (1995) emphasise that framing judgements in frequency terms (as opposed to the more traditional subjective "degree of belief") can reduce assessment bias in a variety of situations. Other studies (Clemen, Jones and Winkler, 1996; Hora, Dodd and Hora, 1993) suggest that embracing the divide and conquer orientation of decision analysis in probability assessment can improve assessment performance (Clemen, 1999).

- *Preference assessment* - While probability assessments can be evaluated readily, the study of preference and preference assessment techniques, is more problematic (Clemen, 1999). The most popular approach to studying preferences has been to consider the extent to which expressed preferences are internally consistent, as exemplified by the Allais paradox (Allais and Hagen, 1979; Allais, 1953) or by Tversky and Kahneman's (1981) work on framing (Clemen, 1999). Decision analysis prescribes a number of approaches that are formally equivalent for assessing preference functions (Clemen, 1999). Farquhar (1984) surveys many of the available preference assessment methods. Hershey, Kunreuther and Schoemaker (1982) discuss the biases induced by different preference elicitation approaches in spite of formal equivalence. Fischer (1975) reviews early studies on the validation of multi-attribute assessment. The typical approach has involved what is called "convergent validity", which is measured in this case by calculating the correlation between the intuitive rankings of the subjects and the rankings produced by the preference function (Clemen, 1999). Although most preference studies have been aimed at understanding and reducing internal inconsistencies, Kimbrough and Weber (1994) describe an experiment with a slightly different orientation. They compared a variety of preference elicitation approaches, each one implemented via a computer program. Some approaches confronted subjects with their inconsistencies and forced them to make modifications; these methods produced recommendations and preference functions that were, by implication, more acceptable to the users (Clemen, 1999).

Clearly then the research conducted to date in behavioural decision theory has focussed on the psychology of judgement. Since decision analysis is based on a system of axioms, it has been reasonable to study whether people naturally follow the logic on which decision analysis rests (Clemen, 1999). Studies have shown that they do not. Following such observations, there is a tendency in the decision theory literature for decision analysts and behavioural decision theorists to become embroiled in a somewhat circular argument over the use and benefits of decision analysis (for example, see the exchanges between French and Tocher summarised in French, 1989 pp139-153). Behavioural decision theorists argue that people do not behave in the manner suggested by decision analysis. Decision analysts reiterate that it is not their aim to predict what the decision-maker will do, but rather to suggest to the decision-maker what they ought to do, if the decision-maker wishes to be consistent. To behavioural theorists this argument is weak. Tocher (1976 reprinted in French, 1989 p139) writes:

> "…any theory which is worth using predicts how people will behave, not how they should, so we can do our mathematics."

Recently researchers such as Clemen and Kwit (2000) have attempted to circumvent this discussion by focussing not on whether people naturally follow the axioms of decision analysis, but on whether learning to do so can lead them to better choices and consequences.

The relationship between performance and the investment decision-making process has attracted much theoretical attention (for example, Bailey *et al.*, in press; Simpson *et al.*, 2000; Wensley, 1999 and 1997; McCunn, 1998; Otely, 1997; Nutt, 1997). In 1977 Hambrick and Snow advanced a model of interaction between current and past performance and the investment decision-making process, but concluded that the effects of the investment decision-making process on performance were not well articulated and that the available evidence was insufficient to support specific theories (Papadakis, 1998). Although many other studies (for example, Dean and Sharfman, 1996; Hart, 1992; Quinn, 1980) have described and explained the investment decision-making process, little consensus has emerged as to the expected relationship between organisational performance and investment decision-making processes (for example, Priem *et al.*, 1995; Rajagopalan *et al.*, 1993). Specifically, whilst it is well established that management science and operations research add value to organisations when used well (Clemen and Kwit, 2000), the value of decision analysis remains less well documented. Although many successful applications have been performed and published (for example, Otis and Schneiderman, 1997; Nangea and Hunt, 1997), the evidence remains largely anecdotal and unsystematic (Clemen and Kwit, 2000). Despite over four decades of research developing decision analysis techniques, gaining an understanding of the behavioural and psychological aspects of decision-making, and the application of decision analysis to real organisational decisions, no research has been able to show conclusively what works and what does not (Clemen, 1999). It is highly likely that being unable to document the value of a decision analysis approach to investment appraisal decision-making has hampered some proponents as they have tried to gain acceptance for decision analysis within their organisations (see Section 6.3 of Chapter 6 and Clemen, 1999). This could be seen as contributing directly to the gap between current practice and current capability in investment appraisal. If decision analysis could be shown to be definitively of value, and that this value easily overwhelms the typical costs of compiling the modelling and analysis, decision analysis would become much more attractive to organisations (Section 6.3 of Chapter 6; Clemen, 1999). Consequently, in time, the current gulf between theory and practice would narrow. Furthermore, such research would contribute to the theoretical debate between decision analysts and behavioural decision theorists (Clemen, 1999). If, as many decision theorists believe (for example, French, 1989), companies that use decision analysis outperform those that do not, such research would contribute to the theoretical debate between the decision analysts and behaviouralists. The behavioural decision theorists would no longer be able to claim that there is no value in a theory that does not aim to predict what decision-makers will do. The third research question that this thesis aims to explore then, is the question of whether success in decision-making depends on the decision-making process managers use (Hitt and Tyler, 1991) and, specifically, whether adopting decision analysis techniques in investment appraisal decision-making has a positive effect on organisational performance.

The literature reviewed in this section has indicated that there is a need for a study to investigate the existence of a relationship between the use of decision analysis techniques and concepts in investment appraisal decision-making and organisational performance. This is the third research question that this thesis aims to answer. However, before such a link can be proved to exist, two assumptions must hold. The next section begins by stating these assumptions and proving their validity. It continues to review previous studies that have been undertaken investigating the relationship between business performance and various aspects of the organisational investment decision-making process. Specifically, the section focuses on those studies that have concentrated on the effects of rationality, formality and consensus in the decision-making process since these are all features inherent in using decision analysis techniques and concepts. The section concludes by advancing a hypothesis for empirical testing.

2.5 DECISION ANALYSIS AND ORGANISATIONAL PERFORMANCE

As Dean and Sharfman (1996) observe, the following two assumptions must hold to prove a link between investment decision process and decision effectiveness. Firstly, it must be assumed that investment decision processes are related to choices; or, more specifically, that the investment decision process followed influences the choices made. Although this assumption appears intuitively obvious, many academics have argued that the operating environment shapes organisational and individual choices (for example, Aldrich, 1979; Pfeffer and Salancik, 1978). Others, however, claim that despite the existence of these external factors, managers retain a substantial degree of control over choices (for example, Miles, 1982; Child, 1972). One argument made in favour of this position by Dean and Sharfman (1996) is that some managers make very poor choices with devastating consequences for their firms, while others in very similar circumstances make much better choices (for example, Bourgeois, 1984). Such variation, the authors assert, could not exist if constraints alone were driving decisions. Hence, Dean and Sharfman (1996) conclude that it appears likely that viable outcomes are a product of the decision process used. Leading on from this, the second assumption is that choices relate to outcomes, and that all outcomes are not equally good. Once again there can be very little doubt that external forces also influence decision effectiveness (Hitt and Tyler, 1991; Pfeffer and Salancik, 1978). Changes in competitor strategies or customer tastes can turn strategic coups into disasters or vice versa. However, Dean and Sharfman (1996) note that it is unlikely that the influence of such forces eliminates the impact of choice on decision effectiveness as it is hard to imagine a decision in which all potential choices will be equally successful or unsuccessful.

The two assumptions then appear plausible (Dean and Sharfman, 1996) which suggests that it is reasonable to expect the investment appraisal decision-making process to influence decision effectiveness. However, as Aldrich rightly observed (1979), the importance of managerial decisions in determining organisational outcomes is ultimately an empirical question (Dean and Sharfman, 1996). Many empirical studies have investigated the existence of a relationship between the investment decision-making process and effectiveness. None have concentrated on the use of decision analysis in the investment decision-making processes of organisations. However, several have explored the effects of comprehensiveness, rationality, formality and consensus in the decision-making process on organisational performance. In much of the decision theory literature, it is argued that decision analysis provides:

> "…convincing rationale for choice, improves communication and permits direct and separate comparisons of different people's conceptions of the structure of the problem, and of the assessment of decomposed elements within their structures, thereby raising consciousness about the root of any conflict." (Humphreys, 1980 in Goodwin and Wright, 1991 p177)

Goodwin and Wright (1991) also argue that adopting a decision analysis approach implies comprehensiveness/rationality and formalisation of the decision-making process, improved communication amongst the stakeholders and provides the organisation with access to a common language for discussing the elements of a decision problem. This, they argue, helps to build consensus in the company, which in turn expedites implementation of the decision. Keeney and Raiffa (1972 pp10-11) say of decision analysis:

> "As a process, it is intended to force hard thinking about the problem area: generation of alternatives, anticipation of future contingencies, examination of dynamic secondary effects, and so forth. Furthermore, a good analysis should illuminate controversy – to find out where basic differences exist, in values and uncertainties, to facilitate compromise, to increase the level of debate and undercut rhetoric – in short, "to promote good decision-making"."

Since adopting decision analysis clearly involves comprehensiveness, rationality, increased formality and high levels of organisational consensus, it suffices to examine that empirical literature that has examined the relationship between these aspects of the investment decision-making process and decision effectiveness. These studies are now examined. Attention is first focussed on the effect of comprehensiveness and rationality in the decision-making process.

Smith *et al.* (1988) provided some empirical support for a positive relationship between performance and comprehensiveness/rationality in the decision-making process. They found that, for both small and larger firms, comprehensive decision-making processes out-performed less comprehensive. Similarly, Jones *et al.* (1992) reported consistently positive relationships between organisational effectiveness and comprehensiveness in decision-making. In addition, a series of publications on hospital integration strategies (for example, Blair *et al.*, 1990), researchers found that successful ventures were associated with comprehensive strategy formulation processes (Papadakis, 1998). Janis' (1989) case studies suggested that public policy decisions that used rational methods were more successful than those that did not. Papadakis' (1998) study also provided evidence that the companies that exhibit the strongest organisational performance tend to be those with rational decision-making processes, a participative approach and extensive financial reporting. Furthermore, studies by Capon *et al.* (1994) and Pearce *et al.* (1987) suggest that formalisation in strategic planning is positively related to organisational performance. Such results led Papadakis (1998) to hypothesise that performance is positively related to comprehensiveness/rationality and formalisation in the investment decision-making process.

Conversely, Fredrickson and his colleagues (Fredrickson and Iaquinto, 1989; Fredrickson, 1985; Fredrickson, 1984; Fredrickson and Mitchell, 1984) looked at prototypical (assessed by response to a scenario) rather than actual investment decision-making processes and related them to firm performance rather than to specific decision outcomes and concluded that:

> "Firms usually do not use slack generated by excellent performance to pay the costs of seeking optimal solutions; instead resources are absorbed as sub-optimal decisions are made. This phenomenon may help explain why managers in historically successful firms sometimes make a series of what appear to be inadequately considered, intuitive decisions that in combination have significant negative consequences." (Fredrickson, 1985 p824).

Similarly, Cyert and March (1963) argued that superior performance lowered the intensity with which organisations "searched" for and analysed information. More specifically, Bourgeois (1981) and March and Simon (1958) proposed that slack resources permit organisations the "luxury" of "satisficing" and sub-optimal decision-making. Whereas in poorly performing organisations the lack of basic funds exerts pressure on management during the making of crucial decisions, as a wrong decision may drive the firm out of business. Consequently, since management has less scope for error, they may have strong incentives to follow rational/comprehensive processes (Bourgeois and Eisenhardt, 1988; Cyert and March, 1963). This suggests that managers of poorly performing firms may hire consultants, seek advice from various sources and conduct extensive financial analyses (Papadakis, 1998). Such observations led Fredrickson (1985) to conclude that the investment decision-making process of poor performers is more comprehensive than that of excellent performers. The above arguments, if correct, would indicate that good organisational performance is negatively related to comprehensiveness/rationality in the investment decision-making process (Papadakis, 1998).

Clearly, then, much of the research to date appears to have produced contradictory results and no consensus seems to have yet emerged. Contrary to the arguments of Fredrickson (1985) and others, it can be argued that good performance enables companies to rationalise/modernise their internal structure and systems and thus be in a position to apply more rational/comprehensive and formalised investment decision-making processes for two reasons. Firstly, as Dean and Sharfman (1996) have previously argued, effective decisions must be based on organisational goal. Rational decisions usually require extensive data collection and analysis efforts and it is difficult to do this unless the decision is closely aligned to the organisations' objectives (Langley, 1989). Hitt and Tyler (1991, p329) described rational, formalised decision-making as a series of analytical processes in which a set of objective criteria is used to evaluate strategic alternatives. This orientation toward organisational goals makes it more likely that procedurally rational decisions will be effective (Dean and Sharfman, 1996). Secondly, formalised, rational decisions are also likely to involve relatively complete information and knowledge of constraints. Executives who collect extensive information before making decisions will have more accurate perceptions of environmental conditions, which has been shown to relate positively to firm performance (Bourgeois, 1985).

A second stream of research deals with the impact of consensus on performance. Despite the profound importance given to the performance-consensus relationship in the normative literature (Papadakis, 1998), there is still much disagreement in the empirical literature which indicates that more testing is required (Ekenberg, 2000; Priem, 1990; Dess, 1987; Dess and Origer, 1987). Consensus is the agreement of all parties to a group decision (Papadakis, 1998). Current thinking attributes tremendous significance to the homogenisation of perceptions and to goal consensus, which is assumed to be fundamental to good economic performance (Papadakis, 1998; Bourgeois, 1985). Child (1974) was among the first to propose that homogeneity among the members of the top management team as to the objectives contributes to higher performance (Papadakis, 1998). Similarly, Bourgeois (1981) argued that the organisational slack generated by business success functions as a source of conflict resolution. Since when a company is on a "winning track" (Papadakis, 1998) everyone prefers to be associated with the winner and there is less place for political activities and long debates over goals and priorities (Dess, 1987). A number of empirical studies have confirmed the existence of a positive relationship between organisational performance and consensus. For example, Eisenhardt and Bourgeois conducted several studies on decision-making in dynamic environments. The results from one of their studies suggested that political behaviour within top management teams leads to poor organisational performance (Eisenhardt and Bourgeois, 1988). However, the majority of studies in this area have been conducted in the laboratory, where environmental forces are not an issue, and the few field studies that have been carried out have not attempted to assess actual decision outcomes (Schweiger *et al.*, 1986). The exception is Dean and Sharfman's 1996 study of twenty-four companies in sixteen industries, which provided an indication that the decision process that was followed influenced the decision-making effectiveness. Unlike earlier studies, the researchers included environmental factors and the quality of implementation of the decision in their model. One of their main findings was that managers who engaged in the use of power or pushed hidden agendas were less effective than were those who did not. Other studies by Janis (1989), Ford (1989) and Nutt (1993) have all indicated a link between politics and unsuccessful decisions.

However, conversely, some researchers have provided evidence that too much internal consensus may be dysfunctional. For example, Whitney and Smith (1983) argued that an emphasis on organisational or management consensus could reduce individuals' receptivity to information that contradicts the views of the dominant coalition despite the fact that such information may be vital for the quality of the final decision. Thus, the pressure for consensus postulated by normative methods to decision-making may produce negative results (Papadakis, 1998). Investigating the performance-consensus relationship, Grinyer and Norburn (1977-78) found that the highest performing firms experienced a negative correlation between performance and consensus. Thus they hypothesised that high levels of cohesiveness may be dysfunctional, and that some disagreement among members of the top management team may be an internal strength related to superior performance (Papadakis, 1998). Langley (1995) also warned that when everyone in power instinctively shares the same opinion on an issue, the wise manager should be wary. Unanimity, she writes, is unlikely to lead to an objective evaluation of options, and normal checks and balances may be short-circuited. Langley argues that unanimity may mean that a proposal has strong value, but it may also be symptomatic of a disturbing trend, that is, a uniformity in which members share values and beliefs and that excludes deviation from the decision-making process. She concludes that whilst obviously a strong culture has many advantages, when the organisation is faced with discontinuities this same culture becomes a liability as common beliefs become invalid.

Finally, contrary to both the above streams of results, Wooldridge and Floyd (1990) found no statistically significant relationship between consensus and organisational performance.

Evidently then, the performance-consensus research has produced some conflicting results. This may be attributed to differences in units of analyses, in methodologies and research questions (Dess and Origer, 1987), or, perhaps, even to the nature and stage of the strategic process under investigation which may impact upon the scope, content and degree of consensus (Wooldridge and Floyd, 1990; Papadakis, 1998). More interestingly, Papadakis (1998) postulates that a lack of any significant relationship suggests the co-existence of two opposite effects that "cancel each other out" in practice. Dean and Sharfman (1996) have argued that effective decisions must be based on organisational goals. Political decision processes are, by their very nature, organised around the self-interests of individuals or groups (Pfeffer, 1981; Pettigrew, 1973), which are often in conflict with those of the organisation. Therefore, it can be argued that good performers are less likely to exhibit less politics and less problem-solving disagreement in their decision-making process.

This section has justified the assumptions that must hold in order to prove a link between investment decision process and effectiveness. It has reviewed those empirical studies that have focussed on the effects of comprehensiveness, rationality, formality and consensus in the decision-making process on organisational performance. It has provided evidence that using decision analysis means rationality, comprehensiveness, formality and increased consensus in investment decision-making. It therefore suffices to advance only one hypothesis for empirical testing in this thesis: organisational performance is positively related to use of decision analysis in investment appraisal decision-making. In answering the third research question, the researcher aims to investigate this proposition.

The current study will use the indication of current capability and current practice gained from answering the first and second research questions to rank the companies according to the number of techniques used in their investment appraisal process. The research will then assume that any value added to the company from using a decision analysis approach, including any "soft" benefits, ultimately affects the bottom-line. This assumption will be justified in Chapter 7. It means that it is therefore permissible to use publicly available financial data to indicate business success. The existence of a relationship between organisational performance and use of decision analysis in investment appraisal will then be analysed statistically.

2.6 CONCLUSION

In seeking to explore the investment decision-making processes of companies, the literature review for the current study has examined the academic literature on investment decision-making. The source of each of the three research questions proposed in Chapter 1 was explored and a hypothesis advanced for empirical testing.

The next chapter examines the context for the current study. It will show how the oil and gas industry is such an extreme example of investment appraisal decision-making under conditions of risk and uncertainty that it provides a useful environment in which to study investment decision-making.

Chapter Three

The Oil Industry in the U.K.

3.1 INTRODUCTION

This chapter draws on the oil industry literature to present a brief description of the industry that highlights the main challenges facing it in the 21^{st} century. Since the current study focuses on oil and gas companies that operate in U.K., the effects of these global changes on the U.K. industry are examined. This indicates the growing complexity of the business environment of those companies operating in the upstream oil and gas sector and highlights why decision analysis is beginning to receive increasing attention in the industry and, consequently, why it provides such a useful context in which to study investment decision-making.

3.2 CURRENT CHALLENGES IN THE GLOBAL OIL INDUSTRY

> *For over a century and a half, oil has brought out both the best and worst of our civilisation. It has been both boon and burden. Energy is the basis of our industrial society. And of all energy sources – oil has loomed the largest and the most problematic because of its central role, its strategic character, its geographic distribution, the recurrent pattern of crisis in its supply – and the inevitable and irresistible temptation to grasp for its rewards. Its history has been a panorama of triumphs and a litany of tragic and costly mistakes. It has been a theatre for the noble and the base in the human character. Creativity, dedication, entrepreneurship, ingenuity, and technical innovation have coexisted with avarice, corruption, blind political ambition, and brute force. Oil has helped to make possible mastery over the physical world. It has given us our daily life and, literally, through agricultural chemicals and transportation, primacy. It has also fuelled the global struggles for political and economic primacy. Much blood has been spilled in its name. The fierce and sometimes violent quest for oil – and for the riches and power it conveys – will surely continue so long as oil holds a central place since every facet of our civilisation has been transformed by the modern and mesmerising alchemy of petroleum.*

The above paragraph has been adapted from the closing remarks made by Daniel Yergin in his book, *The Prize* (1991), which chronicles the development of the world's oil industry. Three themes are used to structure the book and these clearly illustrate the global impact of the oil and gas industry. The first of these is that oil is a commodity intimately intertwined with national strategies, global politics and power as evidenced by its crucial role in every major war in the last century. The second is the rise and development of capitalism and modern business. According to Yergin (1991 p13):

> "Oil is the world's biggest and most pervasive business, the greatest of the great industries that arose in the last decades of the nineteenth century."

A third theme in the history of oil illuminates how ours has become a "hydrocarbon society" (Yergin, 1991 p14). Oil has become the basis of the great post-war sub-urbanisation movement that transformed both the contemporary landscape and our modern way of life. Today, it is oil that makes possible, for example, where we live, how we live, how we commute to work and how we travel as well as being an essential component in the fertiliser on which world agriculture depends, and key material in the production of pharmaceuticals.

Globally, the industry has evolved from primitive origins through two world wars, the Suez Canal crisis, the Gulf War and significant fluctuations in supply and demand, all with their subsequent impact on the oil price, to become a multi-billion pound business comprised of some of the world's biggest and most powerful companies. It is now recognised as an essential national power, a major factor in world economies, a critical focus for war and conflict, and a decisive force in international affairs (Yergin, 1991 p779). However, the global industry is changing. Four factors in particular are contributing to the uncertainty surrounding the industry's future. These are reviewed in this section. The following section analyses the effect of these challenges on the U.K. oil and gas industry. The impact of these recent changes on investment decision-making in the industry will then be discussed.

• Field size

Globally many of the oil majors still generate much of their output – and profits – from giant fields discovered decades ago. For example, in 1996 it was estimated that 80% of BP's (British Petroleum) oil and gas production was from North America and Britain, mainly from a handful of large fields in Alaska and the North Sea (The Economist, 1996). Production from nearly all these giant fields is either near its peak or is already declining. New fields are rarely as large or as profitable as these earlier large reservoirs. Worldwide since the mid-1980s, few giant oilfields have been discovered (figure 3.1) and, although, many smaller fields have been found, they have not delivered the same economies of scale (The Economist, 1996).

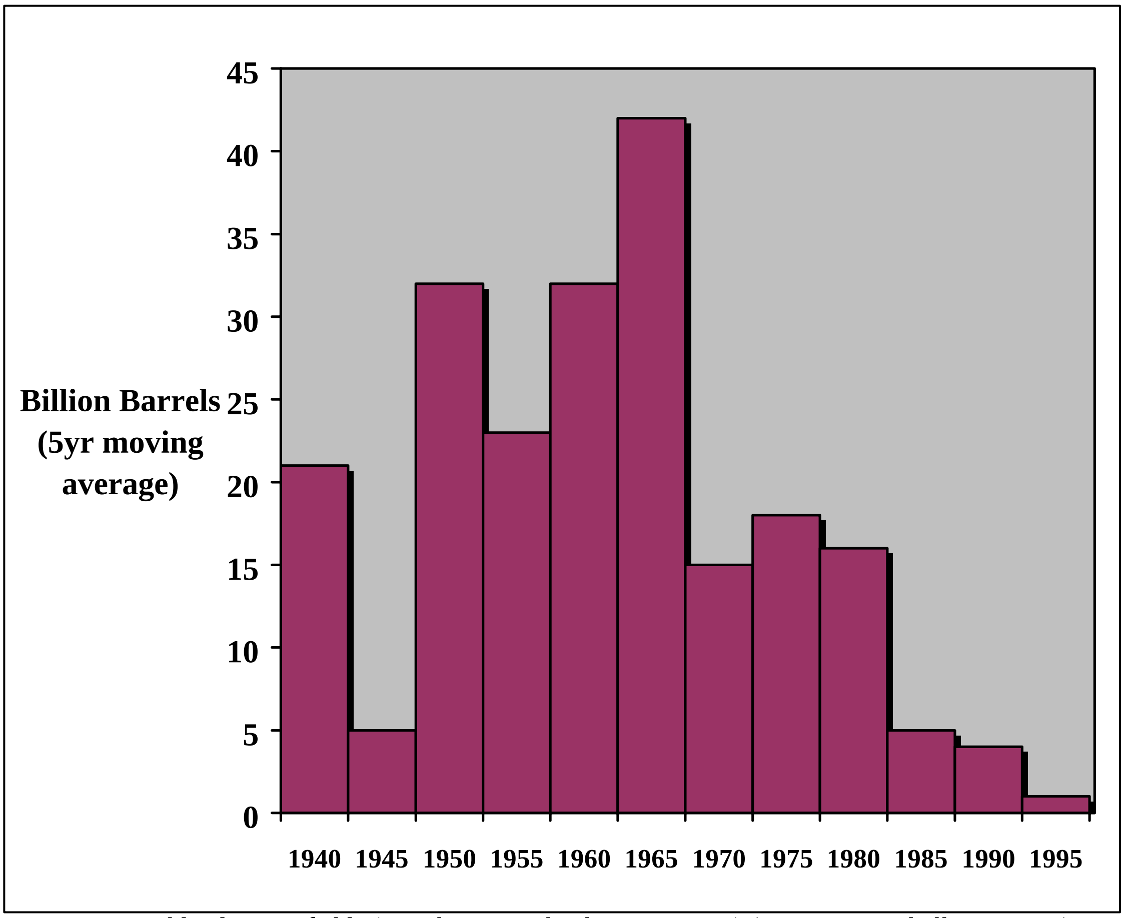

Figure 3.1: *Worldwide giant fields (initial reserves by discovery year) (source: Campbell, 1997 p52)*

- Finite resource

Whilst virtually everyone is agreed that oil is a finite resource there is much disagreement in the industry about exactly when demand will irreversibly exceed supply. Some analysts, such as Campbell (1997) argue that production of conventional oil, which he defines to be that oil with a depletion pattern which starts at zero, rises rapidly to a peak, and then declines rapidly, will peak in 2010 (figure 3.2). Others believe it will last much longer:

> "…the world is running into oil not out of it ... The issue [of limited oil resources will be] unimportant to the oil market for 50 years" (Odell, 1995)

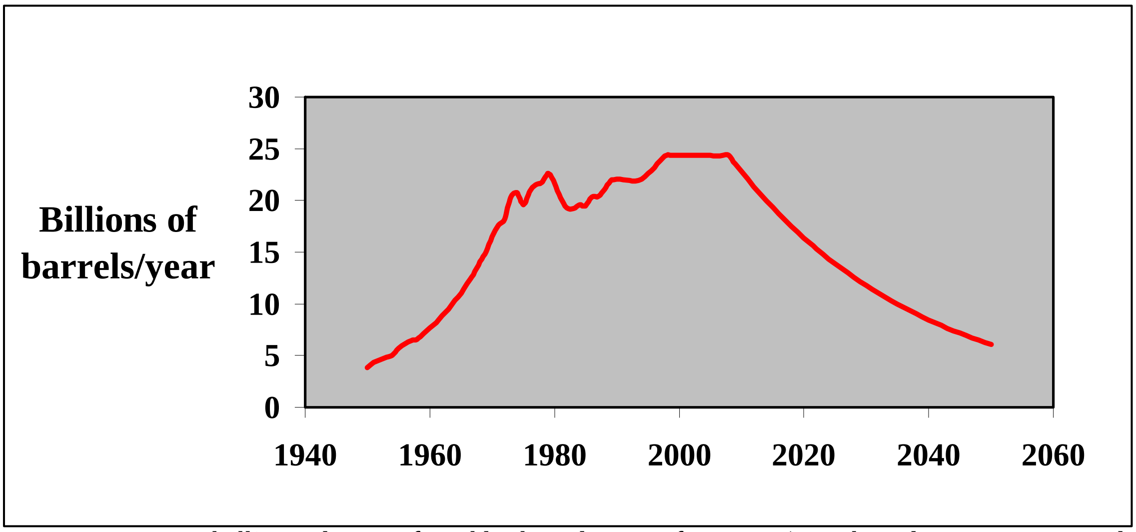

Figure 3.2: Campbell's prediction of world oil production after 1996 (actual production to 1996 and then predicted thereafter) (source: Campbell, 1997 p100)

Yet, much of this is conjecture. What is known is that worldwide proven reserves have increased by approximately two thirds since 1970 but the countries that contain ample quantities of low cost oil, and which account for most of that increase, are currently inaccessible to western firms (figure 3.3). Middle Eastern countries that are members of the Organisation of Petroleum Exporting Countries (OPEC), for example, account for almost sixty percent of the worlds' proven reserves (figure 3.4).

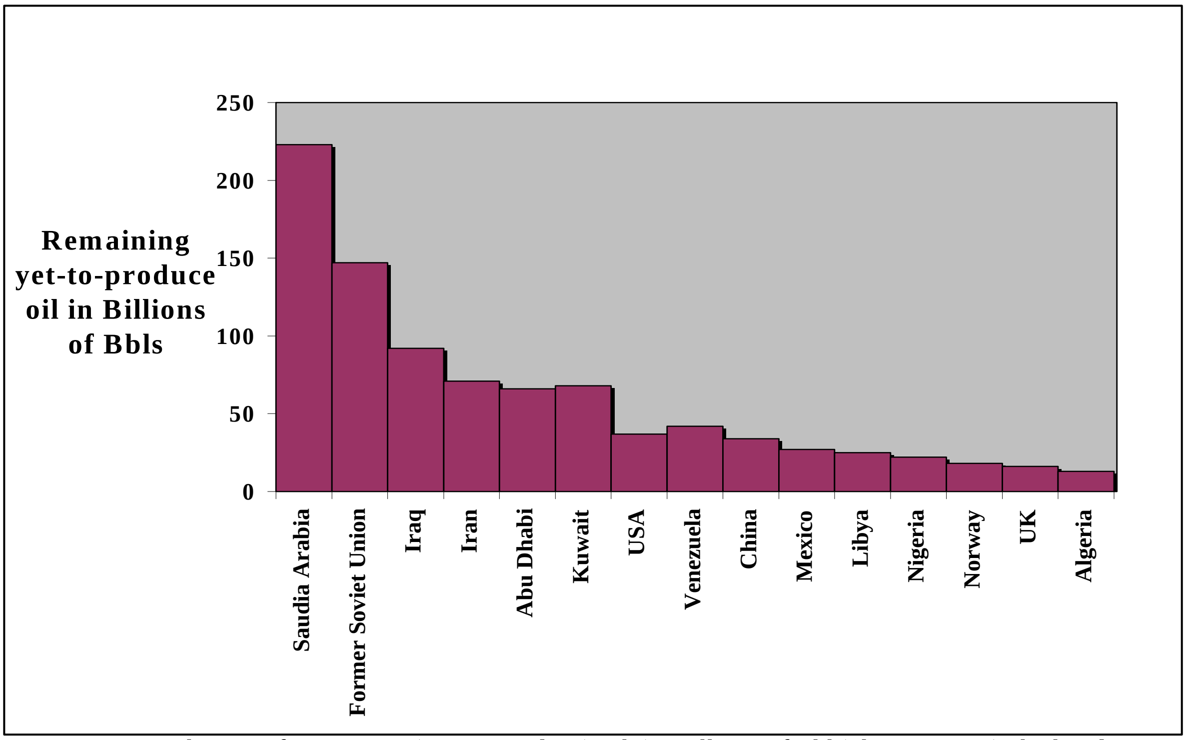

Figure 3.3: *Distribution of remaining (Yet-to-Produce) oil (in Billions of Bbls) by country (calculated by subtracting total production of conventional oil to date from Campbell's estimate of cumulative production of conventional oil and dividing by country) (source: Campbell, 1997 p 95)*

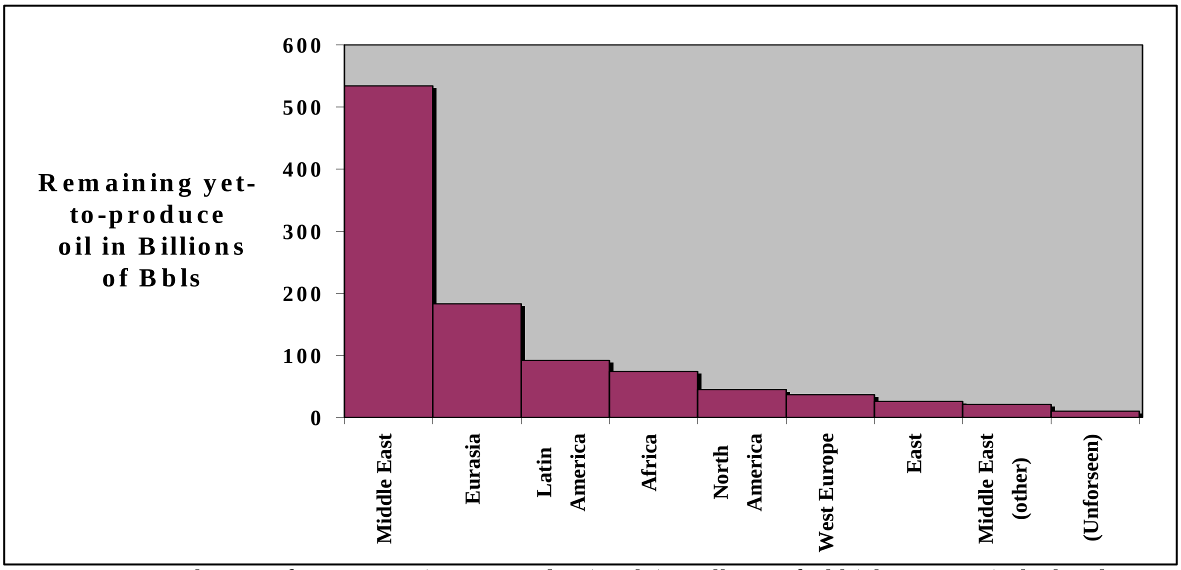

Figure 3.4: *Distribution of remaining (Yet-to-Produce) Oil (in Billions of Bbls) by region (calculated by subtracting total production of conventional oil to date from Campbell's estimate of cumulative production of conventional oil and dividing by region) (source: Campbell, 1997 p95)*

However, nationalism runs high in Saudi Arabia and Kuwait and relationships within Iraq are tenuous – a situation which is unlikely to change in the near future (The Economist, 1996). Moreover, whilst the statistics might indicate that technically the oil firms are reporting increased reserves in reality this conceals two trends. Firstly, by using new technology either to extend field life or to exploit fields that were previously inaccessible, oil companies have been able to increase their reported reserves. Secondly, petroleum companies are becoming increasingly reliant on gas which is harder to transport and less profitable to produce (The Economist, 1996). Some, such as Laherrère (1999), are more cynical and believe that the bulk of the recent "reserves growth" can be attributed to faulty reporting practices.

- Demand

World demand for oil, gas and coal in the 21st century will depend on two contrary forces. Firstly, there is the possible reduction in demand by the countries in the Organisation for Economic Co-operation and Development (OECD) caused by structural changes, saturated markets, ageing populations and increasing efficiency. Such efficiency gains are driven by competition, concerns for energy security and environmental measures. Action to meet Kyoto targets, set in a summit on global warming in Kyoto, Japan in December 1997, will put a cost on carbon emissions – either by taxation or by trading. Coal and oil will face fierce competition in power generation. As indicated above, oil majors are relying increasingly on gas (The Economist, 1996). Skeikh Ahmed Zaki Yamani believes that new hybrid engines could cut petrol consumption by almost 30%, while fuel-cell cars, which he predicts will be widely used by 2010, will cut demand for petrol by 100%. In a recent article in *Energy Day* he said:

> "Thirty years from now there will be a huge amount of oil – and no buyers. Oil will be left in the ground. The Stone Age came to an end not because we had a lack of stones and the oil age will come to an end not because we have a lack of oil." (Energy Day, 3rd July 2000 p7)

His claims are substantiated by a study from U.S. based *Allied Business Intelligence* (ABI), which forecasts millions of fuel-cell vehicles by 2010. ABI business analyst Atakan Ozbek is also quoted in the same *Energy Day* article:

> "By the second decade of this century mass production of automotive fuel cells will result in first a glut in the world oil supply and then in a total reduction of oil as a vehicle fuel." (Energy Day, 3rd July 2000 p7)

Secondly, there is the potential demand in developing countries. How it is fulfilled depends on future economic growth. The oil companies, however, are optimistic with Shell suggesting that energy consumption will be between sixty and eighty percent higher by 2020, with developing countries consuming over half of the available energy (Moody-Stuart, 1999).

- Restructuring

International oil prices are notoriously volatile (figure 3.5). However, when, in the winter of 1998-1999, oil prices dropped to their lowest levels in real terms for twenty-five years, the profit margins of even the largest companies were squeezed and all companies were forced to reduce costs. This proved difficult and with the need to improve their return on capital employed, which has historically been lower than the cost of that capital, the boards of some of the largest companies perceived the only way to make further savings was through big mergers, followed by ruthless restructuring (The Economist, 1998).

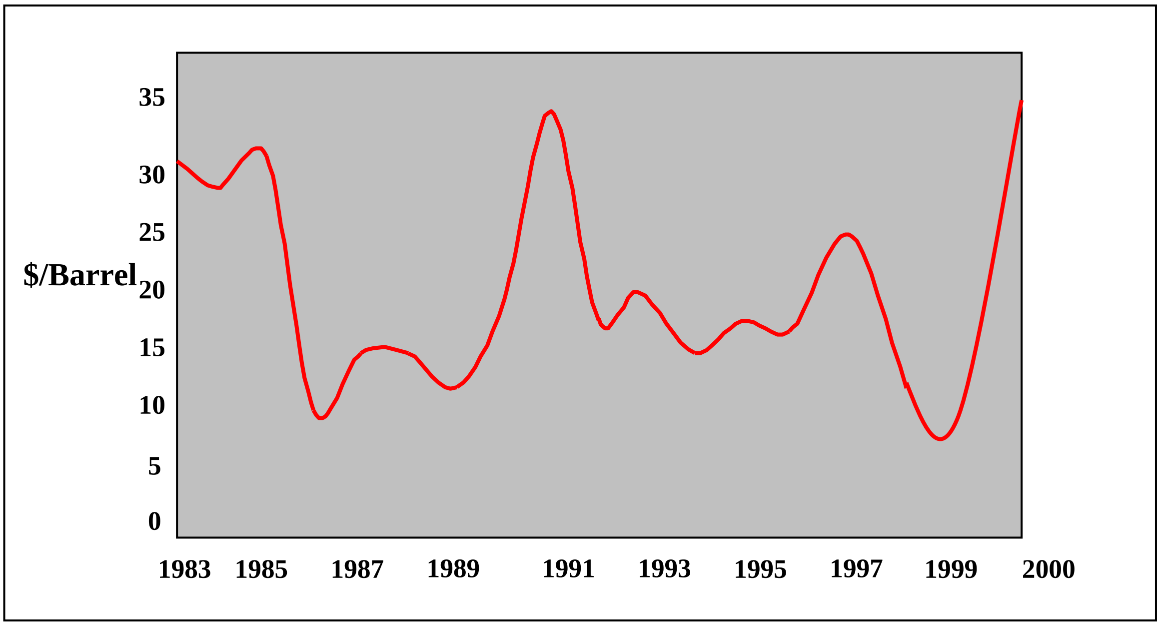

Figure 3.5*: Actual spot Brent oil price over time (source: BP Statistical Review of World Energy, 2000)*

In 1998 BP agreed to buy Amoco for $48 billion, Exxon and Mobil, America's biggest oil firms, announced a $77 billion merger that has made Exxon Mobil the world's biggest oil firm – and, on some measures, the largest firm in the world. The merger is already starting to transform the world's oil industry. Firms that were once considered big, such as Chevron and Texaco, are rushing to find partners. This is true even in Europe, where national champions have traditionally resisted pressures to merge. France's Total announced in 1998 that it was buying Belgium's Petrofina for some $13 billion (The Economist, 1998) and, more recently, Total Fina have also bought France's Elf.

Whilst some argue that this is just typical oil industry over-reaction to the bottom of the price cycle (for example, Euan Baird of Schlumberger in The Economist, 1998), others believe that the structure of the oil industry has altered irreversibly:

> "…the changes unleashed by the mergers look unstoppable" (The Economist, 1998 p74)

Indeed, whilst there may well always be a role for the "scrappy entrepreneur" (The Economist, 1998), size is becoming increasingly important in the oil industry. It takes a great deal of capital and a "matching appetite for risk" (The Economist, 1998), to succeed in the Caspian or West Africa. Tackling a $6 billion project in China will be a huge effort for Texaco, with its revenues of some $50 billion. For Exxon Mobil though, which is four times that size, such projects will be, according to The Economist (1998), "small potatoes".

This section has highlighted the current global challenges facing the oil industry. Since the current study will focus on those petroleum companies operating in the U.K., the next section examines the effect of the worldwide challenges on the U.K. industry. The impact on investment decision-making will then be investigated.

3.3 THE OIL INDUSTRY IN THE U.K.

In the U.K. there are approximately 257 offshore fields currently in production on the United Kingdom Continental Shelf (UKCS) and 12 under development. In 1999 in the U.K. North Sea, daily oil output averaged 2.69 million barrels per day including a contribution of some 89,000 barrels per day from onshore fields. In 2000, Wood Mackenzie predicts that oil production will remain at this level. In total, North Sea production (including Norway) averaged some 6.15 million barrels per day in 1999. This is forecast to increase to an average of some 6.46 million barrels per day in 2000 (Wood Mackenzie Newsletter, February 2000). Since 1964, the industry has contributed significantly to the U.K. economy. It has provided, via taxes, £89 billion to the exchequer; significant employment, with currently 30,000 jobs offshore and over 300,000 direct and indirect jobs onshore (Foreword of The Oil and Gas Industry Task Force Report published by the Department of Trade and Industry, 1999); and in 1999 it was responsible for 36% of the U.K.'s industrial investment (U.K. Energy in Brief published by the Department of Trade and Industry, 2000).

However, in the early 1970s the average size of a UKCS discovery was about one billion barrels of oil (Brown, 1992). Today, nearly half of all developed fields in the UKCS contain less than fifty million barrels of oil (Shell, 1998). This decline is shown in figures 3.6 and 3.7.

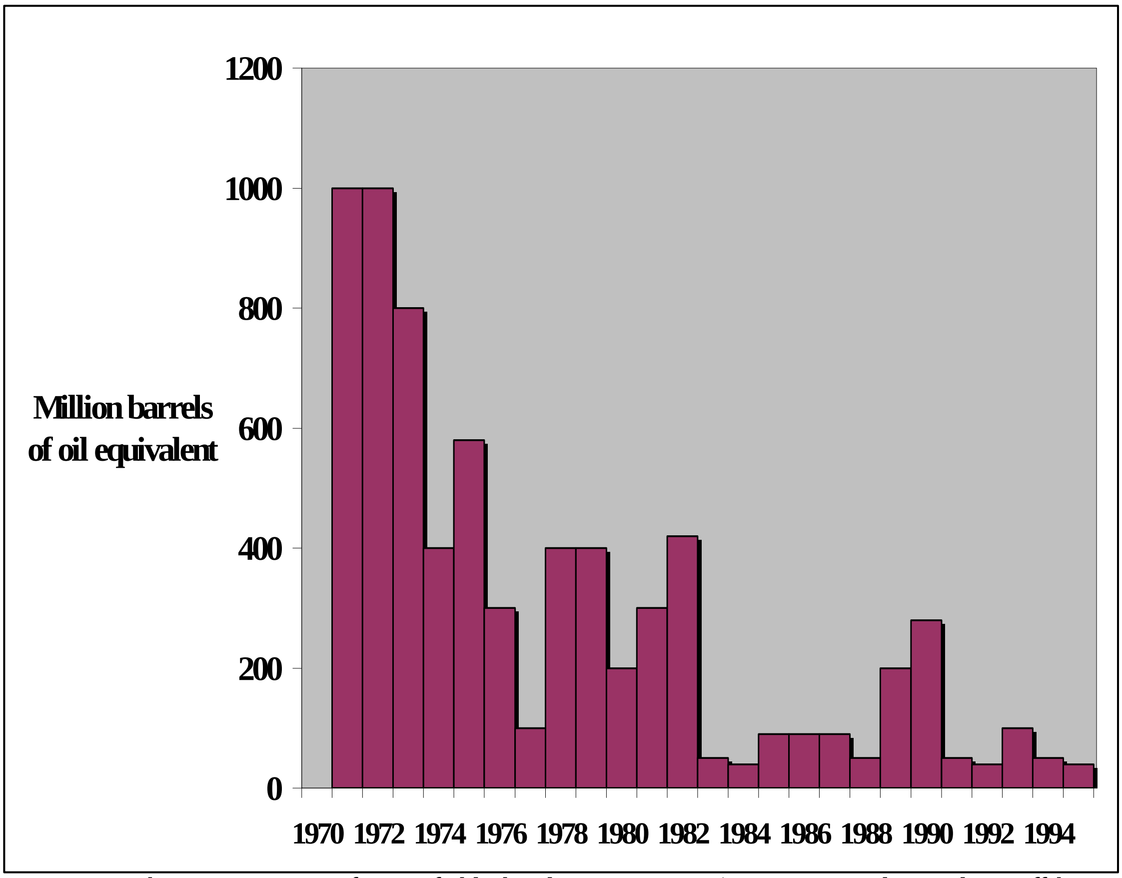

Figure 3.6: *The average size of U.K. fields by discovery year (source: United Kingdom Offshore Operators Association, 2000a, http://www.ukooa.co.uk)*

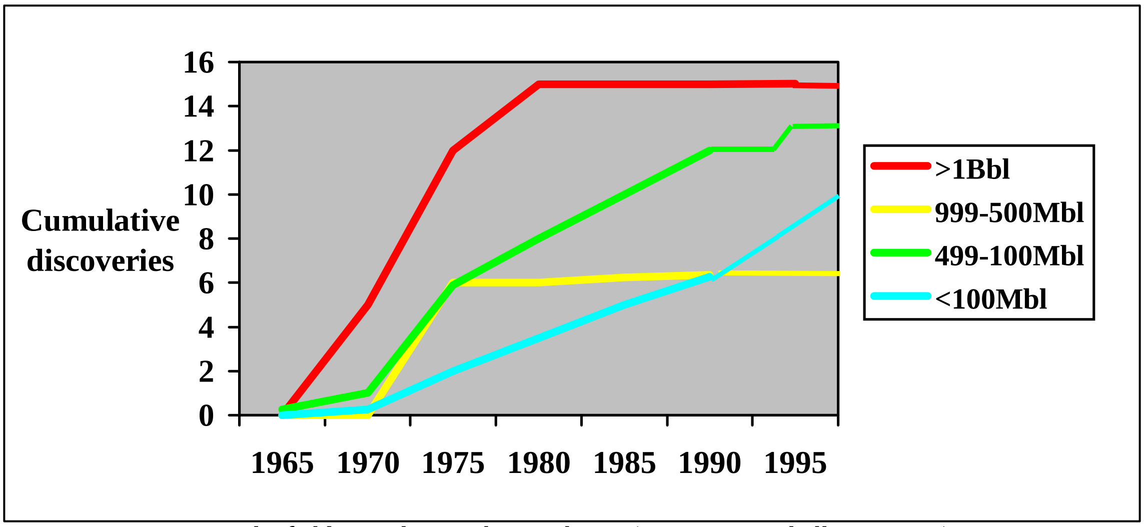

Figure 3.7: *Discoveries by field-size class in the North Sea (source: Campbell, 1997 p84)*

Nearly all the significant discoveries made in the first ten years of North Sea exploration have been developed or are approved for development. Typically, operators in the North Sea are focusing on cost cutting strategies as production from their existing fields declines. Due to high maintenance costs and low margins, large operators are pursuing retrenchment strategies by selling off their mature oil fields to smaller lower cost operators in order to concentrate their resources (human and financial) on much larger and rewarding fields in other countries. Reflecting this trend, over the past two years exploration activity on the UKCS has declined substantially (The Oil and Gas Industry Task Force Report published by the Department of Trade and Industry, 1999).

In the UKCS, experts estimate that there is a further sixteen to twenty billion barrels of oil equivalent remaining in fields that are either already in production or under development and between five and thirty billion barrels of oil equivalent yet to be found (United Kingdom Offshore Operators Association, 2000b). However, much of this is likely to be located in smaller, increasingly complex geological structures requiring innovative techniques to develop them safely and viably. The costs of developing fields and producing oil from the UKCS remain higher than other oil basins with similar characteristics elsewhere in the world (for example, see figure 3.8). Downward pressure on oil prices has coincided with the rising costs of operations for new field developments. Increasing competition for new investment is coming from other prospective areas of the world, where countries are now offering competitive fiscal and regulatory terms and conditions. In 1999, a task force team of experts from the U.K. Government and oil industry considered the current position and future scenarios for the industry in the U.K.. Their conclusions were that total UKCS production is likely to peak at over six million barrels of oil equivalent per day in the near future. Due to the maturity of the North Sea as an oil province, production will then start to fall, even allowing for the potential reserves in the Atlantic Margin (The Oil and Gas Industry Task Force Report published by the Department of Trade and Industry, 1999). However, they perceived the speed of this decline to be dependent on a number of factors, including: technology, the cost base of activity, the level of continued investment - particularly in exploration, the maintenance of existing infrastructure, the fiscal regime and the level of world oil prices.

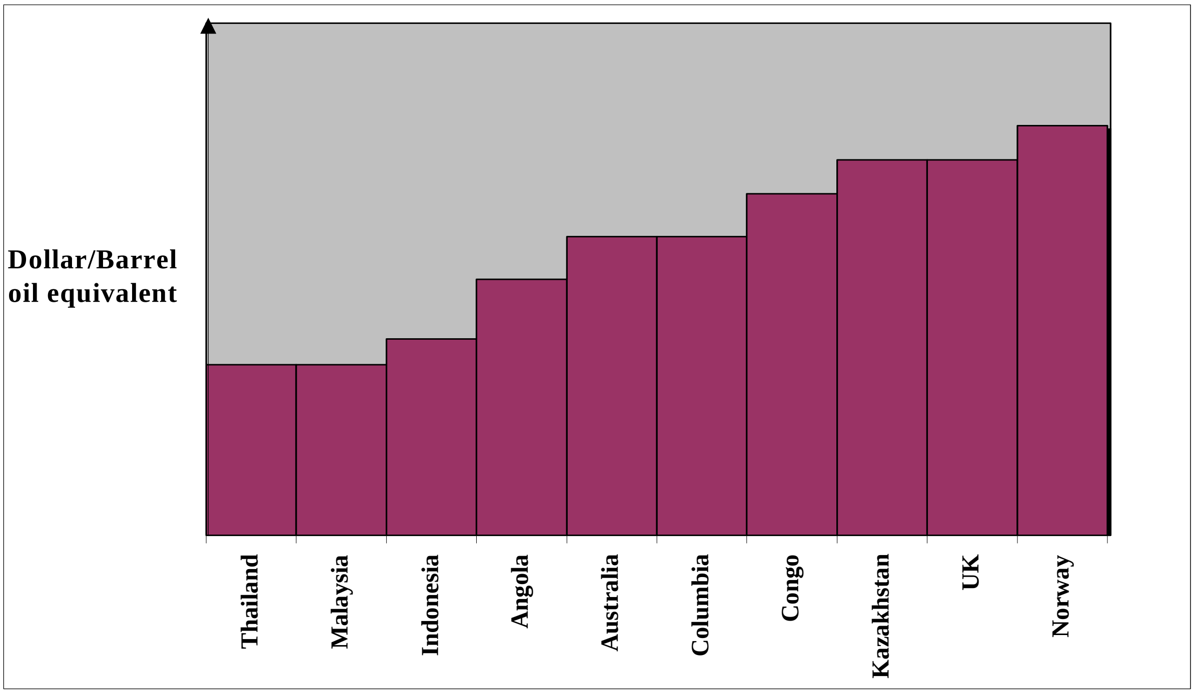

Figure 3.8: *Worldwide operating costs (source: United Kingdom Offshore Operators Association, 2000c, http://www.ukooa.co.uk)*

In the U.K., these pressures have led the U.K. Government and industry to seek ways to improve the attractiveness of the U.K. in comparison to international petroleum provinces. The U.K. Government introduced the first out-of-round licensing awards in 1992 to facilitate the early development of fields (Department of Trade and Industry, 1998). In the same year, the CRINE (Cost Reduction In the New Era) Network was launched. This is an initiative supported by the U.K. oil and gas exploration and production industry that aims to increase the global competitiveness of the U.K. by focussing on reducing the costs of its participants - the domestic and international operators that operate on the UKCS and the contracting and supply companies in the U.K.. The resulting cost reduction initiative has led to savings of 30% in capital and operating costs (Department of Trade and Industry, 1998 p4). In 1996, CRINE turned its attention to competitiveness in a wider sense than cost reduction. The objective became to find ways of enhancing the value of the services and equipment provided by contractors and suppliers to operators not just in field developments but also in field operations. The aim is to extend the commercial life of the UKCS and through improving the global competitiveness of the supply industry, to increase export market share and to secure employment in this sector well beyond the time when U.K. becomes a net importer of oil again. In response, in 1997 the Department of Trade and Industry's Infrastructure and Energy Projects Directorate commissioned a study on the impact of changing supply chain relations on the upstream oil and gas supplies industry particularly on small, medium-sized enterprises. At the time of the study, supply chain management (SCM) was seen as a set of management processes that could usefully help the industry cope with some of the challenges it then faced. When the oil price dropped in 1998, what was simply desirable became imperative. SCM is now seen as a technique that can make a considerable contribution to the economics of upstream development. The CRINE network SCM initiative has identified cost savings and substantial improvements in value through the implementation of a range of SCM and collaborative initiatives. In parallel with the CRINE network SCM initiative, the Oil and Gas Industry Task Force (OGITF) has been established. The OGITF was launched in November 1998 to address the impact on the U.K.'s oil and gas industry of the low world oil price. The resulting initiatives were announced in September 1999 and include the creation of a new industry body LOGIC (Leading Oil and Gas Industry Competitiveness) which will seek to change fundamentally the way in which the oil and gas industry does business by driving improved SCM and industry-wide collaboration.

This section has examined the current situation in the U.K. oil industry. It has highlighted the increasing complexity of the business environment of petroleum companies operating in the U.K.. The next section shows why, given these recent changes, the industry provides such a useful example in which to study investment decision-making. The effect of these changes on the investment decision-making processes adopted by companies in the industry will then be examined using the results from recent studies of current practice.

3.4 INVESTMENT APPRAISAL DECISION-MAKING IN THE OIL INDUSTRY

Risk and uncertainty are inherent in petroleum exploration (Bailey *et al.*, in press; Simpson *et al.*, 2000 and 1999; Lamb *et al*, 1999; Watson, 1998; Newendorp, 1996; Rose, 1987; Ikoku, 1984; Megill, 1971 and 1979). The circumstances that led to the generation of oil and gas are understood only in a very general sense (Newendorp, 1996; Ikoku, 1984). The existence, or more particularly the location of traps, cannot be predicted with certainty. Even when a trap is successfully drilled, it may prove barren for no immediately discernible reason (Ikoku, 1984). Indeed, worldwide approximately nine out of ten wildcat wells (which cost approximately $15 million to drill offshore) fail to find commercial quantities of hydrocarbons (Watson, 1998; Pike and Neale, 1997; Hyne 1995). Whilst in the North Sea, of the 150,000 square miles of the U.K. area that have been offered for licence, it has been estimated that only 2% has hydrocarbons beneath it (Simpson *et al.*, 1999). Furthermore, the economic factors that ultimately affect the exploitation of the resources are subject to capricious shifts that, it has been claimed, defy logical prediction (Ikoku, 1984); an effect that is exacerbated in the oil industry since exploration projects require a large initial capital investment without the prospect of revenues for ten to fifteen years (Simpson *et al.*, 1999). Such observations led Newendorp (1996) to conclude that risk and uncertainty are frequently the most critical factors in decisions to invest capital in exploration. In reality he argues, each time the decision-maker decides to drill a well, he is playing a game of chance in which he has no assurance that he will win (Newendorp, 1996).

Previously, when most exploration wells were shallow and drilling anomalies were numerous and easy to locate, the upstream decision-maker was content to utilise intuition, judgement, hunches and experience to determine which prospects to drill (Newendorp, 1996). However, as noted in sections 2.2 and 2.3, the worldwide petroleum industry has changed, and many decision-makers are uncomfortable basing their investment decisions on such an informal approach (Chapter 6; Ball and Savage, 1999; Newendorp, 1996). Consequently, decision analysis tools, which allow risk and uncertainty to be quantified, have recently begun to receive increasing attention in the oil industry investment appraisal literature (for example, Bailey *et al.*, in press; Simpson *et al.*, 2000 and 1999; Lamb *et al*., 1999; Galli *et al.*, 1999; Ball and Savage, 1999; Schuyler, 1997; Murtha, 1997; Smith and McCardle, 1997; Otis and Schneiderman, 1997; Nangea and Hunt, 1997; Newendorp, 1996).

There have been two recent studies into current practice in investment appraisal across the oil industry (Schuyler, 1997; Fletcher and Dromgoole, 1996) and both have sampling limitations. Schuyler's study drew only on the observations from participants on a decision analysis course and so some formal bias to formal decision analysis practices must be assumed and Fletcher and Dromgoole only included sub-surface employees in their cross-company survey. Hence, the results from both pieces of research can only be regarded as indicative rather than conclusive. Both studies tend to suggest that decision analysis is receiving increasing attention in the industry and that the techniques are widespread in exploration investment decision-making but have yet to be applied to production investment decisions (the differences in these types of investment decision will be discussed in Chapter 5). The most useful indication of current practice in investment appraisal comes from individual companies publishing details of their approach to investment appraisal in the oil industry literature. Unfortunately there are few such reports and those that there are usually tend to describe how decision analysis has been used in specific cases. This in itself is indicative of how organisations use the techniques, a point that receives further attention in Chapter 6, but, moreover, make it impossible to use such accounts to describe company-wide practice. There are a few exceptions. For example, Otis and Schneidermann (1997) describe the decision analysis approach used in Chevron and Nangea and Hunt (1997) outline that used in Mobil prior to their merger with Exxon. These and the other similar publications are reviewed in Chapters 5 and 6. Clearly though, these company accounts, by their nature, are not indicative of industry practice.

This section has shown why, given the recent changes in the operating environment of the industry that it provides such a useful example in which to study investment decision-making. The effect of these changes on investment decision-making in the industry has been examined using the results from recent studies of current practice. This has highlighted the growing interest in decision analysis in the industry and identified the need for an empirical study to investigate investment appraisal decision-making in the oil and gas industry.

3.5 CONCLUSION

This chapter has used the oil industry literature to present a brief description of the industry. The main challenges facing the industry in the 21^{st} century were identified. The effects of these global changes on the U.K. industry were examined. This highlighted the growing complexity of the business environment of those companies operating in the upstream oil and gas industry that has prompted increasing interest in decision analysis techniques in the industry (Chapter 6). The chapter showed how there have been limitations in the recent studies into current practice in investment appraisal in the oil industry and that therefore there is a need for a study to investigate investment decision-making in the oil and gas industry. The following chapter first states the methodological approach adopted for this study and second, evaluates its effectiveness.

Chapter 4

Methodology

4.1 INTRODUCTION

The current study contributes to the current deepening understanding of the value of the application of decision analysis to organisational investment decision-making. Set in the context of the operating companies in the U.K. oil industry the research has three specific objectives. It aims firstly to propose which decision analysis techniques are the most appropriate for upstream oil and gas companies to utilise in their investment decision-making; secondly, to ascertain which of these tools upstream companies choose to use in their investment appraisal and why; and lastly, to establish if there is a relationship between the use of decision analysis in investment decision-making and good organisational performance in the operating companies in the upstream oil and gas industry.

A qualitative methodology was chosen to answer these research questions with semi-structured interviews being chosen as the primary research method. The interview transcripts allowed the researcher to be able to model companies' investment decision-making processes and, in particular, organisations' use of decision analysis techniques in investment appraisal. Then, using this model, together with published financial measures and other criteria indicative of organisational performance in the upstream, non-parametric statistical analysis was employed for the examination of the relationship between the use of decision analysis in investment appraisal decision-making and organisational performance. In this chapter, this methodology will be evaluated. Particular attention will be focussed on the different methods of qualitative data analysis used and their appropriateness for the study of investment decision-making. The choice of the oil industry as the context for the current study has already been justified in the preceding chapter hence it will be taken as given here. Directions for future research will not be discussed in this chapter but instead will be proposed in Chapter 8.

The chapter follows the approach outlined by O'Mahoney (1998) and is written as a case history of the methodology of the current study. The chapter aims to recreate the iterative and dynamic flows between research area and methodology that has been the feature of several recent works. A feature of the research has been the development of the researcher as an academic researcher. In this regard, the papers and presentations that have been prepared during the course of the current study are shown in Appendix 2.

4.2 Adopting an appropriate methodological framework

Orton's (1997) summary of Daft's (1985) distinction between deductive research (theory, method, data, findings) and inductive research (method, data, findings, theory) suggests that the management research process can be viewed as a coherent series of logically directed steps. Gill and Johnson (1991) believe that such statements and the neat, tidy accounts of the conduct of the research process produced by seasoned researchers (Burgess, 1984a), are misleading. In particular, the authors argue that they simplify concepts which are frighteningly out of step with those researchers who have given a "warts and all" account of their methodologies (O'Mahoney, 1998; Barley, 1995; Bryman and Burgess, 1994; Ferner, 1989). Discussions by such researchers have revealed that social research is not a set of neat procedures. Rather, it is a social process whereby interaction between researchers and researched will directly influence the course of action which a research project takes (O'Mahoney, 1998; Okley, 1994; Burgess, 1984b; Shaffir *et al.*, 1980; Shipman, 1976; Bell and Newby, 1977; Bell and Encell, 1978; Hammond, 1964). The research process, and hence the methodology employed, is not a clear cut sequence of procedures following a neat pattern, but a messy interaction between the conceptual and empirical world, with deduction and induction occurring at the same time (Bechofer, 1974 p73). Laing (1997) argues that the methodological framework cannot be seen as a rigid, purely objective construct. Rather, it should be perceived as a framework, the final version of which is determined by environmental pressures. It is within such a context that the methodological framework employed in this research has evolved. There is widespread recognition that there can be a significant gap between the methodological approach and intentions articulated at the commencement of the research project and that ultimately implemented (for example, O'Mahoney, 1998; Laing, 1997). Consequently, in seeking to demonstrate the validity and reliability of the data gathered and the results presented, it is necessary to examine and evaluate critically the actual research process undertaken (Laing, 1997) and this is the aim of this chapter.

In describing the core elements of management research, Gill and Johnson (1991 p154) stress the centrality of a comprehensive review of the existing literature to the research process. They describe the literature review phase of research as constituting:

> "…a critical review which demonstrates some awareness of the current state of knowledge on the subject, its limitations and how the proposed research aims to add to what is known."

A comprehensive review and critical appraisal of the relevant literature is thus crucial to formulating the underlying research questions to be examined by the study and in the subsequent development of the specific research instruments to be utilised in the data gathering process. Following the approach used by Laing (1997), at the outset of this research, the literature review involved the systematic searching of a number of major databases against a list of key words and phrases. This allowed the researcher to identify as fully as possible all published material that broadly related to aspects of the research subject. From this comprehensive search, relevant articles and texts were obtained, analysed, annotated and classified. Subsequently, the references and bibliographies of key articles and texts identified from these databases were searched in order to follow up additional potentially relevant material. This literature review was continually updated throughout the duration of the research process as additional relevant material was published. The new publications, though not impacting on the development of the underlying research questions or the specific research instruments, enhanced the subsequent analysis of the primary data gathered during the field research.

In seeking to explore the investment decision-making process of the upstream oil and gas industry, the literature review for the study, presented in Chapters 2 and 3, examined research from two different areas. Firstly, it investigated the academic literature on investment decision-making and, in particular, that relating to decision theory and secondly, it explored the literature relating to the industry and its investment decision-making process. Reviewing these literatures highlighted gaps in existing knowledge and the identification of the research questions for the current study. These three questions are:

1. Which techniques are the most appropriate for companies to utilise in their investment decision-making?
2. Which techniques do companies use to make investment decisions and how are they used in the investment decision-making process?
3. Is there a relationship between using decision analysis techniques in investment appraisal decision-making and good organisational performance?

This section will examine the specific research instruments used to explore these questions in turn. The following section will evaluate the effectiveness of the methodological approach.

To answer the first research question and identify the decision analysis tools that are most appropriate for investment appraisal decision-making in the upstream oil and gas literature, the current study drew primarily on the decision theory and oil industry literatures. This involved firstly, identifying the whole range of techniques that are available and, secondly deciding which of these tools are the most appropriate for upstream investment decision-making. It demanded careful consideration of factors such as the business environment of the upstream industry and the level and type of information used for investment decision-making in the industry. Through this process, the research identified the decision analysis techniques that are particularly useful for upstream investment decision-making. Then, drawing again on the investment appraisal and industry literatures, and also on insights gained at conferences and seminars, an approach to investment decision-making in the oil industry was developed that utilised the full spectrum of tools identified. Some decision analysts advocate using one decision analysis technique for investment appraisal (for example, Hammond, 1966). However, in reality, each tool has limitations (Lefley and Morgan, 1999) some that are inherent, others which are caused by a lack of information or specification in the literature (see Chapter 5). As such, the knowledge that the decision-maker can gain from the output of one tool is limited (see Chapter 5 and Newendorp, 1996). Therefore, a combination of decision analysis techniques and concepts should be used to allow the decision-maker to gain maximum insight, encouraging more informed investment decision-making (this is justified in Chapter 5). Some oil industry analysts have recognised this and presented the collection of decision analysis tools that they believe constitute those that decision-makers ought to use for investment decision-making in the oil and gas industry (for example, Newendorp, 1996). However new techniques have only recently been applied to the industry (for example, Galli *et al.*, 1999; Dixit and Pindyck, 1998 and 1994; Ross, 1997; Smith and McCardle, 1997) and as such, these previously presented approaches now require modification. Consequently, although informed through secondary data sources, the identification of the decision analysis techniques that are most appropriate for investment appraisal decision-making and the approach to investment appraisal that is presented in this thesis, are believed to be two of the main findings of the research.

In exploring the second research question, the current study aimed to establish current practice in investment appraisal decision-making in the operating companies in the U.K. oil and gas industry. Two factors directly affected the choice of research method chosen to investigate this question; firstly, there is widespread recognition in social science research that the primary strength of qualitative research is that it facilitates the in-depth exploration of the perceptions and values of key organisational stakeholders. Bryman (1989 p12) identified the principal advantage of qualitative research as being that:

> "…it expresses commitment to viewing events, actions, norms and values from the perspective of the people being studied."

This reflects the primarily interpretive approach inherent in qualitative research involving the exploration of meanings and perceptions within a naturalistic rather than positivist framework (Hammersley and Atkinson, 1983). Such essentially intangible issues, Laing (1997) argues, cannot be explored adequately by traditional quantitative survey-based research methods. A second factor that impinged on the choice of research method was that previous empirical research had typically used quantitative survey-based research which had produced statistical results that indicated the percentage of organisations using decision analysis techniques (defined in Chapter 5) (for example see studies by Arnold and Hatzopoulous, 1999; Carr and Tomkins, 1998; Schuyler, 1997; Buckley *et al.*, 1996; Shao and Shao, 1993; Kim, Farragher and Crick, 1984; Stanley and Block, 1983; Wicks Kelly and Philippatos, 1982; Bavishi, 1981; Oblak and Helm, 1980 and Stonehill and Nathanson, 1968). Researchers such as Clemen (1999) perceived that through using survey-based research methods these studies had overlooked many interesting issues. For example, they had not indicated why decision analysis was used in some organisations but not others nor had they provided an explanation of why companies endorsed the use of certain techniques and failed to implement others (Clemen, 1999). It can be argued that the failure of such studies to examine these issues had contributed to the division between behavioural decision theorists and decision analysts outlined in Section 2.4 of Chapter 2. Therefore, *qualitative* methods were chosen to build a picture of decision analysis use in upstream organisations. In using such an approach the researcher aimed to investigate the relationship between normative decision analysis models and behavioural decision theory descriptions.

The next step involved deciding which companies would comprise the population for the current study. Limited resources had already dictated that the research had to be constrained to oil companies who had offices in the U.K.. A list of all the operators active in the U.K. was obtained via UKOOA (United Kingdom Offshore Operators Association). These thirty-one companies then constituted the population for the research study.

Following this, the next decision was which qualitative instrument, or combination of instruments, to use. Methods such as case study research and participant observation were clearly impractical with such a large number of companies within a relatively short and finite time-period. Acknowledging that the companies in the sample were all competitors, and that the issues that would be under discussion are commercially sensitive multi-company focus group discussions were also omitted from consideration. Intra-company focus groups were considered and rejected since it was felt that this would prohibit a frank expression of attitudes and experiences and become an exercise in reporting the formal organisational perspective. This process of elimination identified a semi-structured style of interviewing with several respondents in each company to be a useful instrument to employ in this research. Using this technique, a set of themes and topics is defined to form questions in the course of conversation. This strategy, it is argued in the qualitative methods literature, gives informants an opportunity to develop their answers and allows the researcher the freedom to follow up ideas, probe responses and investigate motives and feelings (for example, Okley, 1994; Bryman, 1989). It also allows the researcher to be sensitive to the participants' understanding of the language and concepts under investigation. In exploring the investment appraisal decision process, the interviews focussed on four core areas. These were firstly, decision analysis techniques that were used and why; secondly, how the tools were used; thirdly, the integration of the results from the techniques into the whole investment decision-making process; and fourthly, respondents' perceptions of the effectiveness of the process. Based on such core themes, a common interview schedule (Appendix 1) was developed. The initial questions focused on relatively broad conceptual issues, progressing to specific practical issues during the course of the interview, with the aim of producing rich and detailed accounts of the participants' perceptions of the investment decision-making process.

BP volunteered to pilot the interview schedule and the researcher visited them several times in April 1998 to conduct interviews. The researcher was unfamiliar with interviewing. Taping the interviews permitted reflection later on the researcher's ability and role as an interviewer. The interviews were transcribed and these transcripts played a valuable role indicating those terms and processes the researcher was using which were academically understood but which required clarification at practitioner level. The interview schedule was amended accordingly with some questions being rephrased, others discarded and several new questions being added. These interviews were used to improve the researcher's technique as an interviewer rather than for data collection. After the modification of the interview schedule, the transcripts from these interviews were discarded.

The researcher then had to decide whom to approach in each of the companies and how best to approach them. Ideally, the researcher wanted to speak to individuals who were actively involved in the whole investment appraisal process. With this rationale, it was decided to approach each operator's Exploration Manager, or equivalent, using the membership list of the Petroleum Exploration Society of Great Britain. Initially the project was outlined in a letter that indicated what would be required of each participant company, detailing what would be done with the collected data and giving assurances of confidentiality and anonymity. This was then followed up with either an e-mail or telephone call.

The letters were sent in March 1998 and the researcher began receiving responses in early April. The number of positive responses was overwhelming. Twenty-seven of the thirty-one companies approached agreed to participate – a response rate of 87%. This high response rate is clearly a function of timing and subject. As indicated in Chapter 3, the increasingly dynamic and complex operating environment of upstream had increased the pressure on petroleum companies to manage their investment decision-making processes better and decision analysis techniques were beginning to receive increasing attention in the industry literature (for example, Ball and Savage, 1999; Galli *et al.*, 1999; Watson, 1998; Schuyler, 1997; Murtha, 1997; Nangea and Hunt, 1997; Otis and Schneiderman, 1997; Newendorp, 1996). During the interviews, many of the respondents reported that their organisations were currently in the process of reviewing their investment decision-making processes and that this was their motivation for participating in the research.

Data collection began in May 1998. The interviews varied in length with the majority lasting approximately two hours. All the interviews were tape recorded in full. In addition, notes were taken during the interviews to highlight key issues and facilitate the subsequent analysis of transcripts. After assurances of confidentiality and anonymity, none of the respondents had any reservations about such recording. This emphasis on confidentiality inevitably influences the way in which the data is subsequently utilised and presented. All the companies interviewed have been assigned a code letter. The letter that was assigned to each company depended on the number of decision analysis techniques used in their investment appraisal approach. Company A used the least number of decision analysis techniques. Company B used the next least number of decision analysis tools and so on. These labels have been used throughout the thesis. Although 27 companies were originally interviewed, subsequent merger activity reduced this number to 20. So only letters A to T have been assigned to represent the interviewed companies, with letter T representing the company that used the highest number of decision analysis techniques. Where more than one respondent was interviewed in an organisation, each interviewee was assigned a number so that, for example, the second respondent that was interviewed from company B would be referred to as B2 and the third as B3. It is important to note that where companies merged, the respondents in these organisations were contacted after the merger and asked to report any changes to their corporate investment appraisal process. These insights were then analysed along with the relevant interview transcripts in the next stage of the research.

While divisions exist amongst researchers over the issue of whether interviews should be transcribed selectively or in full (Bryman, 1989), given the emphasis within this research on securing an in-depth understanding of attitudes and experiences, it was decided to transcribe all interviews in full. Such an approach, though time-consuming, facilitated the identification of themes, utilisation of quotations and the avoidance of biased judgements arising from initial impressions of the interview data. In addition, when coding the interview data from the transcripts, the original tapes were utilised, alongside the contemporaneous notes, in order to ensure that the interviewees' expression and emphasis was taken into account (Laing, 1997). Where necessary, respondents were contacted by telephone or e-mail for clarification.

The challenges of analysis and interpretation of qualitative data are widely recognised and well documented (Rossman and Rallis, 1998; Bryman and Burgess, 1994; Hammersley, 1992; Denzin, 1978). The difficulty of handling such data is well illustrated by Miles' (1979) description of qualitative data as "an attractive nuisance". In analysing the data from this research, rigorous use was made of appropriate structural approaches such as inductive analysis. In inductive approaches to data analysis, hypotheses are not generated before the data are collected and therefore the relevant variables for data collection are not predetermined. The data are not grouped according to predetermined categories. Rather, what becomes important to analyse emerges from the data itself, out of a process of inductive reasoning (Maykut and Morehouse, 1994 pp126-127). In this research project, the analysis of the interview data involved the coding of this data against both the core themes contained in the interview schedule which were derived from the analysis of the relevant literature and the emergent themes identified through the contemporary notes. After this initial coding, the data was further coded under more specific themes as well as additional emergent themes. Such multi-stage coding is vital in order to avoid as far as possible constraining any potential empirically based conceptual development to flow from this research (Denzin, 1978). It must be noted that while the data collection and data analysis elements of the research are described separately here, they cannot be seen as discrete stages (Laing, 1997). In common with many other qualitative studies, the collection and inductive analysis of the data ran concurrently although the balance between the two elements shifted over the duration of the research. Okley (1994 pp20-21) writes that

> "...to the professional positivist this seems like chaos. … The fieldworker cannot separate the act of gathering the material from that of its continuing interpretation. Ideas and hunches emerge during the encounter and are explored or eventually discarded as fieldwork progresses."

Wiseman (1974 p317) writes that this constant interplay of data gathering and analysis is the essence of qualitative research. It facilitates the flow of ideas between the two processes and this contributes to the development of theoretical constructs (Eisenhardt, 1989). Moreover, whilst the author has attempted here to detail the techniques used to assist in the data analysis, the precise mechanism by which this occurred cannot be fully documented. This point is echoed by Okley (1994 p21):

> "After the fieldwork the material found in notebooks, in transcripts and even contemporary written sources, is only a guide and trigger. The anthropologist writer draws on the totality of the experience, parts of which may not, cannot be cerebrally written down at the time. It is recorded in memory, body and all the senses. Ideas and themes have worked through the whole being throughout the experience of fieldwork. They have gestated in dreams and the subconscious in both sleep and waking hours, away from the field, at the anthropologist's desk, in libraries and in dialogues with people on return visits."

With so much of the data analysis taking place in the sub-conscious mind, it is impossible to present a full account of it (Whyte, 1955 p279). The current study then uses the approach of Laing (1997) who believes one way to ensure the integrity of the data and the objectivity of the resultant findings is for researchers to use verbatim accounts taken within their original context.

Through this process a description of current practice was produced and, therefore, research question two was answered. As indicated earlier, through the answering the first research question, the quantitative techniques available to companies for investment appraisal decision-making had been identified and an approach to investment decision-making developed that utilised the full spectrum of available techniques. These both acted as input into the third stage of the research which aimed to establish if there is a relationship between the use of decision analysis in investment appraisal decision-making in companies and business success in the operating companies in the U.K. upstream oil and gas industry.

As indicated in Chapter 2, very few studies have attempted to value the usefulness of a decision analysis approach (Clemen, 1999). Clemen and Kwit (2000) are the only researchers who have attempted to evaluate the benefits of a decision analysis approach to managing risk and uncertainty in investment decision-making. These authors investigated the value of a decision analysis approach within one company using a qualitative methodology, specifically using depth interviews and documentary analysis to inform their research. This methodological approach permitted these researchers to value the "soft" benefits to an organisation of utilising a decision analysis approach. However, whilst their research provides useful insights, as the authors themselves acknowledge, the focus on one organisation means that the results cannot be generalised to a larger sample. The current study differs from this since it aims to produce an indication of the value of using a decision analysis approach in upstream oil and gas companies. Therefore, by implication, the research involves numerous companies and this prohibits use of the time-consuming qualitative methodology implemented by Clemen and Kwit (2000). Instead, using the results from the semi-structured interviews as input, it was assumed that any value added to the company from using a decision analysis approach, including "soft" benefits, ultimately affects the bottom-line (this assumption is justified in Chapter 7). It was then possible to investigate the relationship between an organisation's use of decision analysis and good decision-making statistically by using criteria that are indicative of organisational performance.

To permit a comparison of companies according to the decision analysis techniques used for investment appraisal (identified by answering the second research question), a ranking scheme was devised which assigned two points for full implementation of each of the techniques identified by answering the first research question, one point for partial implementation of, or some familiarity with, the technique, and zero for non-use. Companies were also graded in the same way on how well the decision analysis techniques were supported – specifically, if there had been an attempt to introduce corporate definitions of the key terms risk and uncertainty. Best practice companies were expected to have implemented definitions that were complementary to their decision analysis approach. Where there were numerical ties according to these criteria, the tie was broken on the basis of other material from the interviews, indicative of level of sophistication, which was not available on all companies and therefore not included as an overall rank measure (for example, company-wide application of a piece of software). This ranking scheme is discussed further in Chapter 7. Performance measures were then selected that are indicative of business success in the upstream. The choice of these outlined and justified in Chapter 7. The appropriate performance data was then gathered on each company. For some of the criteria, it was only possible to access ordinal level data. For the some however, categorical data was available. The relationship between the rank each company achieved in the decision analysis ranking and their rank, or otherwise, on each performance measure were then analysed together statistically.

There is a large number of statistical techniques available for analysing any given set of data. The author has chosen in this thesis to use those tools known as non-parametric or distribution-free. These techniques may be contrasted with others known as parametric techniques. Parametric techniques make a large number of assumptions regarding the nature of the underlying population distribution that are frequently untestable. Leach (1979) argues that social scientists using parametric statistical analysis are taking a gamble. If the population assumptions are correct or approximately correct, then the researcher has very good test. However, if the population assumptions are incorrect, then a non-parametric test may well give a more accurate result. Non-parametric tests make relatively few assumptions about the nature of the data and hence are more widely applicable. Finch and McMaster (2000 p19) write:

> "…non-parametric techniques do not invoke such restrictions. Techniques involved in measuring association do not require the employment of cardinal measures redolent of interval scales. Instead the only measurement requirement is that ordinal scales can be deployed (Lehmann and D'Abrera, 1975; Siegel and Castellan, 1988)."

Since only ordinal level data were available for some of the performance criteria and there were no ties in the data, the primary non-parametric technique that the researcher elected to use was Spearman's rank correlation test. It is outlined in Appendix 3.

Spearman's rank order correlation coefficient is a modified form of the more typically used Pearson's correlation coefficient. It is mathematically equivalent to Pearson's correlation coefficient computed on ranks instead of scores. Just as Pearson's correlation coefficient is interpreted as a measure of linearity, Spearman's correlation coefficient can be interpreted as a measure of monotonicity. That is, Spearman's correlation coefficient is a standardised index of the degree to which two variables covary in a monotonic fashion. The Spearman's correlation coefficient index can range from –1.0 to 1.0. It will attain these maximum values when a perfect monotonic relationship is negative or positive, respectively. The rank order correlation coefficient will be zero when there is no relationship between two variables, or when the relationship is strong but nonmonotonic. Since Spearman's rank correlation coefficient is equivalent to Pearson's correlation coefficient computed on scores, it has some of the same characteristics. For example, since Pearson's correlation coefficient is equal to the regression coefficient in the special case where the variances of the two populations are equal it now follows that Spearman's correlation coefficient is also the linear regression coefficient for two ranked variables. As such, it indicates the amount of "rank change" in one population when the other increases by one rank. It can also be shown that Spearman's rank order correlation coefficient indicates the proportion of variation in one population that is explained by variation in the other population. Spearman's rank order correlation test is considered by some statisticians to be a "quick and dirty" approximation for Pearson's correlation coefficient. However, when data are ordinal the Pearson's correlation coefficient is not appropriate. In this case, Spearman's correlation coefficient is the most desirable index (Leach, 1979).

Where categorical data was available and there was sufficient number of data points on a performance criterion, a Kruskal Wallis test was also used. This test is outlined in Appendix 4. The Kruskal Wallis test is a direct generalisation of the Wilcoxon Rank Sum test. When a significant result is obtained with the Kruskal Wallis test, all that can be concluded is that there is some difference in location between the samples.

To find the location of this difference, the Wilcoxon Rank Sum test was used. This is also outlined in Appendix 4.

Through the utilisation of these two non-parametric tools, the author was able to produce evidence of an association between good organisational performance and the use of decision analysis techniques in investment appraisal decision-making in the operating companies in the U.K. upstream oil and gas industry.

This section has outlined the research methodology used to answer the three research questions proposed in Chapter 1. The following section will assess its effectiveness and suggest possible improvements.

4.3 EVALUATING THE EFFECTIVENESS OF THE RESEARCH METHODOLOGY

Through the utilisation of qualitative methods and statistical analysis the research presented in this thesis has generated a robust body of data. This claim can be justified on three counts.

First, using the academic investment decision-making and oil industry literatures, an approach to investment decision-making has been developed that utilises the full complement of decision analysis techniques presented in the decision theory literature. Second, using semi-structured interviews a description of the use of decision analysis in investment decision-making in the upstream was produced that is representative of current practice in the industry. The data from this second stage are consistent with previous research that indicated a gap between current practice and current capability in investment appraisal (for example see studies by Arnold and Hatzopoulous, 1999; Carr and Tomkins, 1998; Schuyler, 1997; Buckley *et al.*, 1996; Shao and Shao, 1993; Kim, Farragher and Crick, 1984; Stanley and Block, 1983; Wicks Kelly and Philippatos, 1982; Bavishi, 1981; Oblak and Helm, 1980 and Stonehill and Nathanson, 1968). The findings as such are demonstrably valid and reliable. Thirdly, using the data gathered from the research interviews and publicly available financial data, the relationship between use of decision analysis techniques in investment appraisal decision-making and good organisational performance was investigated statistically. As such the research has contributed to the current discussion (for example, Clemen and Kwit, 2000; Clemen, 1999) in the decision theory literature of the relationship between normative and descriptive models of investment decision-making. Furthermore, since the sample used in this research contains 87% of the U.K. petroleum operators, it is clear that the findings are representative of all U.K. petroleum operators. Moreover, since most of the oil companies that operate in the U.K. are amongst the major players in the oil industry, the findings can be said to be indicative of investment decision-making practices in the major companies in the worlds' upstream oil and gas industry.

As with any research, the results have to be interpreted bearing in mind some limitations. The context within which the research is undertaken inevitably impinges on the actual articulation of the research methods employed. In this regard the time, and by implication the resource limitations, influenced the final methodology adopted in three ways.

Firstly, time and resource constraints precluded the use of observational research techniques that would have facilitated an enhanced understanding of the dynamics of the investment decision-making process and the links between the different stages of the process, the "soft" effects on organisation performance from using decision analysis and the relationships between the individuals involved.

Secondly, the research was limited to a single time period that coincided with a period of very low oil prices, proliferation of mergers and corresponding job losses. Interviewing respondents who knew that they were to be made redundant affected the data gathered from them since respondents often perceived their organisations' approach to decision-making as extremely poor and portrayed their management in a less than favourable light. In all cases this data was disregarded and other respondents were used in these companies. Furthermore, there was tremendous uncertainty in the industry at this time and many companies were changing their approach to investment decision-making and, as indicated above, were becoming more interested in decision analysis. Often the respondents from these companies were actively involved in this change and, on many occasions, they perceived the current study as a vehicle for initiating or encouraging it. As indicated in section 4.2, this significantly affected the response rate and also resulted in these respondents being particularly forthcoming with information on company practice. If it had been possible to return to these companies, it would have been interesting to look further on the effect of the mergers on companies' investment appraisal decision-making practices.

Thirdly, resource and time constraints affected the number of people consulted in each company. Despite the initial intention to consult multiple respondents in each company this was often not possible. Typically, only one person in each company was interviewed usually this individual was the Exploration, Commercial or License Manager. Bowman and Ambrosini (1997) have described the dangers of using single-respondents to ascertain company practice. They argue that where single-respondents are used, the researchers must be convinced that the research results are not dependent on the person that happened to be surveyed or interviewed. In this study, where the researcher felt there was the possibility of bias from a particular company representative, this data was disregarded and another respondent in that organisation sought. Hence, the researcher is confident that the data gathered is representative of company practice. Furthermore, in this study, as indicated above, it was the Exploration Managers that were usually interviewed. In most companies Exploration Managers are usually involved in generating investment proposals and presenting these proposals to the boards of their companies. So, in most cases, this individual is often the only person in the company who has been involved in both generating the analysis and witnessing the investment decision-making process.

4.4 CONCLUSION

The methodology that was used to explore the research questions set out in Chapter 1 has been described and critically evaluated in this chapter. In doing so, it has provided an example of how research can differ from the ordered and rational approaches of the more prescriptive research methodology texts. The limitations of the current study have been highlighted. Directions for future research will be proposed in Chapter 8.

The following chapter presents the results from the first stage of the research. Specifically, it aims to identify the tools that are available to the upstream oil and gas industry for investment appraisal decision-making.

Chapter 5

Current capability in investment appraisal in the upstream oil and gas industry

5.1 INTRODUCTION

This chapter focuses on answering the first research question proposed in Chapter 1. It draws on the discussion in Chapters 2 and 3, the decision theory and industry literatures and insights gained at conferences and workshops, to present the range of decision analysis techniques that are applicable to the upstream oil and gas industry for investment appraisal decision-making. This constitutes current capability in investment appraisal in the upstream. It will be compared with current practice in Chapter 6 and used in Chapter 7 to construct a ranking of companies according to the sophistication of their investment appraisal approach.

There are numerous tools described in the decision theory and industry literatures for investment appraisal decision-making. All the techniques presented in this chapter allow risk and uncertainty to be quantified and have been applied to upstream investment decisions in the literature. Each of the techniques has limitations, so that reliance by decision-makers only on the output from one tool for investment decision-making is inadvisable. By combining the output from a variety of tools, the decision-maker is more likely to assess the risk and uncertainty accurately. The techniques described in this chapter all use similar input and, hence their use together does not place unnecessary strain on the resources of an organisation. The other tools described in the literature (for example, the analytic hierarchy process (Saaty, 1980) and Markov chain analysis (Das *et al.*¸1999)) have either not been applied to the upstream in the literature, or the input they demand and, in many cases, the output they produce, is not complementary to the other investment techniques currently used by organisations. Hence their use would represent a significant amount of additional work for organisations. For these reasons, the tools described in this chapter, the researcher believes, comprise the toolkit currently available to the upstream investment decision-maker.

The chapter begins by presenting the decision analysis techniques described in the industry and prescriptive decision theory literatures. Fundamental to decision analysis are the concepts of expected monetary value (EMV) and decision tree analysis. They are widely applied to investment decision-making in the oil industry (see Chapter 6 and studies by Schuyler (1997), Fletcher and Dromgoole (1996) and Newendorp (1996)). The chapter proceeds to explore the other techniques in a similar manner. Following this there is a discussion of how these techniques could be used by the upstream for investment appraisal. This indication of current capability is then used as input into Chapter 6, where current theory in investment appraisal in the upstream is compared with current practice. (It is important to note that in this chapter descriptions of standard techniques are referred to, rather than reproduced. Where necessary, the reader is referred to the relevant literature for further details.)

5.2 THE CONCEPTS OF EXPECTED MONETARY VALUE AND DECISION TREE ANALYSIS

A general understanding of the oil industry can be gained from the process model shown in figure 5.1. In particular it highlights the extent to which investment appraisal decision-making in the upstream is characterised by risk and uncertainty as indicated in Chapter 3. The figure indicates the points at which investment decisions are taken to proceed with or to abort the project. If the decision is to continue, a further investment decision must be taken on whether to invest in the gathering and analysis of additional data in order to assess better the risk and uncertainty (at abandonment, the decision is not whether to abandon but when and how to do so). At any of these decision points, the consequences of that investment decision on all the subsequent processes, right through to the abandonment phase, need to be estimated and considered in the investment decision-making. For example, when a company is considering drilling a further appraisal well in a field, an estimate of the total recoverable reserves from the field needs to be produced and used as input to the economic analysis (Lohrenz and Dickens, 1993). The economic analysis will then model the cash flow throughout the project's life including a prediction of when the field will be abandoned and the estimated cost (Simpson *et al.*, 2000).

The upstream oil and gas industry shares with some other businesses, such as the pharmaceutical industry and aerospace engineering, typically long payback periods. Payback is defined as the length of time between the initial investment in a project by the company and the generation of accumulated net revenues equal to the initial investment (figure 5.2). In the oil industry, this period is typically between ten to fifteen years.

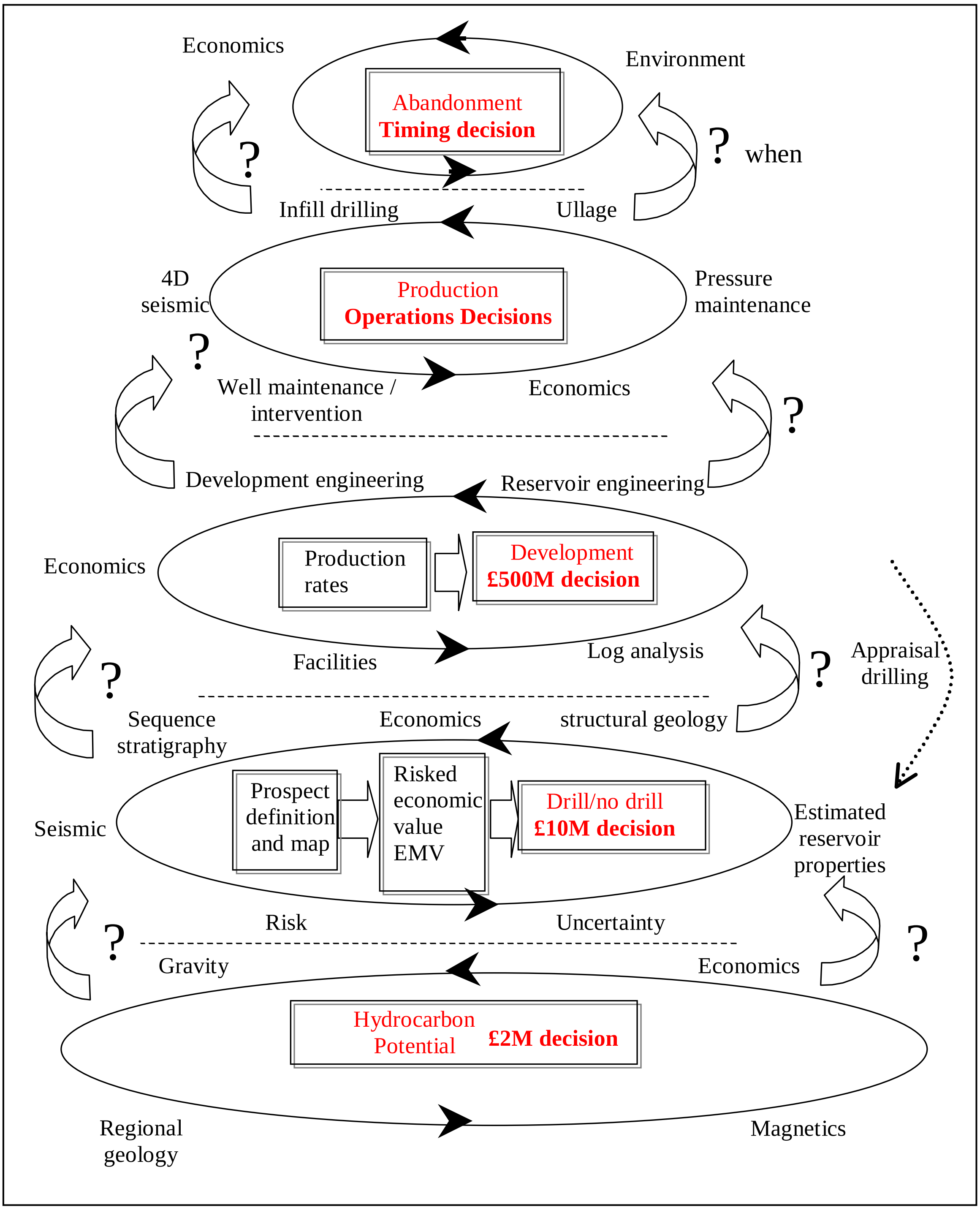

Figure 5.1: *The upstream oil and gas industry: a multi-stage decision process*

For example, in the North Sea there is an average gap of seven years between initial exploration expenditure and the commitment to develop a prospect. It takes another three or four years to get to the point when oil is actually produced and then fields normally produce for around twenty years before they are abandoned. (It should be noted that currently average lead times are being reduced through the wider availability of infrastructure and technology). Most of the main costs or cash outflows are incurred in the earlier, exploration and development, years while the cash inflows or revenues are spread over the active productive lifetime of the field. This makes economic modelling particularly difficult since at each investment decision point indicated in the process map in figure 5.1, estimates must be generated of the values in a decade's time of variables, some of which are notoriously volatile, such as, oil price and inflation. It also means that it is critical that discounted cash flow (DCF) techniques are adopted in investment appraisal (Simpson *et al.*, 1999). The most well known DCF tool is the net present value (NPV) method and it will be reviewed here. The intention is to give only a brief overview of NPV. More detailed explanations can be found in finance and economics texts (for example, Atrill, 2000; Brealey and Myers, 1996; Drury, 1985; Weston and Brighman, 1978).

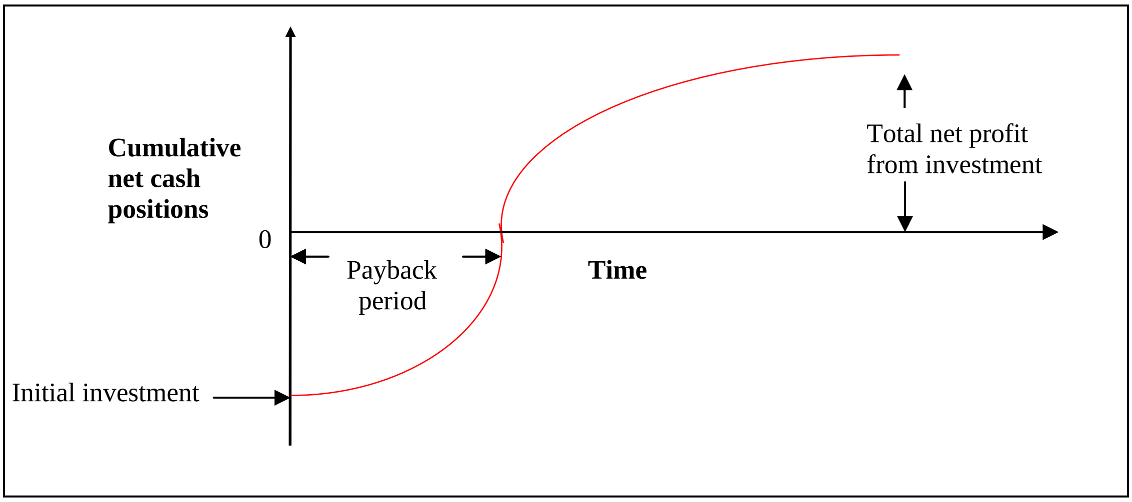

Figure 5.2: *Cumulative cash position curve (source: adapted from Newendorp, 1996 p14)*

As indicated above, when money is invested in a project a commitment of funds is generally required immediately. However, the flow of funds earned by the investment will occur at various points of time in the future. Clearly, receiving £1000 in, for example, a year's time is less attractive than receiving £1000 now. The £1000 now could be invested so that in a year's time it will have earned interest. This implies that money that will be earned in the future should be discounted so that its value can be compared with sums of money being held now. This process is referred to as discounting to present value (Goodwin and Wright, 1991 p147).

The severity with which future sums of money are discounted to their present value is a function of the discount rate applied. Determining the appropriate discount rate for a company's potential investment project is, ultimately, a matter of judgement and preference. However, many attempts have been made to make the choice of a discount rate as "objective" as possible, making this a complex area which is beyond the scope of this thesis. Edinburgh based oil industry analysts Wood Mackenzie's base case nominal discount rate is made up of four different elements:

- The risk-free real rate of return available through an index-linked, long-term gilt yield. This comprises the real rate of interest known at the time of purchase and whatever inflation rate occurs over the period of redemption.
- An assumption of the long-term inflation rate.
- The equity risk premium. This is the return expected by equity investors over and above the return on risk free assets. A premium is required because equity returns – like upstream investments – can only be estimated and are not guaranteed.
- The exploration risk premium. Oil companies are generally perceived as being "riskier" than the equity market (Wood Mackenzie, 1998).

For many situations it is convenient to let the discount rate reflect the opportunity cost of the capital which is being invested. Most firms now using the NPV measure of profitability appear to be using discount rates in the range of 9% to 15% for petroleum exploration investments. Some companies adopt a higher discount rate as a crude mechanism for quantifying risk and uncertainty (Newendorp, 1996 pp35-36). This is a practice that is not encouraged by many theorists since it does not explicitly consider the varying levels of risk between competing investment options (for a full discussion see Newendorp, 1996 pp307-308).

Having determined the discount rate, the process of discounting future sums of money is very straightforward. If the discount rate is equal to $i_{NPV,}$ the net cash flow of year k is equal to CF_k and the project life is equal to n years, the NPV is given by (Ross, 1997 p40):

$$NPV = \sum_{i=1}^{n} CF_i \, [1/(1+i_{npv})^i]$$

If the NPV is positive, the required rate of return will be earned and the project should be considered (the size of the NPV is often used to choose between projects that all have a positive NPV). If NPV is negative, the project should be rejected.

Table 5.1 provides an example of DCF analysis. It shows that at a 10% discount rate, the value of a $2000 net cash flow ($2500 of revenues less $500 of operating expenses) that is received in year 5 is worth $1242 now. If $5000 is invested today the total NPV (that is the sum of all the discounted net cash flows) is $2582. In other words; the $5000 is recovered, plus a 10% return, plus $2582. If the $5000 had been invested in a bank at 10% interest, an investor would have been $2582 worse off than he would have been by investing in this project (Bailey *et al.*, in press).

YEAR	INVESTMENT	REVENUE	OPERATING EXPENDITURE	NET CASH FLOW	10% DISCOUNTED CASH FLOW	20% DISCOUNTED CASH FLOW
0	$5000			$-5000	$-5000	$-5000
1		$2500	$500	$2000	$1818	$1667
2		$2500	$500	$2000	$1653	$1389
3		$2500	$500	$2000	$1503	$1157
4		$2500	$500	$2000	$1366	$965
5		$2500	$500	$2000	$1242	$804
TOTAL	**$5000**	**$12,500**	**$2500**	**$5000**	**$2582**	**$982**

Table 5.1: *Discounted cash flow concept (source: Bailey et al., in press)*

Most of the companies that use NPV as their principal "no risk" profit indicator in investment appraisal decision-making do so in conjunction with a sensitivity analysis (Newendorp, 1996). Once they have generated the NPV for a particular investment project, sensitivity analysis is used as a mechanism for investigating whether the decision to invest would change as the assumptions underlying the analysis are varied. Sensitivity analysis can involve varying one, two, or all the parameters' values simultaneously (Newendorp, 1996). Spider diagrams are commonly used to present the results of a sensitivity analysis with the sensitivity of the NPV to each factor, reflected by the slope of the sensitivity line (figure 5.3). As the curve for a variable becomes steeper, then changes in this parameter will result in large changes of the dependent variable. As the curve becomes flatter, the implication is that changes in the value of the parameter cause very little change in the dependent variable (Newendorp, 1996 pp660-662).

Sensitivity analysis is simple to use and it allows the analyst to focus on particular estimates. However, it does not evaluate risk and interrelated variables are often analysed in isolation giving misleading results (Atrill, 2000 p165).

While NPV is widely used, it has several disadvantages. One such disadvantage is highlighted here. The others are discussed in the section of this chapter that is concerned with option theory (section 5.6).

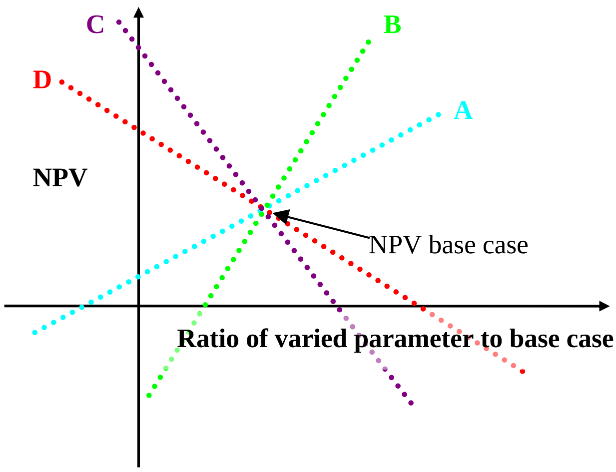

Figure 5.3: *Typical spider diagram (where NPV is the dependent variable and A, B, C and D are factors in the economic analysis)*

The NPV approach assumes the values of the input parameters are known. For example, in the case of the petroleum industry, its use presumes the analyst knows the original oil-in-place, decline rate, the oil price for each year of production, costs for each year, discount rate and tax structure, amongst others (Galli *et al.*, 1999). However, in almost all cases, there is uncertainty surrounding the input variables. Expressing such parameters as single figures creates an illusion of accuracy. It also means that the decision-maker has no indication as to how reliable the resulting decision-making criterion is. Clearly, it would be much more realistic if there was a mechanism for incorporating the uncertainty surrounding the cash flows into the analysis. As indicated in Chapter 2, decision analysis techniques now exist and these allow the dimensions of risk and uncertainty to be incorporated into investment decision-making (Newendorp, 1996 p58).

Fundamental to decision analysis are the concepts of EMV and decision tree analysis. Both these tools have received much attention in the decision analysis literature and have been applied to numerous real and hypothetical examples in the industry literature. In this section, the two concepts will be briefly outlined. Particular attention will be focussed on their impact on investment decision-making in the upstream.

The EMV concept is a method for combining profitability estimates of risk and uncertainty to yield a risk-adjusted decision criterion. The expected value decision rule holds that when choosing among several mutually exclusive decision alternatives, all other factors being equal, the decision-maker should accept the decision alternative which maximises the EMV. The EMV of a decision alternative is interpreted to be the average monetary value per decision that would be realised if the decision-maker accepted the decision alternative over a series of repeated trials. The key words in this interpretation, particularly for exploration decisions, are "per decision" and "repeated trials" as Newendorp (1996 p67) emphasises in the following excerpt:

> "If the decision-maker consistently selects the alternative having the highest positive expected monetary value his total net gain from all decisions will be higher than his gain realised from any alternative strategy for selecting decisions under uncertainty. This statement is true even though each specific decision is a different drilling prospect with different probabilities and conditional probabilities."

This statement, he argues, is the essential element for any rational justification of the use of expected value in business decisions. The remark suggests that, as long as whenever the decision-maker makes an investment, he or she adopts the strategy of maximising expected value, then he or she will do better in the long run than another decision-maker would do by using any other strategy for selecting decision alternatives under conditions of risk and uncertainty. Consequently, Newendorp (1996) believes EMV should be seen as a strategy, or philosophy, for consistent decision-making rather than an absolute measure of value. Furthermore, the EMV strategy can only be applied to advantage if used consistently from day to day:

> "The decision-maker cannot use expected value today, some other criterion tomorrow, and yet a third criterion on the third day." (Newendorp, 1996 p67)

Whilst some decision-makers have rejected EMV since they believe it is difficult, if not impossible, to assign the probabilities to the variables used in expected value computations (Newendorp, 1996 p93), the concept has been gaining increasing acceptance in investment decision-making in the upstream as the business environment has become more complex as outlined in Chapter 3 (Schuyler, 1997; Section 6.1 of Chapter 6). Although each drilling decision is essentially unique, a decision-maker may, over time, make a large number of investment decisions that involve similar monetary sums so that the returns will still be maximised by the consistent application of this criterion. This has led some to argue that the EMV concept is perhaps particularly applicable to large organisations since they usually have the resources to sustain losses on projects that represent only a small part of their operations (Goodwin and Wright, 1991 p65). This may explain why some small exploration companies have rejected using EMV (Newendorp, 1996; Section 6.2 of Chapter 6). However, it is arguable that the smaller company ought to be even more aware of risk and uncertainty because of their smaller asset position and the possibility of "gambler's ruin" from bad decision-making. Hence, the more likely the rationale for the failure of some small companies to use EMV, is that they lack the resources to conduct the necessary computations (Section 6.3 of Chapter 6).

The easiest way to illustrate how to calculate EMV is to use a decision tree. A decision tree is a tool that encourages the decision-maker to consider the entire sequential course of action, before the initial decision (Newendorp, 1996). It is accepted, almost universally, that decision trees provide decision-makers with a useful tool with which to gain an understanding of the structure of the problems that confront them. Keeney (1980) writes:

> "Often the complex problems are so involved that their structure is not well understood. A simple decision tree emphasising the problem structure which illustrates the main alternatives, uncertainties, and consequences, can usually be drawn up in a day. Not only does this often help in defining the problem, but it promotes client and colleague confidence that perhaps decision analysis can help. It has often been my experience that sketching out a simple decision

tree with a client in an hour can lead to big advances in the eventual solution to a problem." (Goodwin and Wright, 1991 p115)

Wells (1982) believes users find decision trees a clear way of understanding the issues.

The following example illustrates both EMV and the decision tree concepts. The example is taken from Galli *et al.* (1999).

Suppose that an exploration well led to the discovery of a field that could have large or small reserves. In the first case, installing a large platform is optimal, while installing a small one is more appropriate in the second case. Installing the wrong size platform is an expensive mistake. The engineer in charge of the project wants to obtain more information before making a decision, but this is costly. What is the best decision?

Figure 5.4 shows the decision tree corresponding to this situation.

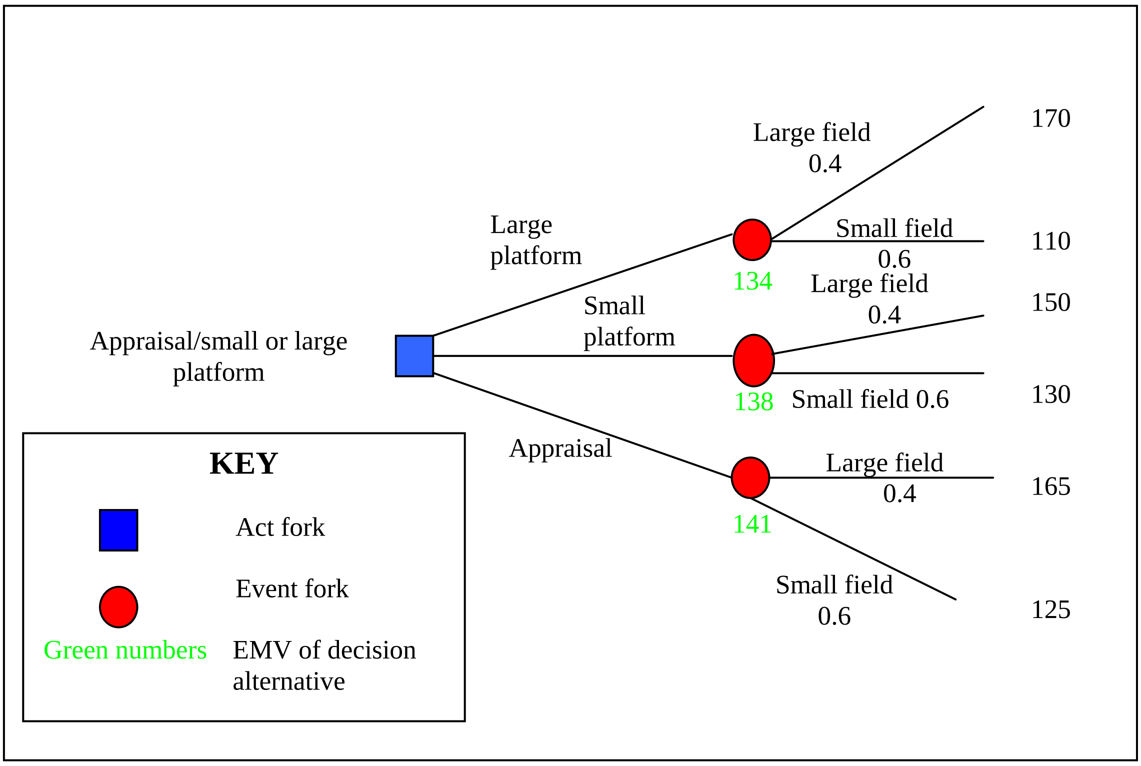

Figure 5.4*: An example of a decision tree (the figure under the decision node is the value of the branch)(source: adapted from Galli et al., 1999)*

Decisions are represented by squares sometimes referred to as act forks (for example, Hammond, 1967). The branches emanating from these correspond to possible decisions (for example, installing a large platform immediately, installing a small one, or getting additional information). Circles represent uncertain (chance) events (in this case, large reserves with a probability of 60% or small ones with a probability of 40%). These are sometimes referred to as event forks (for example, Hammond, 1967). At the end of each branch (or terminal node), the final NPV is marked. For example, installing a large platform when the reserves prove to be large generates an NPV on 170 if carried out immediately compared to an NPV of 165 if additional information is obtained.

To compare the decisions, the EMV for each decision alternative is calculated at each circular node (event fork). For the top branch, for example, it is 170*0.4+110*0.6=134. Because the EMVs at the other two nodes are 138 and 141, respectively, the best decision is to carry out additional drilling before choosing the size of the platform. (Note, calculations are carried out from the terminal branches and are "folded back" to the trunk.)

A large number of practical applications of these two concepts have been published over the years. For example, Uliva (1987) used the decision tree and EMV concepts to help the U.S. postal service to decide on whether to continue with the nine-digit zip code for business users. The analysis was designed to compare the monetary returns that might result from the use of various types of automatic sorting equipment either with or without the code. The author reported that the approach helped the decision-makers:

> "…to think creatively about the problem and to generate options.". (Goodwin and Wright, 1991 p111)

Madden *et al.* (1983) applied decision tree analysis to a problem faced by the management of a coal-fired power plant in evaluating and selecting particular emission control equipment. Winter (1985) used the techniques in management union bargaining. A number of researchers (for example, Newendorp, 1996; Hosseini, 1986; Grayson, 1960) have applied decision tree analysis and EMV to drilling decisions.

Often these problems consider only two possible outcomes, namely success and failure. However, in some problems the number of possible outcomes may be very large or even infinite. Consider, for example, the possible levels of recoverable reserves a company might achieve from drilling an exploration well. Such a variable could be represented by a continuous probability distribution. This can then be included in a decision tree by using a discrete probability distribution as an approximation. A number of methods for making this type of approximation have been proposed in the literature, the most commonly referred to is the Extended-Pearson Tukey approximation (EPT). This approximation technique, developed by Keefer and Bodily (1983), based on earlier work by Pearson and Tukey (1965), is acknowledged to generate good approximations to a wide range of continuous probability distributions. For an illustration see Goodwin and Wright (1991 p110). As Keefer and Bodily acknowledge however, the EPT approximation does have limitations. For example, it is not applicable when the continuous probability distribution has more than one peak or the continuous probability distribution is highly skewed. Despite this, the technique is widely recognised as providing a useful mechanism for generating an approximation for continuous probability distributions (Goodwin and Wright, 1991 p110).

The prescriptive decision analysis literature does not provide a normative technique for eliciting the structure of a decision tree (some behavioural analysts have proposed influence diagrams as a useful tool for eliciting the decision tree structure from the decision-maker; see Goodwin and Wright (1991 p118) for a full explanation). Structuring decision trees is therefore a major problem in the application of decision analysis to real problems and, clearly if the structure is wrong, the subsequent computations may well be invalid. Following such observations Von Winterfeldt (1980) notes that it is good decision analysis practice to spend much effort on structuring and to keep an open mind about possible revisions. However, problem representation, according to Goodwin and Wright (1991), is an art rather than a science. Fischoff (1980) argues similarly:

> "Regarding the validation of particular assessment techniques we know … next to nothing about eliciting the structure of problems from decision-makers." (Goodwin and Wright, 1991 p115)

Many decision-makers report that they feel the process of problem representation is perhaps more important than the subsequent computations (Goodwin and Wright, 1991 p117). Humphreys (1980) has labelled the latter the "direct value" of decision tree analysis and the former the "indirect value". Some studies have illustrated that the decision-makers' estimates, judgements and choices are affected by the way knowledge is elicited. This literature was reviewed in Chapter 2. Despite this, the value of decision tree analysis is undisputed, not least because decision tree analysis is not exclusively linked to the EMV with its inherent and questionable assumptions about the decision-maker's attitude to money. These are now reviewed.

The expected value decision rule makes several assumptions. Firstly, it assumes that the decision-maker is impartial to money. This assumption, not surprisingly, has been widely criticised. Such criticisms are well illustrated by the St Petersburg Paradox first described by Daniel Bernoulli in 1738 and outlined here.

A decision-maker is offered the following gamble. A fair coin is to be tossed until a head appears for the first time. If the head appears on the first throw then the decision-maker will be paid £2, if it appears on the second throw, £4, if it appears on the third throw £8, and so on. The question is then, how much should the decision-maker be prepared to pay to have the chance of participating in this gamble?

The expected returns on this gamble are:

$$£2*(0.5)+£4*(0.25)*£8(0.125)+...etc.$$

which is equivalent to 1+1+1+ … to infinity. So the expected returns will be infinitely large. On this basis, according to the EMV criterion, the decision-maker should be prepared to pay a limitless sum of money to take part in the gamble. However, given that there is a 50% chance that their return will only be £2, and an 87.5% chance that it will be £8 or less, it is unlikely that many decision-makers would be prepared to pay the amount prescribed by the EMV criterion.

Secondly, the EMV criterion assumes that the decision-maker has a linear value function for money. An increase in returns from £0 to £1 million may be regarded by the decision-maker as much more preferable than an increase from £9 million to £10 million, yet the EMV criterion assumes that both increases are equally desirable.

Thirdly, the EMV criterion assumes that the decision-maker is only interested in monetary gain (Goodwin and Wright, 1991 p64). However, when a company is deciding how best to decommission an offshore production facility, for example, they will want to consider other factors such as corporate image and environmental concerns. All these attributes, like the monetary returns, would have some degree of risk and uncertainty associated with them.

Users of expected value theory have long recognised these shortcomings. As early as 1720 academics were beginning to modify the concept to include the biases and preferences that decision-makers associate with money into a quantitative decision parameter. In essence these attempts were trying to capture the decision-maker's intangible feelings in a quantitative decision parameter which the decision-maker could then use to guide judgements. This approach is typically referred to as preference theory and the following section discusses this further. It draws on the prescriptive decision analysis literature to outline first the mathematics underlying preference theory and then proceeds to evaluate critically its contribution to investment decision-making particularly in the upstream.

5.3 PREFERENCE THEORY

Most formal analyses of business decisions involving risk and uncertainty, for example the EMV concept described above, assume that every individual or company has, or ought to have, a consistent attitude toward risk and uncertainty. The underlying assumption is that a decision-maker will want to choose the selected course of action by "playing the averages" on all options, regardless of the potential negative consequences that might result, to choose the course of action that has the highest expected value of profit. However as Hammond (1967) and Swalm (1966) observed, few executives adopt such an attitude toward risk and uncertainty when making important investment decisions. Rather, decision-makers have specific attitudes and feelings about money, which depend on the amounts of money, their personal risk preferences, and any immediate and/or longer-term objectives they may have. As Bailey *et al.* (in press) argue:

> "In the case of industries like oil where risk plays such an important part in the thinking of executives, individual (or group) attitudes to risk and risk taking can be important."

Such attitudes and feelings about money may change from day to day and can even be influenced by such factors as business surroundings and the overall business climate at a given time (Newendorp, 1996 p138).

Similar observations led Hammond (1967) and others (for example, Goodwin and Wright, 1991; Swalm, 1966) to argue that since the EMV concept does not include, in any quantitative form, the consideration of the particular attitudes and feelings the decision-maker associates with money, it may not provide the most representative decision criterion. These writers perceive preference theory as offering a useful tool to incorporate these attitudes and feelings regarding money into a quantitative parameter.

The concepts of preference theory are based on some very fundamental, solid ideas about decision-making that are accepted by virtually everyone who has studied the theory (Newendorp, 1996). However, the real world application of preference theory is still very controversial and, some academics, and many business executives, question its value in the investment decision-making context. In the many articles and books on investment decision-making, preference theory is some times referred to as utility theory or utility curves. While the latter is used more frequently in the decision analysis literature, it is also used to describe another subject in economics. Hence, the term "preference theory" will be used here (Newendorp, 1996 p137). This section will discuss first the principles of preference theory before reviewing its applicability to investment decision-making in the upstream.

In 1738 the mathematician Daniel Bernoulli published an essay in which he noted a widespread preference for risk aversion. In an often referred to article in *Scientific American* in the 1980s Daniel Kahneman and Amos Tversky gave a simple example of risk aversion (Kahneman and Tversky, 1982). Imagine you are given a choice between two options. The first is a sure gain of $80, the second a more risky project in which there is an 85% chance of winning $100 and a 15% chance of winning nothing. With the certain outcome you are assured of $80. With the riskier option your EMV would be $85 ($100*0.85 plus $0*0.15). Most people, say Kahneman and Tversky, prefer the certain gain to the gamble, despite the fact that the gamble has a higher EMV than the certain outcome (Bailey *et al.*, in press).

In 1944, von Neumannn and Morgenstern expanded preference theory and proposed that the fundamental logic of rational decision-making could be described by eight axioms that are paraphrased in the following statement:

> "Decision-makers are generally risk averse and dislike incurring a loss of $X to a greater degree than they enjoy making a profit of $X. As a result, they will tend to accept a greater risk to avoid a loss than to make a gain of the same amount. They also derive greater pleasure from an increase in profit from $X to $X+1 than they would from $10X to $10X+1" (Bailey *et al.*, in press)

They went on to show that if a decision-maker had a value system which was described by these axioms, then there existed a function, or curve, which completely described his attitude and feelings about money (Newendorp, 1996 p152). This curve is known as a preference, or utility curve. An example of a preference curve is shown in figure 5.5.

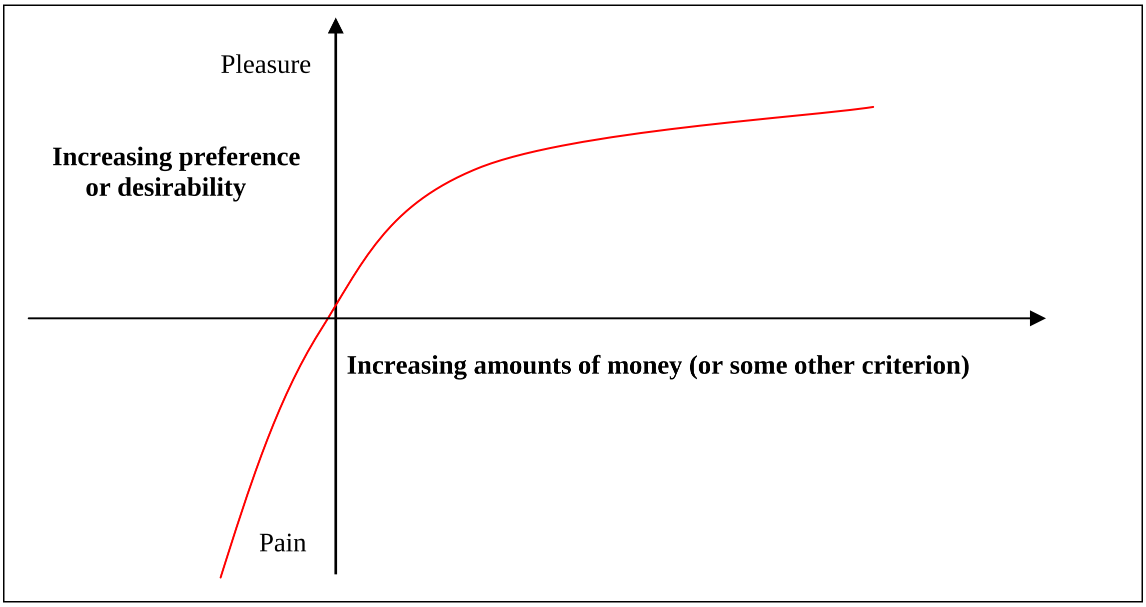

Figure 5.5: *A preference curve (source: adapted from Newendorp, 1996 p147)*

According to risk consultant Peter Rose (1987), a preference curve shows two things:

- The pleasure (utility) associated with winning is generally less than the displeasure of losing the same amount (that is, it hurts more to lose than it feels good to win.) People will take a greater chance to avoid a loss than to make a gain of the same amount.
- People feel more pleasure about gaining $10 going from, say, $10 to $20, than they do about gaining $10 going from $1500 to $1510.

Theoretically at least it is possible to draw just such a curve for any individual. Different shaped curves would denote different types of decision-maker. The shape of the curve in the lower left-hand quadrant describes how the individual feels about loss and the one in the upper right quadrant is the individual's attitude to risk and the levels of profit associated with risk. Many writers have categorised decision-makers according to the shape of their preference curves. In general, these authors perceive there to be three types of decision-maker: risk averters, average players (who would always choose the decision alternative with the maximum EMV) and risk-seekers. Each, they believe, has a distinctive preference curve. These curves are shown in figure 5.6. As indicated above, extensive studies (for example, Newendorp, 1996; Hammond, 1967) have provided strong evidence that the majority of decision-makers are risk averse to some degree, so concave downwards preference curves are the most commonly observed in practice.

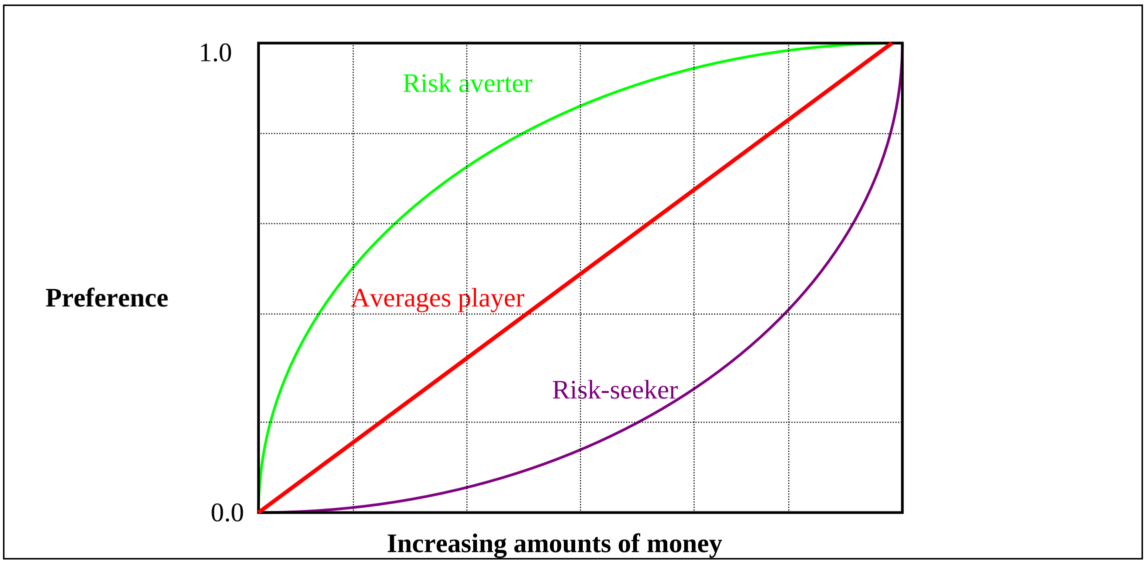

Figure 5.6: *Typical preference curves (source: Hammond, 1967)*

Once the decision-maker's preference curve has been drawn, von Neumann and Morgenstern showed that it could be used to solve decision problems using an extension of decision tree analysis. The basic principle is if the decision-maker wishes to make the decision consistent with his attitude toward risk, then the decision-maker must choose that course of action that has the highest preference.

Preference theory is well illustrated by the following example taken from Hammond (1967). Imagine an oil company executive is facing the decision of whether to drill a well. The decision-maker has three choices: firstly, drill immediately; secondly, pay to acquire and interpret seismic data and then, depending on the result of the test, decide whether to drill or not; or lastly, to let the option expire.

The seismic analysis can be performed for a fixed fee of $30,000 and the well can be drilled for a fixed fee of $100,000. A large organisation has promised the decision-maker that if this well discovers oil, it will purchase the company's rights to the oil for $400,000. The geologists have estimated that there is 0.55 probability that if a well is drilled it will discover oil. Data on the reliability of the seismic analysis indicate that if the analysis is favourable, the probability of finding oil will increase to 0.85, but if the analysis is unfavourable, it will fall to 0.1. The geologists have computed that there is a 0.6 probability that the result will be favourable if seismic interpretation is carried out.

Figure 5.7 shows the decision tree for this example. At each terminal fork in the decision tree, the expected value of the decision alternative is noted. (Recall that this is the weighted-average of the numbers at the end positions emanating from the fork). For example, the top-most terminal fork expected value is $340,000 (0.85*$400,000+15*$0). Rolling back the decision tree the decision-maker would end up with the decision tree in figure 5.8 and the decision, according to EMV, would be to drill immediately. Using preference theory, the result is somewhat different.

To implement preference theory, assume that the decision-maker's preference curve has been ascertained. This is shown in figure 5.9. Then:

1. Convert all of the end positions of the decision tree into preferences (ascertained from the decision-maker's preference curve in figure 5.9). These numbers are red in figure 5.10.
2. Find the decision-maker's preference for an event fork by taking the mathematical expectation of the preferences values at the end position of the fork. In other words, instead of multiplying the dollar values by probabilities, as in a decision tree analysis using expected values, multiply the preferences by the probabilities. So, at each event fork take a weighted-average of the preferences, where the weights are the probabilities. For example, at the uppermost event fork representing "oil-no oil", the preference is 0.83 (0.85*0.93+15*0). The preference is written under the fork in green in figure 5.10.
3. For each act fork, the decision-maker or analyst then selects the act with the highest preference. For example, the upper most decision fork in figure 5.10, the choice is between "drill" with a preference of 0.83 and "don't drill" with a preference of 0.60, so the choice is to drill. The preference of the act chosen is written in pink at the base of each act fork in figure 5.10. The act not chosen is scored off and this is shown by the double bar in figure 5.10.
4. Continue backwards through the tree, repeating steps 2 and 3 until the base of the tree is reached. For instance, the preference of the decision to take the test is 0.74 (0.60*0.83+0.4*0.6), while the preference not to take the test is 0.68.

The analysis using preference theory therefore indicates the decision-maker's best strategy is to take the test and, if it gives a favourable result, drill; if it produces an unfavourable result, do not drill.

With EMV, the decision-maker would be advised to drill immediately. The preference theory approach takes into account the executive's natural conservatism and tells him to take the seismic test first and drill only if it is favourable. The seismic test then is a form of "insurance policy", which is good for the conservative decision-maker in this case, but not worth its price to the averages-player (who would always choose the decision alternative that would maximise their EMV).

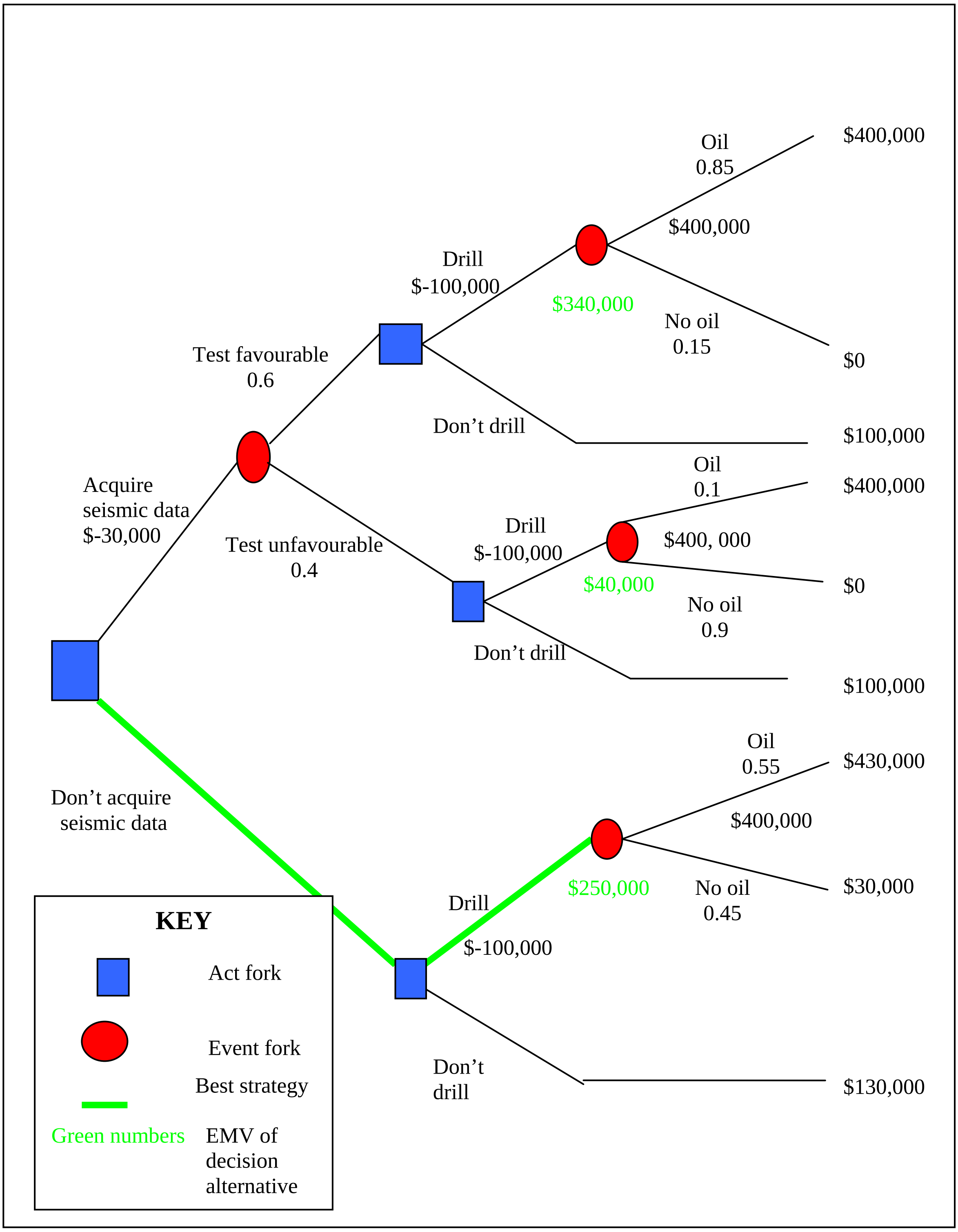

Figure 5.7: *Analysis using EMV*

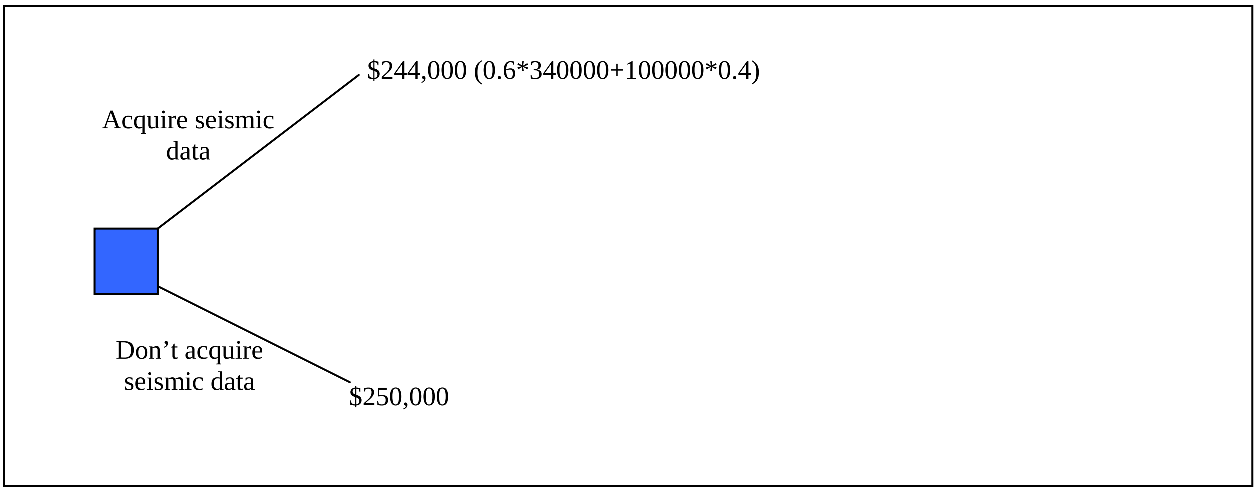

Figure 5.8: *Test results eliminated*

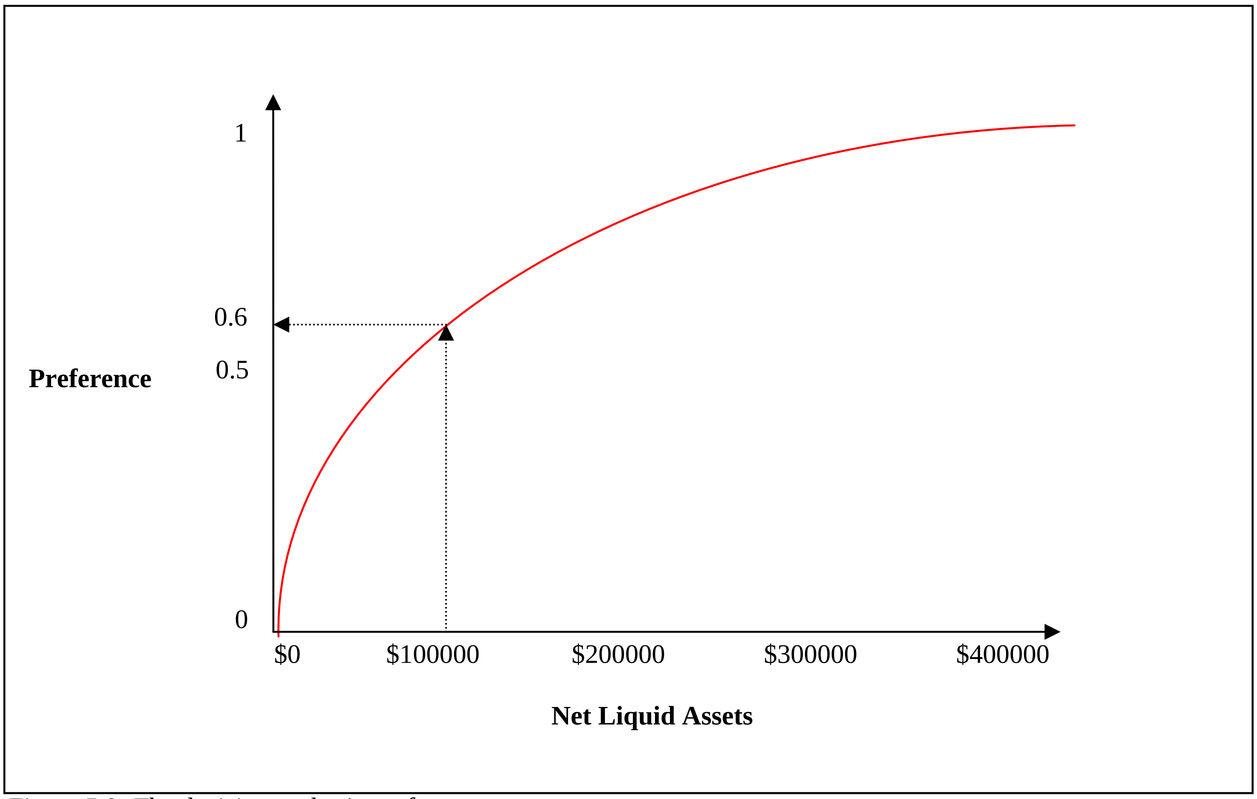

Figure 5.9: *The decision-maker's preference curve*

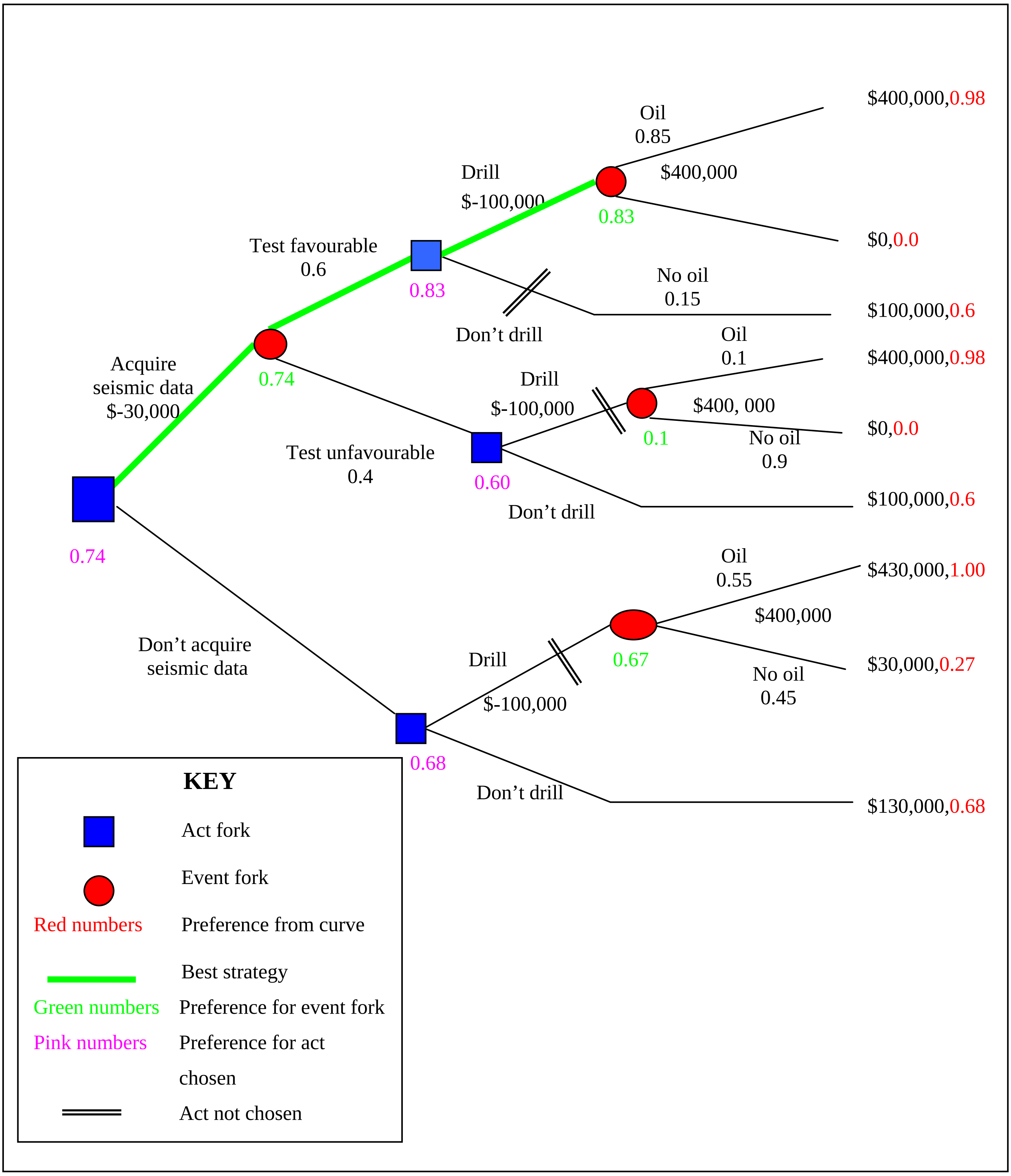

Figure 5.10: *Analysis using preferences*

Preference theory can be extended to decisions involving multiple attributes. Multi-attribute preference theory (more commonly referred to as multi-attribute utility theory) shows how, provided certain conditions apply, the main decision problem can be broken into sub-problems and a single attribute preference function (or curve) can be derived for each attribute and then these can be combined to obtain a multi-attribute function (Goodwin and Wright, 1991 p86). A number of methods have been proposed for performing this analysis, but the approach described by Keeney and Raiffa (1976) is the most popular.

A number of researchers have questioned the application of preference theory to real problems. Most of their concerns relate to the generation of a decision-maker's preference curve. Since, crucially, whilst von Neumannn and Morgenstern proved that a preference curve exists for each decision-maker who makes decisions consistent with the eight axioms they did not specify how to obtain this curve.

Since 1944, many researchers have studied this problem, but so far, their attempts have been only marginally successful:

> "The unfortunate truth is that we (as a business community) do not as yet have a satisfactory way to construct an individual's preference curve." (Newendorp, 1996 p162)

Generally researchers have attempted to describe a decision-maker's preference curve by obtaining the decision-maker's responses to a carefully designed set of hypothetical investment questions (Newendorp, 1996 p160; Hammond, 1967; Swalm, 1966). In these tests, the decision-maker is offered a choice between a gamble having a very desirable outcome and an undesirable outcome, and a no-risk alternative of intermediate desirability. Such tests, though, have only been marginally successful for two reasons. Firstly, the test procedures have to use hypothetical gambles and decisions rather than actual gambles. The rationale for this is that if the procedure used real decision-making situations, decision-makers generally would either accept or reject a decision without stopping to explicitly state what the probabilities would have to be for them to have been indifferent between the gamble and the no-risk alternative (Newendorp, 1996). Tocher (1977) argues that since these gambles are only imaginary, the decision-maker's judgements about the relative attractiveness of the gambles may not reflect what the decision-maker would really do. This is known as the preference reversal phenomenon and has been researched extensively (Slovic, 1995; Mowen and Gentry, 1980, Grether and Plott, 1979; Lichenstein and Slovic, 1971; Lindman, 1971) and many theories have been proposed to explain it (for example, Ordonez and Benson, 1997; Goldstein and Einhorn, 1987). Secondly, most decision-makers are not used to making decisions on the basis of a precise discernment of probabilities used to justify a gamble. Rather, the probabilities are usually specified for a given investment, and the parameter that the decision-maker focuses on is whether the successful gain is sufficient to justify the gamble (Newendorp, 1996).

A further limitation of the application of preference theory to real problems is the inability to construct corporate preference curves. Hammond (1967) argues that an organisation's propensity for risk is higher than that of an individual, and that therefore companies' preference curves are usually more risk seeking than those of individuals'. However, Hammond believes, that the individual manager could unwittingly apply his own much more conservative preference curve when making decisions on behalf of the company. Therefore, Hammond (1967) concludes that organisations should have a corporate preference curve for individual mangers to use when making company decisions. However, whilst research into constructing corporate preference curves has been attempted, its theoretical results have, to date, been too complex for practical application (Hammond, 1967). Recently, though one company based in Aberdeen, Det Norske Veritas (DNV), has started offering preference theory-based analysis to upstream companies.

Despite these limitations, proponents of preference theory claim that it provides the decision-maker with the most representative decision parameter ever developed. They argue that its use will produce a more consistent decision policy than that which results from using EMV and that preference theory also accounts for the non-arbitrary factors in an arbitrary way (Swalm, 1966). Others are more cautionary. Bailey *et al.* (in press) argue that proponents of preference theory should not claim that it is a descriptive tool but rather offer it as a prescriptive technique that can be used to help individuals or companies take decisions. They write:

> "…preference theory does have a more limited but still important role. It can graphically demonstrate to decision-makers what their style of decision-making implies. It might show a highly conservative, very risk averse decision-maker that there was room for much more flexibility without incurring enormous penalties, or it might show an intuitive decision-maker that his decision-making was altogether too risky."

However, opponents argue that it is impossible to quantify emotions regarding money, and therefore the whole idea of preference theory is an exercise in frustration (Tocher, 1977).

Underpinning preference theory, the EMV concept, decision tree analysis and indeed the whole of decision analysis, as highlighted in the sections above and in Chapter 2, is the ability of the analyst to generate subjective probabilistic estimates of the variables under investigation, as a mechanism for quantifying the risk and uncertainty. Traditional probability theory relies on the relative frequency concept in which probability is perceived to be the long-run relative frequency with which a system is observed in a particular state in a series of identical experiments. However, given its emphasis on repeated experiments, the frequentist concept is unsuitable for modelling under the conditions of risk and uncertainty present in the majority of investment decision problems. As such, the subjective probabilities used in decision analysis are founded upon a quite a different conceptual base. As indicated in Chapter 2, to a subjectivist, probability represents an observer's degree of belief that a system will adopt a particular state. There is no presumption of an underlying series of experiments. The observer need only be going to observe the system on one occasion. Moreover, subjective probabilities encode something about the observer of the system, not the system itself. The justification for using subjective probabilities in decision analysis does not just rest on the case that frequentist probabilities are inappropriate but also in the principles of consistency that the Bayesians suggest should be embodied in rational decision-making (for a full discussion see French, 1989 p31). Accepting the rationale that subjective probability estimates should be used for investment decision-making under conditions of uncertainty however does cause problems since, partly because of their subjective nature, there is no formula in the decision analysis literature for generating these probabilities. Therefore, analysts typically use their judgement, extrapolate from historical data or, for example when estimating recoverable reserves for a particular field, use the results achieved in other similar plays to guide their predictions. Traditionally analysts used single-value probability estimates to express the degree of risk and uncertainty relating to the uncertain parameters. More popular now is to generate subjective probability estimates using risk analysis which adds the dimension of simulation to decision analysis.

The following section draws on the prescriptive decision analysis literature first to provide a brief overview of the main concepts of risk analysis and then to indicate the impact of risk analysis on investment decision-making in the upstream. It is important to recognise that risk analysis is a special case of decision analysis that uses techniques of simulation. Often in the literature, the terms are used interchangeably leading to confusion when comparing accounts.

5.4 RISK ANALYSIS

Simulation as a means of risk analysis in decision-making was first applied to petroleum exploration investments in 1960 (Grayson, 1960). The technique can be applied to any type of calculation involving random variables. It can be used to answer technical questions such as ("What is the volume of recoverable reserves of hydrocarbons in this acreage?") and economic ones such as ("What is the probability that the NPV of this prospect will exceed the target of $x million?") (Bailey *et al.*, in press). The main concepts of risk analysis using simulation will now be presented before its applicability to the upstream is examined.

Risk analysis based on Monte Carlo simulation is a technique whereby the risk and uncertainty encompassing the main projected variables in a decision problem are described using probability distributions. Then by randomly sampling within the distributions, many, perhaps thousands, of times, it is possible to build up successive scenarios, which allow the analyst to assess the effect of risk and uncertainty on the projected results. The output of a risk analysis is not a single value, but a probability distribution of all expected returns. The prospective investor is then provided with a complete risk-return profile of the project showing all the possible outcomes that could result from the decision to stake money on this investment.

It is perhaps easiest to see how Monte Carlo simulation works by using an example of a hypothetical field. The main data is given in table 5.2. The decision facing the decision-makers is whether to develop the field. Performing a simple deterministic calculation, with a discount rate of 10%, gives an NPV of $125 million and the decision to go ahead on development should be straightforward.

But a probabilistic assessment of the same field gives the decision-maker a broader picture to consider. Assume the probabilistic assessment uses the figures in table 5.2 as the "most likely" inputs (those falling at the mid-point of the range) but also suggests the ranges of possible values for inputs in table 5.3.

- Reserves of 150 million barrels of oil (MB0)
- Production has a plateau (assumed to be reached immediately) of 12% per annum of total reserves (i.e. 12% of 150 MBO=18MBO/yr) for 5 years, then declining at 20% per year thereafter, until all 150MBO have been produced.
- 5 production wells are needed, at a cost of $15m per well over two years
- Platform/pipeline costs are $765m over three years
- Abandonment expenditure is $375 million after last production
- Operating expenditure is $75million per year
- Corporation tax is 30%
- Inflation is 3.5% throughout the period
- Discount rate is 10%
- Oil price assumed to be $18 per barrel rising at the rate of inflation

Table 5.2: *Hypothetical field data*

- Drilling, capital and operating expenditures are assumed to be "normal" distributions with a standard deviation (SD) of 10% of the mean (SD is a measure of the range of uncertainty)
- Abandonment expenditure is "normal", with SD=20% of the mean
- Production volumes are "normal", but with a positive correlation to operating expenditure
- Oil price is "lognormal", with SD=10% of the mean, in the first year of production (2004), rising by 2% per year, reaching 34% by the last year of production. This gives a roughly constant low oil price at about $10/barrel, with the high price rising from $23 to $37.5/barrel through field life.

Table 5.3: *Hypothetical field data for Monte Carlo simulation*

Ten thousand Monte Carlo trials give the results shown in table 5.4. The mean, or average, or expected value is $124 million (that is, a statistically significant number of identical opportunities would, on average, be worth $124 million, in NPV terms.).

Percentile	Value
0	-112
10	27
25	71
50	122
75	176
90	223
100	422

Table 5.4*: Results from the Monte Carlo simulation*

But in fact there is a range of possible outcomes and a chance of very different results. For example, the so-called p10 value, or forecast with 10% possibility of occurrence, (see table 5.4) is $27 million, so 10% of the cases run in the simulation gave values less than $27 million. The lowest possible outcome is $-112M and 5% of the cases, or trials, gave negative NPVs. On the other hand, the p90 was $223 million, so 10% of the trials gave values greater than $223 million (Bailey *et al.*, in press).

For this particular field, there is a small, but not zero (that is, approximately 4%) chance of losing money. The decision would probably still be to go ahead, but the Monte Carlo analysis, by revealing the wider picture, gives the decision-makers greater comfort that their decision has taken everything into account.

Using risk analysis in investment appraisal has a number of advantages. Firstly and most importantly, it allows the analyst to describe risk and uncertainty as a range and distribution of possible values for each unknown factor, rather than a single, discrete average or most likely value. Consequently when Monte Carlo simulation is used to generate a probability distribution of NPV, Newendorp (1996 p375) believes that:

> “The resulting profit distribution will reflect all the possible values of the variable.”

This is a slightly dubious claim since the resulting profit distribution will not contain every possible value of NPV. It will only include those that the decision-maker or analyst feels are likely to occur. There is always the possibility of “acts of God” or “train wrecks” (see section 5.7 and for a full discussion refer to Spencer and Morgan, 1998). However, it is certainly true, that in generating probabilistic output, the decision-maker is *more likely* to capture the actual value in the predicted range.

Secondly, risk analysis allows the analyst to identify those factors that have the most significant effect on the resulting values of profit. The analyst can then use sensitivity analysis to understand the impact of these factors further. There are several ways this sensitivity analysis can be carried out and the reader is referred to Singh and Kinagi (1987) for a full discussion.

Implementing risk analysis using Monte Carlo simulations has limitations and presents a number of challenges. Firstly, Monte Carlo simulations do not allow for any managerial flexibility. This can be overcome by running simulations for several scenarios (Galli *et al.*, 1999). Gutleber *et al.* (1995) present a case study where simulations were carried out to compare three deals involving an oil company and local government. Murtha (1997) provides many references to practical applications of this procedure. Secondly, whilst geologists intuitively expect to find a correlation between, for example, hydrocarbon saturation and porosity, this is not acknowledged explicitly in the literature nor are analysts given any guidance concerning how to model such relationships.

Goodwin and Wright (1991 pp153-157) describe types of dependence and approaches to modelling dependence are given in Newendorp (1996 pp406-431), Goodwin and Wright (1991 pp153-157), Eilon and Fawkes (1973) and Hull (1977). There is significant evidence in the prescriptive decision analysis literature that decision-makers have difficulty assigning the strength of association between variables. Nisbett and Ross (1980 p26) have given the following concise summary of this literature:

> "The evidence shows that people are poor at detecting many sources of covariation … Perception of covariation in the social domain is largely a function of pre-existing theories and only very secondarily a function of true covariation. In the absence of theories, people's covariation detection capacities are extremely limited. Though the conditioning literature shows that both animals and humans are extremely accurate covariation detectors under some circumstances, these circumstances are very limited and constrained. The existing literature provides no reason to believe that … humans would be able to detect relatively weak covariations among stimuli that are relatively indistinctive, subtle and irrelevant motivationally and, most importantly, among stimuli when the presentation interval is very large."

Chapman and Chapman's 1969 study provided evidence of a phenomenon that they refer to as illusory correlation. In their experiment, naïve judges were given information on several hypothetical mental patients. This information consisted of a diagnosis and drawing made by the patient of a person. Later the judges were asked to estimate how frequently certain characteristics referred to in the diagnosis, such as suspiciousness, had been accompanied by features of the drawing, such as peculiar eyes. It was found that judges significantly overestimated the frequency with which, for example, suspiciousness and peculiar eyes occurred together. Moreover, this illusory correlation survived even when contradictory evidence was presented to the judges. Tversky and Kahneman (1974) have suggested that such biases are a consequence of the availability heuristic. It is easy to imagine a suspicious person drawing an individual with peculiar eyes, and because of this, the real frequency with which the factors co-occurred was grossly overestimated. So, in the case of the relationship between porosity and water saturation, this research suggests that because geologists expect there to be a correlation, if there is any evidence of a correlation in any particular case, the geologist is likely to overestimate the strength of this relationship. This research indicates the powerful and persistent influence that preconceived notions can have on judgements about relationships (Goodwin and Wright, 1991 p153).

The third limitation of Monte Carlo simulations is perhaps most significant. In the industry literature, no published study has indicated which probability distribution most accurately describes the reservoir parameters of reservoir rocks of similar lithology and water depth. Similarly, there has been no research that has identified the appropriate shape of probability distribution to be adopted for economic factors such as oil price. Section 6.2 of Chapter 6 will discuss how companies cope with this lack of prescription in the literature. It is possible here, to perform a crude test to investigate whether the shape of the probability distribution used for each input variable, affects the estimate generated by a Monte Carlo simulation. Such a test is carried out below.

For each reservoir parameter, base values are entered and probability distributions are assigned to each of these variables from the seventeen available in Crystal Ball™ . Then a Monte Carlo simulation is run and the estimate of recoverable reserves generated expressed in percentiles, is noted. This process is repeated twelve times altering only the probability distribution assigned to each variable each time. The base value data and the probability distributions used for each trial are shown in table 5.5. The output produced is summarised in table 5.6 and provides evidence that altering the probability distribution assigned to each reservoir parameter, significantly affects the forecast of the recoverable reserves. (Note, that although some of the distributions used here are more unusual (for example, the Weibull), the lack of prescription in the literature over the shape of probability distribution that analysts should adopt for reservoir parameters (and economic variables) means that, if these results are accurate, analysts could, unwittingly or otherwise, use these types of distribution to distort the results.)

Further studies are needed to confirm these results. This would then prompt researchers to explore the shape of the probability distributions to be used for the reservoir parameters of reservoir rocks of similar lithology and burial history and the nature of the probability distributions to be used to model the economic variables. Future research should also investigate the nature of correlation between the reservoir (and economic) variables. The author of this thesis tried repeatedly throughout the course of the study to access “real” reserves and economic data to conduct such research but was unable to collect enough data to make any results achieved meaningful. Whilst much of the economic data is regarded by companies as commercially sensitive and this makes such research unlikely in the near future, a book due for publication next year should contain the relevant reserves data (Gluyas *et al.*, 2001). It is hoped that the interest provoked by this thesis will motivate researchers and practitioners to conduct the necessary studies.

Despite these limitations, risk analysis using simulation is perceived by the majority of decision analysts to enable a more informed choice to be made between investment options (for example, Newendorp, 1996; Goodwin and Wright, 1991 p151). Certainly, by restricting analysts to single-value estimates the conventional NPV approach yields no information on the level of uncertainty that is associated with different options. Hespos and Straussman (1965) have shown how the simulation approach can be extended to handle investment problems involving sequences of decisions using a method known as stochastic decision tree analysis.

Reservoir parameters	Base value	Type of distribution assigned to reach reservoir parameter for each run					
		Rec Res 1	**Rec Res 2**	**Rec Res 3**	**Rec Res 4**	**Rec Res 5**	**Rec Res 6**
GRV	0.2	Normal	Normal	Normal	Normal	Normal	Normal
N/G	0.8	Triangular	Triangular	Triangular	Uniform	Lognormal	Lognormal
Porosity	0.32	Triangular	Lognormal	Triangular	Uniform	Lognormal	Lognormal
Shc	0.8	Triangular	Triangular	Triangular	Triangular	Lognormal	Lognormal
Re	0.45	Triangular	Triangular	Lognormal	Triangular	Lognormal	Lognormal
		Rec Res 7	**Rec Res 8**	**Rec Res 9**	**Rec Res 10**	**Rec Res 11**	**Rec Res 12**
GRV	0.2	Normal	Lognormal	Lognormal	Weibull	Normal	Beta
N/G	0.8	Triangular	Weibull	Uniform	Weibull	Beta	Weibull
Porosity	0.32	Weibull	Beta	Uniform	Weibull	Pareto	Triangular
Shc	0.8	Triangular	Uniform	Uniform	Weibull	Uniform	Lognormal
Re	0.45	Triangular	Triangular	Uniform	Weibull	Weibull	Weibull

Table 5.5: *Base value data and probability distributions assigned to each of the reservoir parameters (GRV=gross rock volume, N/G=net to gross, Shc=hydrocarbon saturation, Re=recovery efficiency, Rec Res=recoverable reserves)*

Percentile	Rec Reserves 1	Rec Reserves 2	Rec Reserves 3	Rec Reserves 4	Rec Reserves 5	Rec Reserves 6
0%	107	93	97	95	94	79
10%	**138**	**132**	**132**	**132**	**137**	**120**
20%	146	143	142	142	145	133
30%	152	150	150	151	153	141
40%	157	157	156	158	158	150
50%	**163**	**162**	**163**	**164**	**164**	**160**
60%	167	169	169	172	170	170
70%	173	176	177	180	176	181
80%	180	185	188	188	184	196
90%	**189**	**198**	**203**	**203**	**196**	**217**
100%	228	255	263	281	260	339
Percentile	**Rec Reserves 7**	**Rec Reserves 8**	**Rec Reserves 9**	**Rec Reserves 10**	**Rec Reserves 11**	**Rec Reserves 12**
0%	150	5	105	2359	17	9
10%	**314**	**44**	**132**	**11599**	**246**	**113**
20%	399	66	141	16651	382	175
30%	467	84	149	21955	527	225
40%	523	103	157	27209	675	280
50%	**598**	**125**	**163**	**32842**	**817**	**337**
60%	657	148	170	40866	984	404
70%	726	176	178	48650	1206	498
80%	817	205	187	62966	1544	626
90%	**971**	**250**	**201**	**88855**	**2273**	**819**
100%	1938	546	287	237909	17143	2903

Table 5.6: *Table of the output generated using the base value data and input distributions specified in Table 5.5 (Rec reserves = recoverable reserves)*

The next section draws on the decision theory and industry literatures to present portfolio theory, a technique that has been used within the finance industry for a number of years but which has only recently been applied to petroleum investment decisions. Therefore, the concepts of portfolio theory will be outlined first before its applicability to upstream investment decision-making is analysed.

5.5 PORTFOLIO THEORY

In practice, a business will normally invest in a range, or portfolio, of investment projects rather than in a single project. The problem with investing all available funds in a single project is, of course, that an unfavourable outcome could have disastrous consequences for the business. By investing in a spread of projects, an adverse outcome from a single project is unlikely to have major repercussions. Investing in a range of different projects is referred to as diversification, and by holding a diversified portfolio of investment projects, the total risk associated with the business can be reduced (Atrill, 2000 p185). This introduces two concepts. First, asset value is additive. The incremental expected value that an asset adds to the portfolio's expected value is the asset's expected value. Second, asset risk is not additive. The amount of risk an asset contributes to the portfolio is not solely dependent on its risk as a stand-alone investment (measured in finance theory by the standard deviation of the expected value probability distribution) (Whiteside, 1997). Atrill (2000 p118) explains this by dividing the total risk relating to a particular project into two elements: diversifiable risk and non-diversifiable risk (figure 5.11):

- Diversifiable risk is that part of the total risk which is specific to the project, such as reserves, changes in key personnel, legal regulations, the degree of competition and so on. By spreading the available funds between investment projects, it is possible to offset adverse outcomes in occurring in one project against beneficial outcomes in another (Atrill, 2000 p188).
- Non-diversifiable risk is that part of the total risk that is common to all projects and which, therefore, cannot be diversified away. This element of risk arises from general market conditions and will be affected by such factors as rate of inflation, the general level of interest rates, exchange rate movements and so on (Atrill,

2000 p188). Arguably, the most critical non-diversifiable risk for exploration companies is the oil price.

It then follows that the incremental risk an asset adds to the portfolio will always be less than its stand-alone risk.

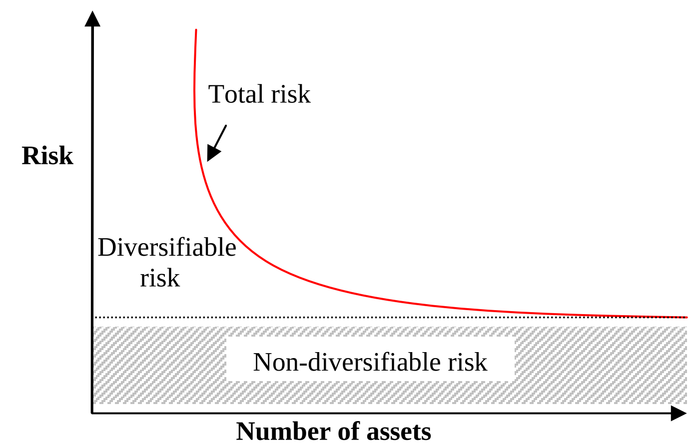

Figure 5.11: *Reducing risk through diversification (source: Higson, 1995 p120)*

There are two types of diversification: simple and Markowitz. Simple diversification (commonly referred to as market or systematic diversification in the stock market) occurs by holding many assets. It holds that if a company invests in many independent assets of similar size, the risk will tend asymptotically towards zero. For example, as companies drill more exploration wells, the risk of not finding oil reduces towards zero. Consequently, companies that endorse a strategy of taking a small equity in many wells are adopting a lower risk strategy than those that take a large equity in a small number of wells. However, the economic returns on independent assets are to, a greater or lesser extent, dependent on the general economic conditions and are non-diversifiable. Under these conditions, simple diversification will not reduce the risk to zero but to the non-diversifiable level. Markowitz diversification relies on combining assets that are less than perfectly correlated to each other in order to reduce portfolio risk. The method is named after a 1990 Nobel Prize recipient, a financial theorist, who first introduced the technique in his 1952 paper entitled *Portfolio Selection*. Markowitz diversification is less intuitive than simple diversification and uses analytical portfolio techniques to maximise portfolio returns for a particular level of risk. This approach also incorporates the fact that assets with low correlation to each other when combined have a much lower risk relative to their return (Whiteside, 1997).

Using these principles, portfolio optimisation is a methodology from finance theory for determining the investment program and asset weightings that give the maximum expected value for a given level of risk or the minimum level of risk for a given expected value. This is achieved by varying the level of investment in the available set of assets. The efficient frontier is a line that plots the portfolio, or asset mix, which gives the maximum return for a given level of risk for the available set of assets. Portfolios that do not lie in the efficient frontier are inefficient in that for the level of risk they exhibit there is a feasible combination of assets that result in a higher expected value and another which gives the same return at lower risk. (Note, in reality, due to real world constraints such as the indivisibility of assets, trading costs and the dynamic nature of the world, all practical portfolios are inefficient).

To calculate the efficient frontier it is imperative to determine the mean return of each asset (usually the EMV in industrial applications), the variance of this value (defined as risk in finance theory) and each asset's correlation to the other assets in the available set of investments (Whiteside, 1997). This classification of risk assumes that:

- Firms' long run returns are normally distributed and can, consequently, be adequately defined in terms of the mean and variance. In reality, it is likely that the distribution describing long run returns would be "skewed".
- Variance is a useful measure of risk. In calculating variance, positive and negative deviations from the mean are equally weighted. In fact, decision-makers are often more pre-occupied with downside risk – the risk of failure. A solution to this problem is to determine the efficient set of portfolios by using another risk measure. A group of suitable risk measures that only takes the dispersions below a certain target into account are the downside risk measures. In the mean downside risk investment models the variance is replaced by a downside risk measure then only outcomes below a certain point contribute to risk.

- There is enough information to estimate the mean and variance of the distribution of outcomes. This does require a high level of information that, in some cases, is not available (Ross, 1997).

However, provided that the assumption that variance is a useful approximation of risk is accepted, the aim is to maximise the expected return under a certain level of variance, which is equivalent to minimising the variance under a certain level of expected return. To determine the variance, Monte Carlo simulation is used. First, information about all the variables that affect the calculation of a cash flow of one of the projects is collected and their probability distributions are estimated. Then for each project, using Monte Carlo simulation, a number of cumulative discounted cash flows and their matching discounted investments can be generated simultaneously. From these points, the EMV of each project, the variance of the EMV of each project and the correlation between the EMVs of the different projects can be calculated. By simulating the cash flows of all projects simultaneously, some of the uncertain variables, which fix the systematic risk and thus provide for the correlation between the different projects, are equal for all projects and therefore the coefficient of correlation between projects can be determined. (The value of this coefficient can range from +1 in the case of perfect correlation, where the two assets move together, to –1 in the case of perfect negative correlation, where the two assets always move in opposite directions. The coefficient is 0 when there is no association between the assets and they are said to be independent.) Then these values, together with any other constraints, are used to generate the efficient frontier. To find the efficient portfolios, Markowitz defined the mean variance model that reduces to a quadratic-programming problem that is easily solved by the many mathematical software packages available. After the efficient set has been determined, a portfolio can be chosen from this group. There are several ways of doing this. For the method advocated by Markowitz (and stochastic dominance) the utility function, or preference curve, of the company would need to be determined, as discussed above in section 5.3, this is particularly difficult. Therefore some finance theorists advocate the use of one of the safety-first criteria (for a full discussion see Ross, 1997).

Investment opportunities of the oil industry have a great resemblance to financial assets. As with the financial assets, there is much risk and uncertainty about the profit of the projects. Assets are highly correlated with each other. They all have some variables, such as oil price, that affect the profitability of the project in common. In the stock market paper assets (stocks and shares) are traded and in the oil business companies hold and trade portfolios of real assets by, for instance buying and selling shares in joint ventures.

The following simple example from Ball and Savage (1999) shows how the application of the principles of portfolio theory to the oil industry can result in decisions that are counter-intuitive.

An oil company has $10 million to invest in exploration and production projects. Only two projects are available and each requires the full $10 million for 100% interest. One project is relatively “safe”; the other relatively “risky”. The chances of success are independent. The facts about the projects are presented in table 5.7.

	Outcome	**NPV ($million)**	**Independent Probability (%)**
SAFE	Dry hole	-10	40
	Success	50	60
RISKY	Dry hole	-10	60
	Success	80	40

Table 5.7: *Safe and risky projects (source: Ball and Savage, 1999)*

The EMVs of each project are the same:

EMV_{safe}=60%*$50+40%*($-10)=$26 million
EMV_{risky}=40%*$80+60%*($-10)=$26 million

A complication is now added. If money is lost, shareholder confidence is forfeited. There is a 40% chance of forfeiting shareholder confidence with the safe project, and a 60% chance with the risky project. Since the EMV for both projects is $26 million, there is no way of increasing that by choosing the risky over the safe project. Under both circumstances the safe project is obviously the better choice.

A further complication is added. Suppose it is possible to split the investment evenly between the two projects. Intuitively it would seem a bad idea to take a 50% out of the safe project and put it into the risky one. However, intuition is not always the best guide.

There are now four possible outcomes and these are shown in table 5.8. The EMV of portfolio is still $26 million (24% *$65+36%*$20+16%*$35+24%*(-$10)=$26 million) but the only way to forfeit shareholder confidence is to drill two dry wells (Scenario 4), for which the probability is 24%. That cuts the risk of forfeiting shareholder confidence by almost half. So, moving money from a safe project to a risky one, which, of course, seems counter-intuitive, reduces risk and is the effect of diversification.

SCENARIO	SAFE	RISKY	PROBABILITY	RETURN($million)	RESULT
1	Success	Success	0.6*0.4=0.24	50%*$50+50%*$80=$65	Shareholder confidence retained
2	Success	Dry hole	0.6*0.6=0.36	50%*$50+50%*($-10)=$20	Shareholder confidence retained
3	Dry hole	Success	0.4*0.4=0.16	50%*($10)+50%*($80)=$35	Shareholder confidence retained
4	Dry hole	Success	0.4*0.4=0.24	50%*(-$10)+50%*(-$10)=-$10	Shareholder confidence lost

Table 5.8: *All possible outcomes of investing 50% in each project (source: Ball and Savage, 1999)*

Most companies that do not use portfolio theory rank their exploration projects based on EMV and then choose the project with the highest EMV (Section 6.2 of Chapter 6). This ignores the diversification effect and in the example above would have led to allocating all the funds to the safe project, with nearly twice the risk of the best portfolio (Bailey *et al.*, in press).

Publications from Whiteside (1997) and Ross (1997) provide further details of how portfolio theory can be applied to the industry. Software companies such as Merak and Indeva produce tools that allow upstream companies to use the technique easily.

Recently the application of another technique from finance theory, option theory, has been gaining attention in the literature as a tool for valuing undeveloped oil reserves. However, currently the discussion raises more questions than it answers, and the method has yet to be shown to be a viable method for evaluating these reserves (see, for example, Lohrenz and Dickens, 1993; Markland, 1992). The following section reviews the industry and decision theory literature on option theory.

5.6 OPTION THEORY

The application of option theory to investment appraisal was motivated by a recognition that the standard DCF approach does not capture all sources of value associated with a given project. Specifically, writers such as Dixit and Pindyck (1994) argue that two aspects of extra value or economic desirability are inadequately captured by a standard NPV analysis. First, the operating flexibility available within a single project, which enables management to make or revise decisions at a future time. The traditional NPV method, they believe, is static in the sense that operating decisions are viewed as being fixed in advance. In reality, Buckley (2000 p422) argues, good managers are frequently good because they pursue policies that maintain flexibility on as many fronts as possible and they maintain options that promise upside potential. Following such an observation Dixit and Pindyck (1994 p6) write:

> "…the ability to delay an irreversible investment expenditure can profoundly affect the decision to invest. It also undermines the simple net present value rule, and hence the theoretical foundation of standard neoclassical investment models."

They go on to conclude:

> "…as a result the NPV rule … must be modified." (Dixit and Pindyck, 1994 p6)

Secondly, they believe that the "strategic" option value of a project, which results from its interdependence with future and follow-up investments, is not accounted for in the conventional NPV method (Dixit and Pindyck, 1998 and 1994). Therefore, Myers (1984) and Kester (1984) suggest that the practice of capital budgeting should be extended by the use of option valuation techniques to deal with real investment opportunities.

Option theory, sometimes called “option pricing”, “contingent claims analysis” or “derivative asset evaluation”, comes from the world of finance (Lohrenz and Dickens, 1993). In its most common form, option theory uses the Black-Scholes model for spot prices and expresses the value of the project as a stochastic differential equation (Galli *et al.*, 1999). In this section, by reviewing the finance literature, the development of option theory will be traced. The popularity and success of option theory algorithms has led to wide interest in analogous application to evaluation of oil and gas assets (Lohrenz and Dickens, 1993). This literature will also be reviewed.

In the 1970s, the financial world began developing contracts called puts and calls. These give the owner the right, for a fee, to buy an option, which is the right (but not the obligation) to buy or sell a financial security, such as a share, at a specified time in the figure at a fixed price (Bailey *et al.*, in press). If the transaction has to take place on that date or never, the options are called European; otherwise they are called American (this does not refer to where the transaction takes place!) (Galli *et al.*, 1999). An option to buy is known as a call option and is usually purchased in the expectation that the price of the stock will rise. Thus a call option may allow its holder to buy a share in company ABC for $500 on or before June 2001. If the price of the stock rises above $500 the holder of the option can exercise it (pay $500) and retain the difference. The holder’s payoff is that sum minus the price paid for the option. A put option is bought in the expectation of a falling price and protects against such a fall. The exercise price is the price at which the option can be exercised (in this case $500) (Bailey *et al.*, in press).

The central problem with options is working out how much the owner of the contract should pay at the outset. Basically, the price is equivalent to an insurance premium; it is the expected loss that the writer of the contract will sustain. Clearly, the ability to exercise the option at any time up to the maturity date makes American options more valuable than European options. What is less obvious is that this apparently minor difference necessitates different procedures for calculating option prices (Galli *et al.*, 1999).

The standard assumption made in option theory is that prices follow lognormal Brownian motion. Black and Scholes developed the model in the early 1970s.

Experimental studies have shown that it is a good approximation of the behaviour of prices over short periods of time. If they obey the standard Black-Scholes model, then the spot price, p_{sp}, satisfies the partial differential equation:

$$d\ p_{sp} = \sigma p W_t + \mu\ p_{sp} dt$$

where p_{sp}=spot price, W_t=Brownian motion, μ=drift in spot prices, p=price and σ=spot price volatility.

Applying Ito's Lemma, the explicit formula for p_{sp} can be shown to be:

$$p_{sp} = p_0 e^{\{[(\mu - \sigma 2)/2]\ t + \sigma Wt\}}$$

where p_{sp}=spot price, W_t=Brownian motion, μ=drift in spot prices, and σ=spot price volatility, p_0=oil price, t=time

It is relatively easy to evaluate European options (which can be exercised only on a specified date), particularly when the prices follow Black-Scholes model because there is an analytic solution to the corresponding differential equation. This gives the expected value of max[p exp (-rt) – p_k, 0] for a call or of max[p_k – p exp(-rt),0] for a put. In general the simplest way of getting the histogram and the expected value is by simulating the diffusion process and comparing each of the terminal values to the strike price of the option. Solving the partial differential equation numerically gives only the option price (Galli *et al.,* 1999).

Evaluating the price of an American option is more difficult because the option can be exercised at any time up to the maturity date. From the point of view of stochastic differential equations, this corresponds to a free-boundary problem (see Wilmot, Dewynne and Howison, 1994). The most common way of solving this type of problem is by constructing a binomial tree. This is similar to a decision tree (for an explanation see Galli *et al.*, 1999).

In the formula for NPV given in section 5.2, the discount rate was used to account for the effect of time on the value of money; however, this is not immediately apparent in the option pricing equations. In option theory, the time value of money is incorporated through the risk-free rate of return and by way of a “change of probability” (Smith and McCardle, 1997, Baxter and Rennie, 1996 and Trigeorgis, 1996, all provide good explanations of this) (Galli *et al.*, 1999).

The application of these methods to “real”, as opposed to financial options, dates back to Myers (1977) and was popularised by Myers (1984) and Kester (1984) (see Mason and Merton (1985) for an early review and Dixit and Pindyck (1994) for a survey of the current state of the art). In this approach rather than determining project values and optimal strategies using subjective probabilities and utilities, the analyst seeks market-based valuations and policies that maximise these market values. In particular, the analyst looks for a portfolio of securities and a trading strategy that exactly replicates the project’s cash flows in all future times and all future states. The value of the project is then given by the current market price of this replicating portfolio. The fundamental principal underlying this approach is the “no arbitrage” principle or the so-called “law of one price”: two investments with the same payoffs at all time and in all states – the project and the replicating portfolio must have the same value.

The idea of investments as options is well illustrated in the decision to acquire and exploit natural resources. The similarity of natural resources to stock market options is obvious. Stock market options give the holder the right but not the obligation to acquire or sell securities at a particular price (the strike price) within a specified timeframe but there is not an obligation to do so. The owner of an undeveloped oil well has the possibility of acquiring the proceeds from the oil well’s output but does not have an obligation to do so and the company may defer selling the proceeds of the asset’s output. Further, much as a stock pays dividends to its owner, the holder of developed reserves receives production revenues (net of depletion). Table 5.9 lists the important features of a call option on a stock (or, at least, all those necessary to enable one to price it) and the corresponding aspects of the managerial option implicit in holding an undeveloped reserve (Siegel *et al.*, 1987).

Using this analogy, Brennan and Schwartz (1985) worked out a way to extend it to valuing natural resource projects using Chilean copper mines to illustrate the procedure. They reasoned that managerial flexibility should improve the value of the project. They allowed for three options: production (when prices are high enough), temporary shutdown (when they are lower) and permanent closure (when prices drop too low for too long). Different costs were associated with changing from one production option to another. They found the threshold copper prices at which it was optimal to close a producing mine temporarily (Galli *et al.,* 1999).

STOCK CALL OPTION	UNDEVELOPED RESERVES
Current Stock Price	Current value of developed reserves
Exercise price	Development cost
Time to expiration	Relinquishment requirement
Riskless rate of interest	Riskless rate of interest
Dividend	Net production revenue less depletion

Table 5.9: *The similarities between a stock call option and undeveloped reserves (source: Paddock et al., 1988)*

In practice, the key to applying options is in defining the options that are actually available to management. Trigeorgis (1996) lists a whole range of managerial options covering research and development and capital intensive industries, as well as oil and mining. Dixit and Pindyck (1994), the other classic text on real options, describes several oil applications, including sequencing decision-making for opening up oil fields and a study on building, mothballing and scrapping oil tankers. Since Brennan and Schwartz's seminal work, many others have studied petroleum options. Copeland, Koller and Murrin (1990) for example, describe a case involving an option to expand production.

Real option theory is best illustrated by an example. The following illustration is taken from Leslie and Michaels (1997).

Suppose an oil company is trying to value its license in a block. Paying the license fee is equivalent to acquiring an option. The company now has the right (but not the obligation) to invest in the block (at the exercise price) once the uncertainty over the value of the developed reserves (the stock price) has been resolved.

Assume that the company has the opportunity to acquire a five-year license and that the block is expected to contain some 50 million barrels of oil. The current price of oil from the field in which the block is located is $10 per barrel and the cost of developing the field (in present value terms) is $600 million. Using static NPV calculations the NPV will be $500 million - $600 million=$-100 million.

The NPV is negative so the company would be unlikely to proceed. The NPV valuation ignores the fact that decisions can be made about the uncertainty, which in this case is twofold; in the real world there is uncertainty about the quantity of oil in the block and about its price. It is, however, possible to make reasonable estimates of the quantity of oil by analysing historical data in geologically similar areas and there is also some historical data on the variability of oil prices.

Assume that these two sources of uncertainty between them result in a 30% standard deviation around the growth rate of the operating cash inflows. Assume also that holding the option obliges the company to incur the annual fixed costs of keeping the reserve active, say $15 million. This represents a dividend-like payout of 3% (15/500) of the value of the asset.

Using the Black and Scholes formula for valuing a real option

$ROV=Se^{-\delta t} * \{(N(d_1)\} - Xe^{-rt} * \{(N(d_2))$

where, $d_1=\{1n(S/X)+(r-\delta+\sigma^2/2)t\}/\sigma * \sqrt{t}$, $d_2= d_1-\sigma * \sqrt{t}$, S=presented value of expected cash flows, X=present value of fixed costs, δ=the value lost over the duraction of the option, r=risk free interest rate, σ=uncertainty of expected cash flow and t=time to expiry,

and substituting for the values in this example:

$ROV=(500e^{-0.03*5}) * \{(0.58)\} - (600e^{-0.05*5}) * \{(0.32)\}$ = $251 million - $151 million = $100 million.

The $200 million difference between the NPV valuation of $-100 million and the ROV valuation of $100 million represents the value of the flexibility brought about by having the option to wait and invest when the uncertainties are resolved.

From a theoretical point of view, the key to applying real option theory is deciding which variable is assumed to follow a Black and Scholes model. Brennan and Schwartz assume that the spot price (here the oil price) obeys this model. Trigeorgis (1996), Kemma (1993) and Paddock *et al.* (1988) show a radically different approach in which the analysis is based on the hypothesis that the project itself obeys this model. The difference is important because the theory of option pricing requires a liquid market for the underlying commodity, no transaction costs and no arbitrage. While this is probably true for oil prices, it is doubtful whether a large enough market exists for oil projects (Galli *et al.*, 1999).

Concerns have been expressed about all these approaches, usually directly questioning the underpinning assumptions of the Black and Scholes methodology and its appropriateness for valuing real options particularly those with long time horizons (for example, Lohrenz and Dickens, 1993). Buckley (2000) bypasses these criticisms by describing an alternative route to valuing real options involving a decision tree approach.

Option theory methods are heralded as an improvement over traditional DCF methods specifically because they allow managerial flexibility to be modelled and included in the investment analysis. However, since the value of an option is, in fact, an expectation or, more precisely, the conditional expectation of the value given the initial conditions, real options, like decision trees, do not give any indications about the uncertainty of the project (Galli *et al.*, 1999). More importantly, a number of professional managers have suggested that while the analogy relating managerial flexibility to options has intuitive appeal, the actual application of option based techniques to capital budgeting is too complex (or certainly more complex than the NPV method) for practical application (see Chapter 6).

This section and the ones that precede it (5.2-5.5) have provided an overview of the decision analysis techniques available to petroleum exploration companies to utilise in their investment appraisal decision-making. All the tools described have been applied to upstream investment analysis in the literature, allow risk and uncertainty to be quantified and, crucially, are complementary. They do not represent alternatives. This is important since, as indicated above, each tool has its limitations, so that reliance only on the output of one tool for investment decision-making would be inadvisable. By combining the output from a variety of tools, the decision-maker is more likely to assess the risk and uncertainty accurately. The tools described in the sections above use similar input and, hence their use together does not place unnecessary strain on the resources of an organisation. There are other techniques described in the literature (for example, the analytic hierarchy process (Saaty, 1980) and Markov chain analysis (Das *et al.*, 1999) but these have either not been applied to the upstream or the input they demand and, in many cases, the output they produce, is not complementary to the other investment techniques used by organisations. Hence their use would represent a significant amount of additional work for the organisations. For these reasons, the tools described in the sections above, the researcher believes comprise the toolkit currently available to the upstream decision-maker.

The following section provides an indication of how these tools can be integrated into one approach for investment appraisal in the upstream. There are numerous other ways that the tools can be combined. The main aim of the next section is to demonstrate that the tools are complementary.

5.7 CURRENT CAPABILITY

The techniques presented above represent current theory in investment appraisal decision-making in the upstream oil and gas industry. This section presents an illustration of how these tools can be used together when an upstream company is considering whether to drill an exploration well in a virgin basin at an estimated cost of £10 million. It has been informed, modified and validated using knowledge gained from the decision theory and oil industry literatures and insights ascertained from attendance at conferences and seminars during the course of the research. The approach is summarised in figure 5.12.

The first step involves the geologist making a prediction based on historic statistics and analogues of other basins and plays with similar geological characteristics, of the chance of there being any hydrocarbons in the prospect. Some practitioners define this chance of success estimate to be “geological risk” (Simpson *et al.,* 1999). Sensitivity analysis can be used here to identify the key reservoir parameters in this case.

1. Assess the chance of success based on historic statistics and analogues of other basins and plays with similar geological characteristics.
2. Use sensitivity analysis to determine the critical reservoir parameters.
3. Conduct a probabilistic analysis of reserves using Monte Carlo techniques. If necessary, perform a further sensitivity analysis here by altering the shapes of the probability distributions assigned to the reservoir parameters and changing the nature of the dependencies between the variables.
4. Extraction from the probabilistic output of the reserves calculation of some deterministic samples –for example, p10, p50 and p90 (high, mid, low cases).
5. Use sensitivity analysis to determine the critical economic parameters.
6. Perform probabilistic economic analysis for each deterministic reserve case using Monte Carlo techniques. If necessary, perform a further sensitivity analysis here by altering the shapes of the probability distributions assigned to the economic factors and changing the nature of the dependencies between the variables.
7. Using influence diagrams draw the decision tree.
8. For each reserve case, recombine the chance of success estimated in step 1 and the economic values generated in step 6, through a decision tree analysis to generate EMVs.
9. Use option theory via decision tree analysis and assess the impact on the EMV.

Figure 5.12: *A 9 Step approach to investment appraisal in the upstream oil and gas industry*

Next, the geologist performs a probabilistic analysis of reserves using Monte Carlo techniques. The following formula is used to generate the estimate of the volume of hydrocarbons recoverable from an underground prospect:

Recoverable reserves = gross rock volume * net pay/gross pay * porosity * hydrocarbon saturation * recovery efficiency * formation volume factor,

where, gross rock volume (GRV) is the total volume of the “container” mapped out by the geologists; net/gross is the proportion of the container that is reservoir rock (for example, sand) as opposed to non-reservoir rock (shale); porosity is a measure of the fluid storage space (or pores) in the reservoir rock, as opposed to sand grains; hydrocarbon saturation is the proportion of fluid in the pore spaces that is hydrocarbons as opposed to water; recovery efficiency is the proportion of hydrocarbons in the reservoir that engineers can actually get out; and, formation volume factor describes the change in volume of hydrocarbons as they flow from the pressure and temperature of the subsurface to the surface (Bailey *et al.*, in press).

The geologists, based on limited data, draw probability distributions for each of these variables. In an ideal world, the individual distributions would be entirely data driven – based on data derived from many porosity measurements, for example. But, in practice, the data available are often minimal. The geologists will suggest the shape of the curve that is consistent with the small amount of data available. Geologists often, for instance, draw analogies between the porosity of the rocks being examined and the porosity of rocks from a similar previously exploited area (Bailey *et al.*, in press). As indicated above in section 5.4, the shape of the distributions to be used is a contentious issue. The distributions can vary enormously and they will be chosen to fit different circumstances. A triangular distribution, for instance, might be chosen for porosity if the experts were confident that they knew the minimum, most likely and maximum porosities. A lognormal distribution might seem most appropriate for GRV, indicating that experts think that there is a slightly higher chance of very high values than of very low. Once each variable has been assigned a distribution type, any dependencies between the parameters are modeled. Section 5.4 explained that due to the lack of prescription in the literature, this is another difficult task for the geologist. Geologists usually presume some correlation between hydrocarbon saturation, porosity and recovery efficiency. The Monte Carlo simulation is then run using, for example, Crystal Ball™ or @risk™, and the end result is a new distribution curve of the range of possible recoverable reserve sizes and the probability of any particular one occurring. Some analysts refer to the range of possible recoverable reserves as “geological uncertainty” (Simpson *et al.*, 1999). A further sensitivity analysis can then be carried out so that the key reservoir parameters in this case can be identified.

From the resulting distribution, the geologist reads off values of the possible recoverable reserves and the chances of their occurrence, for input to the economic model. These values need to be representative of the whole distribution and so it is good practice to use the p10, p50 and p90 values since these represent the highest, mid and lowest reserve cases.

Then the economists for each reserve case, with input from other specialists as necessary, build the economic model. This involves generating “most likely” predictions of drilling, capital and operating and abandonment expenditures, production volumes, oil price and exchange rate. Probability distributions are then assigned to each variable. The dependencies between any parameters are also modelled. Section 5.4 indicated that these tasks are particularly difficult because of the lack of prescription in the literature. The Monte Carlo simulation is run, again using @risk™ or Crystal Ball™, and the result is a probability distribution of the range of possible NPVs and the probability of any particular one occurring. Sensitivity analysis can then be used to identify the key parameters in this case.

Using influence diagrams as necessary, decision trees can then be drawn up for each reserve case. The organisation’s decision-makers ought to be involved in this process. This ensures that the analysts capture the decision-makers beliefs and preferences in the analysis. Combining the chance of success estimate generated in the second step with the NPV prediction for each reserve case, an EMV for each reserve case can be produced. Option theory, which perhaps most easily applied using Buckley’s (2000) advanced decision tree, can then be used to allow analysts and decision-makers to assess the impact on the EMV of future events.

Variations of the approach could be used for development decisions, any production decisions and for the decision of when to abandon production and how to decommission the facilities. For example, when organisations are considering developing a field, the question of whether there are any hydrocarbons present is omitted, since exploration and appraisal wells have already established their presence. They focus instead on whether there are enough hydrocarbons present for the prospect to be commercially viable. In the language of Simpson *et al.* (1999) and Watson (1998), the organisation is now interested in “commercial risk” and “commercial uncertainty” as opposed to “geological risk” and “geological uncertainty” (This will be discussed further in Section 6.2 of Chapter 6). As an asset proceeds through its life from exploration, through development to production and, ultimately, to abandonment, the relative risk and uncertainty associated with it decrease, though the relative risk and uncertainty may increase. (For example, at a recent Society of Petroleum Engineers seminar in Aberdeen, Mike Cooper and Steve Burford demonstrated how the relative risk and uncertainty associated with the Murchison field actually increased with time). Unfortunately, most of the decisions have to be made near the beginning of the asset's life when the risk and uncertainty are particularly high. This makes it paramount that organisations use probabilistic methods for the generation of both reserves and economic estimates.

Some companies use a combination of deterministic and probabilistic techniques. For example, Nangea and Hunt (1997) describe how Mobil used such an approach for reserve and resource evaluation prior to their merger with Exxon. The authors, and presumably the company, believed that both methods have valid justification for utilisation and that when they are used jointly, they can provide greater insights into the recoverable hydrocarbon volumes and the probability of recovering those volumes, than when they are used in isolation. During exploration, proved and probable reserves (as defined by the World Petroleum Congress, see Section 7.4 of Chapter 7) were calculated deterministically. A Monte Carlo simulation was then run to establish the cumulative probability distribution for recoverable hydrocarbons. This curve and the deterministic results were then utilised to determine the possible volumes ("geological uncertainty") and associated confidence factors ("geological risk") for each of these categories. The mean value of this probabilistic curve (the expected value) was the case used for the economic analysis. No indication is given in the Nangea and Hunt's (1997) paper as to how Mobil conducted their economic analysis. However, clearly by using only one reserves case to run the economic analysis, the economic impact of the high and low reserve cases was ignored. As fields went into production and new information became available, Mobil's analysts generated new deterministic and probabilistic estimates of the proven and possible reserves of each field. Near the end of fields' lives, Mobil believed that there is a little uncertainty associated with the reservoir parameters or the size of the field. Consequently, the company discontinued using probabilistic analysis at this stage, and the production volumes (and associated confidence factors) were calculated deterministically.

Whilst it is certainly true that during production risks and uncertainties are significantly reduced, they are by no means eliminated. For example, the oil price prediction used in the economic models may prove inaccurate, as was the case with the Brent field. The physical structures could fail. This occurred with the facilities for Foinaven, Balder and Sleipner (Wood Mackenzie, 1999). As indicated earlier, there is also the possibility of phenomena occurring that are out with management control so-called "acts of god". Spencer and Morgan (1998) refer to such acts as "train wrecks". They define a "train wreck" to be an exceptional event that is not accounted for in the analysis. In a mature field, an example of a train wreck is the reaction of Greenpeace to the decommissioning of the Brent Spar. There are also still significant investment decisions to be made. For example, well intervention and side track decisions. For these and other production decisions, it is evident from the examples above that companies ought to use decision analysis techniques with probabilistic input acknowledging the risks and uncertainties that remain. By selecting a single value, Mobil were ignoring other probable outcomes for each project variable (data which are often vital to the investment decision as they pertain to the risk and uncertainty of the project) implying a certainty which does not exist.

Spencer and Morgan (1998) describe the application probabilistic techniques to production forecasting using the choke model (figure 5.13) in BP. This model considers the reservoir, wells, facilities and export decisions as a system analogous to a pipeline with various chokes restricting flow. Each "choke" is a probability distribution of either production or efficiency. These individual distributions are then combined by Monte Carlo simulation. It is usually assumed that all the distributions are independent. The authors recognise that, in practice, this is often not the case and they highlight the need for this issue to be addressed. Using probabilistic techniques for production decisions explicitly recognises the inherent uncertainty in the input parameters. The authors claim that using these methods has reduced the gap between actual and predicted outcomes.

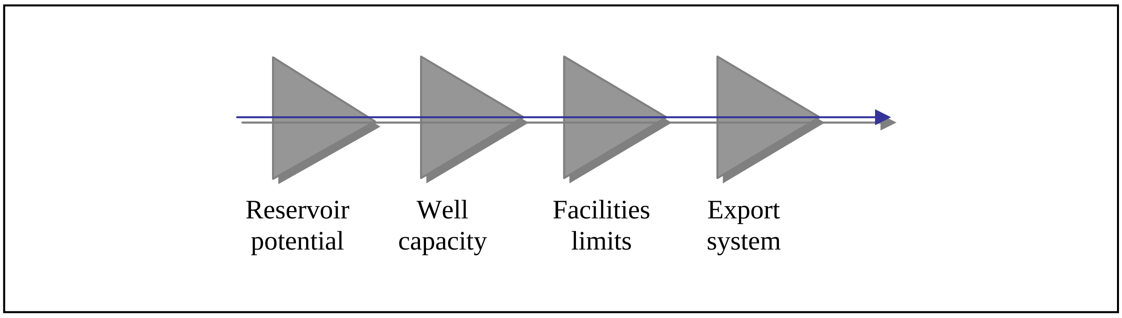

Figure 5.13: *Choke model (source: Spencer and Morgan, 1998)*

This section has provided an indication of the way the tools identified in this chapter can be used together. Since their use together is resource-intensive, the approach that is suggested in figure 5.12 would only be appropriate for investment decisions that require "significant" capital expenditure. This is a relative measure, for example, a small petroleum company might regard the investment needed to acquire seismic data as "significant" (figure 5.1), whereas for a large company, the sums involved only become "significant" when it is considering whether to develop the field (figure 5.1) (Section 6.3 of Chapter 6). Variations of the approach summarised in figure 5.12 could also be used in other industries with a similar business environment to the oil and gas industry, for example, the pharmaceutical or aerospace industries. In these businesses, the investment decisions are similar in scale to the oil industry, also characterised by high risk and uncertainty and have a high initial investment without the prospect of revenues for a significant period.

Commercially available software packages can be used to assist the decision-maker with some of these steps. For example, Merak produces various tools such as Decision Tree™, Portfolio™ and PEEP™ (Petroleum Economic Evaluation Package) which uses Crystal Ball™ to perform Monte Carlo analysis. DNV (Det Norske Veritas) have developed a software tool, Easy Risk™, for preference theory analysis. However, currently there is no single piece of software that allows the upstream decision-maker to utilise all the tools in their toolkit. Through recently established collaborative relationships, the major players (CSIRO (Commonwealth Scientific and Industrial Research Organisation) Australia, Merak, Gaffney, Cline & Associates, Wood Mackenzie and DNV) are now working together in an attempt to deliver to the upstream investment decision-maker the definitive software tool.

5.8 CONCLUSION

This chapter has answered the first research question posed in Chapter 1 by presenting the spectrum of techniques available to the industry for investment decision-making. This is not intended to be a comprehensive study of the mathematics governing and underpinning each technique. This is widely documented elsewhere. The aim here was only to give an overview of the methods and indicate current theoretical capability. Recent studies suggest that current practice is some way behind this potential. However, this research has been limited and it is apparent there is a need for a study that establishes common practice in upstream investment appraisal. The following chapter addresses this issue.

Chapter Six

Current practice in investment appraisal in the upstream oil and gas industry

6.1 INTRODUCTION

There has been much research published on decision-making (for example, Ford, 2000; Gunn; 2000; Ekenberg, 2000; Markides, 1999; Harrison and Pelleteir, 2000; Milne and Chan; 1999; Nutt, 1999; Burke and Miller, 1999; Papadakis, 1998; Dean and Sharfman, 1996; Quinn, 1980; Mintzberg *et al.*, 1976; Cyert and March, 1963). The numerous qualitative studies that have been conducted are useful for providing broad insights into the field of decision-making. However, very few of these studies have examined the use of decision analysis in investment decision-making. Several have focussed on the existence of formalisation and rationality in decision-making (for example, Papadakis, 1998; Dean and Sharfman, 1996) but few have explicitly examined the use, and usefulness, of decision analysis in investment appraisal decision-making. Fewer again have considered cases where the decision situation is characterised by a substantial initial investment, high (absolute) risk and uncertainty throughout the life of the asset and a long payback period, features that are common in, though not unique to, the petroleum industry. Typically, where such research has been undertaken, it has been conducted within one company, usually by an employee of that organisation and has often not been published due to commercial sensitivity (for example, Burnside, 1998). There has only been one previous qualitative study researching the use of decision analysis across the whole oil industry (Fletcher and Dromgoole, 1996). However, as stated in Section 3.4 of Chapter 3, this study focused on the perceptions and beliefs of, and techniques used by, one functional area within the organisations active in the upstream. Hence, its findings can only be regarded as indicative rather than conclusive. There are also many quantitative studies of decision-making. As indicated in Chapter 2, where these have been centred on the use of decision analysis in investment appraisal decision-making by organisations, they have only provided an indication of how widely used a particular decision analysis technique is (for example see studies by Arnold and Hatzopoulous, 1999; Carr and Tomkins, 1998; Schuyler, 1997; Buckley *et al.*, 1996 Fletcher and Dromgoole, 1996; Shao and Shao, 1993; Kim, Farragher and Crick, 1984; Stanley and Block, 1983; Wicks Kelly and Philippatos, 1982; Bavishi, 1981; Oblak and Helm, 1980 and Stonehill and Nathanson, 1968). They do not provide any insights, based on behavioural decision theory, into the reasons why some techniques fail to be implemented and others succeed, and, more importantly, which techniques perform better than others do (Clemen, 1999).

The research presented in this chapter differs from these studies. Using a qualitative methodology, it attempts to integrate perspectives from individuals employed in a variety of functions within organisations who are involved throughout the investment appraisal decision-making process. This allows insights to be gained into issues such as why organisations use certain techniques and yet reject others. Combining this with the review of the relevant behavioural decision theory literature (summarised in Section 2.4 of Chapter 2), allows the second research question that was proposed in Chapter 1, which aimed to ascertain which decision analysis techniques upstream companies use and to understand how they use them, to be answered.

The chapter first establishes which techniques are currently used for investment appraisal in the upstream. Research by Schuyler (1997) and Fletcher and Dromgoole (1996) has suggested that there is a significant gap between practice and capability in the techniques used for investment appraisal in the upstream oil and gas industry. Chapter 5 presented the decision analysis tools currently available to the industry. Some of these techniques have only been applied to the oil industry recently and hence, were not available to companies at the time of these previous studies. The chapter begins by drawing on the research interviews to establish first, which techniques upstream companies now use for investment appraisal and second, if there is still a gap between current theory and practice in investment appraisal decision-making. This indication of current practice will be used in Chapter 7 to produce a ranking of the companies according to the sophistication of the decision analysis tools they use for decision-making. The chapter concludes by developing a model of current practice in investment appraisal in the upstream. If there is a gap between current practice and capability, this model will allow possible reasons for its existence to be explored.

6.2 THE USE OF DECISION ANALYSIS BY ORGANISATIONS

Drawing on the research interviews, this section establishes first the extent to which companies are aware of and second, the amount to which they use each of the techniques identified in Chapter 5. This picture of current practice can then be compared with the 9-step approach presented in figure 5.12 of Section 5.7 in Chapter 5 that represented current capability.

- The concepts of decision tree analysis and EMV

Awareness in the industry of the concepts of EMV and decision tree analysis is high and, in all but one of the companies interviewed, their use in investment appraisal decision-making is commonplace. Confirming the literature that was reviewed in Section 5.2 of Chapter 5, the value of a decision tree is appreciated almost universally in the upstream. Most of the companies have been using decision trees for some time and find the tool useful. Several respondents believe that decision trees are more effective in organisational investment decision-making than techniques such as Monte Carlo simulation because they encourage the explicit consideration of all the potential outcomes of a decision. This, interviewees feel, is especially valuable when an investment decision is particularly complex. Some organisations have software packages to assist with structuring and presenting their decision trees. The most commonly used package is Decision Tree™ (produced by Merak). The majority, however, are of the opinion that it is easier to draw decision trees by hand:

> "…and then they say, "Can you put this decision tree into a drawing program? And you go, "Eh?" Because it asks for your hierarchies, sub-hierarchies or whatever. And with our decision tree program there's an awful lot of language." (C)

None of the companies reported using influence diagrams to structure their decision trees. Pearson-Tukey approximations are not employed by any of the companies in decision tree analysis. Decision trees tend to be used for all the investment decisions throughout the life of an asset (see figure 5.1 and Section 5.2 of Chapter 5 outlines these decisions). However, in most organisations decision trees are not presented to, or used by, the main board. This is issue receives further attention in section 6.3.

Recognising the folly of reliance on only one decision-making criterion (Atrill, 2000) and echoing earlier observations by Schuyler (1997) and others (Arnold and Hatzopoulous, 1999; Carr and Tomkins, 1998; Schuyler, 1997; Buckley *et al.*, 1996

Fletcher and Dromgoole, 1996; Shao and Shao, 1993; Kim, Farragher and Crick, 1984; Stanley and Block, 1983; Wicks Kelly and Philippatos, 1982; Bavishi, 1981; Oblak and Helm, 1980 and Stonehill and Nathanson, 1968), companies report that for significant decisions, a range of decision-making criteria is generated and presented to the board. Organisations weight these measures according to environmental conditions and the particular decision under analysis. As several of the respondents explain, an EMV only tends to be generated by organisations when they are trying to decide whether or not to drill an exploration prospect:

> "They are used for different things. NPV is very important. EMV is used on a drill or don't drill decision. … It is used because the managing director likes it. ROR [Rate of Return] is used as well. We always quote NPV and ROR in any conversation. But the others are used." (J)

and,

> "Drill or not drill is EMV. ROR is important we have a threshold – if an E&P [Exploration and Production] project doesn't have a ROR greater than a particular threshold … and we use NPV to give us an idea of the size of the project value." (F)

One of the representatives from company R explains why an EMV is only calculated for drilling decisions:

> "…really because once you've made the decision to spend the money then basically EMV becomes a slightly meaningless term because … EMV tends to be used more when you are risking an exploration prospect but once you've found something and you feel as though there is a good chance that you are going to make money out of it, then really how do you manage that risk? So it's the sensitivity around the core, the base value. I would say EMV would tend to be used where you've got significant levels of risk of failure, where you are probably more likely to fail than to succeed and that would typically be in an exploration venture. NPV would definitely be used when you've found something and you are going ahead." (R1)

Recall from Section 5.2 of Chapter 5, the EMV of an outcome is defined by Newendorp (1996) to be the product that is obtained by multiplying the chance (or probability) that the outcome will occur and the conditional value (or worth) that is received if the outcome occurs. The EMV of a decision alternative is then the algebraic sum of the expected values of each possible outcome that could occur if the decision alternative is accepted. After the decision has been made to drill an exploration well in a field and the presence of hydrocarbons has been confirmed, the chance (or "geological risk" – for a full discussion see Section 5.7 of Chapter 5) of there being a dry hole is zero and, consequently, the EMV of the outcome "dry hole" is zero. However, the dry hole is only one of the outcomes on the decision tree. There are still many outcomes that could occur. For example, the field could contain fifty million barrels or it might only contain ten million barrels. Each outcome has a chance of occurrence and a conditional value that would be received if the outcome occurred. Hence, theoretically, at least, the EMV could be used for all the decisions in the life of an asset. As indicated in Section 5.7 of Chapter 5, this observation has led some companies to differentiate between geological risk and uncertainty and commercial risk and uncertainty. Such organisations define geological risk to be the chance of there being any hydrocarbons and they perceive geological uncertainty to be the range of possible volume outcomes given there is some hydrocarbons. An EMV can then be calculated for the decision to drill. Once the presence of hydrocarbons has been detected the focus then shifts to commercial risk and uncertainty. Commercial risk is defined to be the chance of the field producing enough hydrocarbons to be commercially viable in the current and future economic climates. Commercial uncertainty is defined to be, given that the field is commercially viable, the possible range of outcomes. An EMV can be calculated again at this stage.

As the following interviewee indicates, decision-making criteria appear to move in and out of favour with management:

> "[We] use all of these. This one [EMV] is used most heavily here in exploration than anywhere else. … Yes we use all these. NPV is the one that we pay most attention to. ROR gets people excited from time to time. They just sort of disappear and come back again a couple of years later." (N1)

As stated in Section 5.2 of Chapter 5, the EMV of a decision alternative is interpreted to mean the average monetary profit per decision that would be realised if the decision-maker accepted the alternative over a series of repeated trials. The EMV decision rule then holds that provided the decision-maker consistently selects the alternative that has the highest positive EMV, then the total net gain from all decisions will be higher than the gain realised from any alternative strategy for selecting decisions under uncertainty. If decision-makers in the upstream vary the decision-making criterion they use to choose exploration prospects, then they are failing to satisfy the repeated trial condition of the EMV decision rule. This occurs in some organisations because there is a misunderstanding at board level of what EMV really means as the following respondent illustrates:

> "[There is a lack] of understanding of what EMV means. People look at an EMV and think that is the value of the prospect not recognising that it is the aggregated expected value of the various outcomes. … I've got a classic one here. I showed to the board a portfolio of 9 major projects. All of which had their own risk and uncertainty and they're highly related in that one or two of them controlled whether or not others of them would go ahead. So if one of them didn't go ahead, for instance, there was a little satellite that wouldn't go ahead too. So you put it all together in a decision tree, you roll it all up and you calculate an EMV and associated with that EMV there are other things like expected CAPEX. And they looked at it and said "mmm not very good is it. It means our company is only worth £50 million." And you say, "Nah, you're wrong. What we are saying is if you did them all, you could expect at the end of the day some failures and some good ones and that's your value. If you get clever and do the good ones first, you may already find that you've got £100 million in your pocket and the clever thing to do is then to stop gambling and go somewhere else … Right?" And again I was always taught positive EMV no matter the magnitude it's good news? But they were looking at the magnitude as being an indicator of success." (D)

In other organisations, as the following interviewee explains, it is not misunderstanding of EMV but the lack of multiple prospects that makes the EMV decision rule impossible to adhere to:

> "I mean for prospect analysis I think it is pretty standard to use an EMV approach which is essentially … the weakness in the EMV approach, any decision tree approach, is that the value that comes out maybe actually a value that will never actually occur in practice. And if you take a very simple approach to prospect analysis which I think a lot of companies do. This two outcome model either a dry hole or a success of a certain size. Then what you say is either a) I am going to lose $10 million or b) I'm going to make $100 million. The EMV will come out at let's say $20 million or $6 million. But that's not going to occur. You are either going to lose 10 or make 100. So how can that represent that decision? Of course if you talk to people like Newendorp who published on this years ago, he would say of course it's a nonsense you can't use it for that. You can use it as a comparative tool. If you've got a lot of prospects, you've got a statistical database and over time it will come out. You'll achieve EMV. Then I come back to this problem … what if I only have one prospect, I don't have a statistical sample here that I can play with, how can I value it? Well I can't think of another way of doing it. So it is a way of doing it but I have never been entirely happy with it." (Q)

Perhaps these observations help to explain why in this study, like Schuyler's (1997) earlier work, so many of the respondents reported difficulty in knowing whether a project would be approved or not. Many of the professionals interviewed admit to being confused about their company's decision policy. Most are unsure about how their company policy might make trade-offs among different decision criteria:

> "I don't know which ones are used for which decisions." (F)

Indeed one respondent commented:

> "[The approach] changes annually, monthly, daily and also vertically, often with a change in chief executive." (R2)

The misunderstandings of decision-makers and the process by which they actually make investment decisions are issues that will be discussed further in section 6.3. The focus in this section is on those decision analysis techniques that companies choose to use for investment appraisal. In this regard, the level of awareness and usage of Monte Carlo by upstream organisations will now be discussed.

- Risk analysis using Monte Carlo simulation

Awareness of Monte Carlo simulation in the upstream is high. All but one of the respondents recognised the technique and it is widely used to generate estimates of prospect reserves. From the resulting probability distribution of recoverable reserves, organisations typically select only one reserve case, usually the p50 or mean value, to run their economic models on. This means that companies are ignoring the economic impact of the high and low reserve cases. Very few of the organisations use Monte Carlo at the prospect economics level. The reason companies choose not to employ Monte Carlo to generate economic estimates is well described by this respondent:

> "No … we don't Monte Carlo our economics. And I had a discussion just the other day about whether we should be using Monte Carlo on our economics. But in the amount of work involved in getting the input data for the economics … you know to get all the costings, and this sort of thing. It's hard enough to get the data together to do an economic run based on the most likely or the mean reserves estimate. That to get enough data and the right data to do it probabilistically - we just couldn't do it. The system would break down. You

> know we are over worked as it is. [We] should be [using probabilistic economics].
>
> I suspect that no one's doing it for the same reason as we're not, because of the amount of work involved is so much greater than the amount of work involved in just, you know, just single figure input economics. Just getting all the sources together. You know we're always up against a time pressure. It always has to be now." (J)

Confirming earlier indications by Schuyler (1997), none of the sampled companies routinely use Monte Carlo decision-making at the production phase of field development (figure 5.1 and Section 5.2 of Chapter 5). All the organisations resort to deterministic analysis for production decisions. Nangea and Hunt (1997) argue that companies are justified in discontinuing probabilistic analysis during production decision-making since there is little uncertainty associated with the reservoir parameters or the size of the field at this stage. However, as indicated in Section 5.7 of Chapter 5, there are cases where the relative uncertainty has actually increased with field life. Moreover, whilst typically the absolute uncertainty decreases with field life, the relative uncertainty associated with, for example, well-intervention decisions, is significant.

As indicated in Section 5.4 of Chapter 5, there are a number of theoretical limitations of Monte Carlo simulation; the most significant of which are the lack of prescription in the literature concerning the shape of probability distribution to be used to represent the reservoir parameters of reservoir rocks of similar lithology and water depth and the dependency to be used to represent the relationships between the reservoir parameters. Most of the organisations interviewed cope with this gap by leaving the type of distribution and nature of the dependencies used to the discretion of the geologist. Geologists report that they decide the distribution shape and dependencies based on a blend of intuition (Baumard, 1999 p67), tacit knowledge (Polyani, 1966) and judgement.

Respondents are divided on whether varying the shapes of these distributions affects the output and, correspondingly, whether there is potential for the non-discerning to manipulate the results. For example according to some respondents:

> "…There are a few unscrupulous people that cheat like crazy. The big one that is abused beyond belief is dependencies. And the programs are, I don't know, lacking in robustness. The one that we've got, you know, is a classic one, porosity versus water saturation. There's normally if you plot the data a correlation, but when does a correlation actually suggest a dependency of less than one and is it 0.5,0.6,0.7? I've actually, way back in my youth, when I was mucking about with all this, actually shown, that without violating anything, you could quite easily alter the [recoverable reserves] by 20%. This is fundamental to the crooked. Everyone here is in the business of procuring funds for their projects. It's not a question of is it right or wrong. It's because I've done this work and it suggests to me that this is a jolly good project. Now the man across the corridor is competing for the same funds so it is a competition. And may the best man win and nobody sets out to cheat but …" (C)

and,

> "…people with a better understanding of statistics were able to "scoogle" and skew the outcome by putting in a particular distribution shape so you don't actually change the numbers you just change the distribution and that can change the output." (D)

Whereas others argue:

> "…the shapes of the distributions is relatively insensitive thing." (N),

> "…the type of distribution you use is not that important" (R1)

and,

> "…it seems to be quite robust to any type of distribution that you put in" (R4)

In an attempt to remove discretion from the analyst and impose more rigour on the process, some organisations do prescribe which distribution shape is used for each reservoir parameters in a Monte Carlo simulation:

> "We have recommendation that we use beta distributions. And that's for consistency because we tried calculating the reserves of a prospect using the same input data with different distributions and we got quite a range of numbers out. So for consistency use beta and that's it." (J)

Newendorp (1996 p387) warns of the dangers of using distributions in this way. Other respondents also warned against such this practice, arguing that it "forced" the data. These interviewees believed that distribution shapes should left to the discretion of the analyst so they can be "data-led":

> "Some companies will deliberately impose a lognormal distribution on everything they do. [This is] based on the belief that all of these ranges are lognormal. I strongly disagree with that. I think it's … invalid and incorrect to do that and [that] you should be guided by the data." (G)

However, questions have been raised over which data companies should be led by (Simpson *et al.*, 1999). Snow *et al* (1996) argue that statistical analysis of parameters from nearby wells is a valid method of determining the shape of input distribution to be used in a Monte Carlo analysis. However, petroleum reservoirs are heterogeneous, and reservoir parameters vary from sample to sample. Therefore, Simpson *et al.* (1999) argue, reservoir modelling requires field-wide weighted average values, derived from detailed mapping of parameters, should be used to derive these probability distributions.

All respondents agreed that the lack of prescription in the literature contributes to the overall dissatisfaction with the process and to companies' reluctance to endorse Monte Carlo simulation:

> "…that is actually one of the reasons why some people are uncomfortable with Monte Carlo simulation because they are not convinced that dependencies are properly handled. They are suspicious of a mathematical black box. And there's a relationship between porosity and water saturation for example, they are not convinced that that it is recognised. Even if you put in a porosity distribution and a porosity water function they are still uncomfortable." (P)

There was broad agreement that a study indicating the shape of distributions and the nature of the dependencies that should be used for different reservoir parameters, in different geological formations at various depths, is long overdue:

> "I wish someone would come up with a British standard for these things – it would make life a lot easier." (N1)

and,

> "[The] ideal scenario is that there would be an industry standard" (R4)

All of the companies use some software to assist with the Monte Carlo simulation. The most popular packages are Crystal Ball™, @risk™ and PEEP™. There was a general recognition that whilst the mechanics of the simulation is straightforward:

> "…the clever bit is in the process that goes on before you press the button and the numbers are churning round in [the] Monte Carlo [simulation]. The clever bit is in the model that you set up where you've got the risk … and you've got the relationship…. That's the clever bit. So you can have a fantastic tool that does Monte Carlo inside and out but [it's]garbage in-garbage out." (N2)

The respondent from company D also stressed:

> "…like a lot of black boxes you've got to be careful that you understand the input." (D)

In Chapter 5, three other techniques were highlighted as being useful to the oil industry. Preference theory has been applied to oil industry investment decisions in the literature since the 1960s. However, software has only recently become available to assist with the generation of individuals' preference curves. Option and portfolio theories are tools from the finance industry that have only recently been adapted to petroleum investment decisions. Consequently, at the time of the previous studies into the use of decision analysis techniques by the industry (for example, Schuyler (1997) and Fletcher and Dromgoole (1996)), these tools were not widely perceived to be particularly applicable to the oil industry. Hence, the findings from this research concerning the levels of awareness and usage of these tools in the upstream are particularly interesting.

- Portfolio theory

Awareness of portfolio theory in the upstream is low and its usage is even lower. Only three of the organisations interviewed fully endorse the use of portfolio theory. However, most companies had an intuitive grasp on its fundamental principles. This is well illustrated by this quote where the interviewee unwittingly describes the difference between diversifiable and non-diversifiable risk:

> "Portfolio Theory … Do we do that? Not as such. To a certain extent. I mean one of the things at the moment is with the oil price being so low and gas prices perhaps still holding up there's a shift from oil to gas in the portfolio. So on that level yes. Do we look at individual projects and say, "umm that's risky, better have a safe one?" No. I would say not. You can get rid of some of the risks but ones like oil price, exchange rate much less likely to be able to mitigate those." (N2)

As such, some respondents reported that while prospects are not analysed according to the rigors of portfolio theory, before drilling a prospect, it is “screened” to see if it fits with various organisational criteria. For example, some companies will only operate in areas where there is low political risk whereas others prefer only to explore where they know they will be the only operators. The following two quotes are indicative of current practice:

> “The starting point, if you like, is that we have identified and review periodically, so-called core areas in particular core countries. There are certain areas of the world, for the sake of argument, South East Asia which we have elected to not invest ourselves in because we are fully occupied elsewhere and we think get better returns elsewhere. If we want to enter a new country one of our responsibilities in [the] commercial [department] is to maintain what we call country evaluations. So within our areas of interest, we keep more or less current evaluations of countries from the point of view of political, economic stability, working environment etc. So the first point of call if the explorationist want to go for the sake of argument Ethiopia, then we would need to consider the overall climate in the country and the technical prospectivity and combining those two we then put a broad brush proposal to our Chief Executive. And this is going into a new country because he has to sign off on any venture of that sort.” (P),

and,

> “We at this moment, I can only speak for what we are doing here in the U.K., there has been a sort of strategic decision made beforehand about where we should operate and how we should operate and so within that framework is where we are now currently working. That’s mainly in the southern gas base. So that is where we stand. So yes. There are strategic decisions and we sort of try to test the waters every now and then to see what head office feels about us going into certain directions.” (G)

In the literature, some authors (Simpson *et al.*, 2000) argue that portfolio theory is particularly applicable to small companies. However, in this study those smaller companies that were aware of the technique had rejected its implementation because they believed they had insufficient properties to constitute a “portfolio”:

> “We tend not to be spoilt for choice for investment opportunities. …We don’t tend to need to rank development opportunities either in terms of risk or reward because we have pretty much only got one or two going at any one time. ...Portfolio theory would certainly be more valuable in a bigger company than ours.” (N1)

- Option theory

Very few of the respondents were aware of real option theory, and in all cases of awareness, the interest had not translated into use. The companies reported finding the technique very complicated and the theory difficult to grasp. This comment from one respondent was typical:

> "Option theory we've been getting, not me personally, but people have been getting excited about option theory but I think it's run a bit out of puff a little bit here at the moment. There are some particular advocates here but nobody has been able to demonstrate it at least here, that on the ground and in practice, it is very helpful. Whether that's right or not, I don't know" (N1)

- Preference theory

Only four of the respondents were aware of preference theory and none of them reported using the technique as part of their investment appraisal decision-making process. The majority was of the opinion that it would be:

> "…difficult to convince the hard-nosed asset manager that they should use such a process." (N1)

Usually their level of knowledge of the technique was based on attending a workshop or seminar by consultants where the technique had been reviewed.

The reason that option and preference theories and, to a lesser extent, portfolio theory, are so rarely used by organisations is explained by one of the representatives of company N:

> "…There's a lot of interesting things at the conceptual level but when it comes down to standing in front of the directors and trying to help them make a better decision regarding an issue, there's a subset I think of these tools that are useful in doing that. …Monte Carlo and decision trees are about as far as it goes here." (N1)

The observations in this section have indicated which techniques are being used by organisations in their investment appraisal decision-making. For exploration decisions, most companies use Monte Carlo simulation to generate estimates of prospect reserves. They then run their economic models on only one reserve case. Typically, Monte Carlo simulation is not used for economic analysis. In production decision-making, the majority of companies only use deterministic analysis. Option, portfolio and preference theories are hardly used at all by any firm. Comparing this approach with the 9-step approach outlined in figure 5.12 (Section 5.7 of Chapter 5), this study has clearly confirmed suggestions from the earlier empirical research, and established, unequivocally, that there is a gap between current theory and current practice in the quantitative techniques used in investment appraisal in the upstream oil and gas industry.

The following section builds on the discussion above. It draws on the interview data and the behavioural decision theory literature (summarised in Section 2.4 of Chapter 2) to gain insights into how organisations use their decision analysis tools and how the decision-makers use the results from the analysis to make decisions. From this, it is possible to suggest why there is a gap between current practice and capability in investment appraisal in the upstream. A model of current practice in investment appraisal in the upstream oil and gas industry can also be developed. This model is presented in section 6.4.

6.3 THE INVESTMENT APPRAISAL DECISION-MAKING PROCESS

Confirming Schuyler's 1997 study, the findings from the research presented in this thesis indicate that decision analysis techniques are being introduced slowly into upstream organisations. Despite the application of decision analysis techniques to the oil industry in the literature in the 1960s (Grayson, 1960), the majority of upstream representatives report that their organisations only began using them within the last five years. Respondents typically explained this trend in two ways. Firstly, several claimed that previously the computing power was insufficient to allow the use of decision analysis techniques to be automated and hence their company had decided against their implementation. Secondly, others perceived that the increasing risk and uncertainty in the operating environment, as discussed in Chapter 3, had contributed to their organisation's recent interest in decision analysis. Most companies first use decision analysis tools on particular fields before recommending employing them company-wide on all prospects and fields. This is confirmed by the tendency for organisations to publish in industry journals, such as the *Journal of Petroleum Technology*, accounts of using decision analysis techniques on specific cases (for example, Spencer and Morgan, 1998). The majority of the sampled companies have a cost threshold that they use to indicate those decisions to which decision analysis techniques ought to be applied. Reflecting their different attitudes to risk, in the smaller companies this value is lower than in the larger organisations. Therefore, decision analysis is used on a higher percentage of the decisions in small organisations than in larger companies.

Most companies have not altered which decision analysis techniques they use or how they use them, since they first introduced the techniques. In some cases, corporate adoption of the tools was accompanied by the production of manuals, which outlined their new approach to investment appraisal, the introduction of corporate definitions of risk and uncertainty and the instigation of training programs for staff. Such organisations are reluctant to change their approach and be forced to repeat this process. This means that in some companies, even though they are aware their approach is not as sophisticated as it might be, they continue to use it:

> "Yes. I'm recommending changes to it. ...I've got an alternate system that we could go to. …The problem is that the company only went to this process, from having nothing really at all, several years ago, so they are loath to change it again. And that's the problem. We are locked into a system that's inadequate and they're loath to change it to anything else. And that's crazy." (B)

In other companies, the reasons for the failure to update the techniques they use or to modify how they use decision analysis, are endemic within the organisation. This section aims first to identify these reasons and, second, to understand their sources. This will allow the author to explain why there is a gap between decision analysis theory and its use in practice.

In Section 2.2 of Chapter 2 decision analysis was defined to be a normative discipline within decision theory consisting of various techniques and concepts that provide a comprehensive way to evaluate and compare the degree of risk and uncertainty associated with investment choices. In addition, in this section of Chapter 2 literature was highlighted that indicated that the definition of risk and uncertainty that the decision-maker adopts affects the method that they use to cope with the risk and uncertainty (Lipshitz and Strauss, 1997; Butler, 1991; Grandori, 1984; Thompson, 1967). In some of the upstream companies interviewed, the organisation had no corporate definition of risk and uncertainty. For example:

> "I don't know what you've found in other companies, but I would say that there's about as many different definitions of risk and uncertainty in our company, as you found in your literature search." (G);

> "Yes every time we start to discuss risk we have arguments and rows." (D);

> "Different people have their own definitions and their own way they would like to look at it. So if I go in speak to someone about their definitions of risk it depends on what asset team they are in. Trying to get consistency of approach is difficult. Even if you speak to people with the same job title within the asset they've got different definitions." (N2);

and,

> "But I do say that when you talk about risk, I think there's quarters here where you would hear folk say it's fundamental to do a risk assessment. But normally it's a risk assessment of health, safety and environmental. Are we going to kill anybody? Are we going to damage the ecosystem? Are we going to pollute the environment? Different types of risk. Again it's a misconception. When I saw the risk analysis manual here, I was in seventh heaven, but it was upsetting the breeding patterns of fish or something ... Within any company, within any department, within any team, there's different definitions." (C)

In most of these companies, only very basic decision analysis techniques were used (company N is the exception. In this company, the respondents described how it is widely recognised that there are multiple definitions of risk and uncertainty within their organisation. When employees communicate about risk and uncertainty they are explicit about their definitions and perceptions of the terms). In other companies where explicit corporate definitions of risk and uncertainty have been introduced, the organisation typically used more decision analysis techniques and had a more formalised investment appraisal process. Clearly then, organisations use of decision analysis is affected by the corporate perception of risk and uncertainty which, in turn, is a product of the decision-makers' beliefs. The sources of decision-maker's beliefs will now be examined.

As indicated above, decision analysis has only been introduced into most organisations within the last five years and, consequently, most of the current chief executive officers (CEOs) of organisations have often not been introduced to its concepts throughout their careers. This point is well articulated by one respondent:

> "…I think there is a definite age imprint on decision-making. Today's CEOs tend to be in their fifties now, and grew up corporately in the 1960s when slide rules and log tables were the norm. The young guns are much more comfortable using [decision analysis] but corporately have to still climb to the highest level." (S3)

This situation is exacerbated since even when companies choose to use decision analysis techniques and believe that their introduction requires staff training, the training is often only given to technical staff:

> "We run an uncertainty workshop which is part of the compulsory training programme for new, mainly subsurface, staff and that's a four day long workshop where we look at some of the statistics and theory and we go through a whole series of worked examples. But it's now being pushed at all of the "challenge graduates", all the people joining the company, it is part of their core skills. For the people who have joined the company within the last three years it's fine because they are going through that. It's more of a problem for the people who have been in the company say five or ten years. That's difficult." (R1)

This lack of knowledge significantly affects top management's ability to understand the philosophy of decision analysis. For instance, there is a tendency for management to prefer to communicate deterministically:

> "The reliance on one number is hard to get away from. It tends to go all the way up. Even [at] the highest level, even the managing director level, they like to know, "Well, what's the number?" Even at board level, they don't tend to deal with numbers for the ranges." (R1).

This preference for deterministic analysis then permeates the entire organisation:

> "I still get the reaction if you ask people … If you go to a cost engineer, the die hard cost engineer, that has been in the shipyard all his life, and you go to him and say, "What I'm after is how bad it could be and how good it could be." The usual story. "What do you mean how good it could be? This is what I'm telling you it's going to be." You know it's going to be £50 million and the sheer concept that it could be anything different from that number he's given you is completely alien and at that end what they'll say is, "You want a

> range on that? Well, it's plus or minus ten per cent," which is completely pointless. So, [it is] still a problem." (N1);

> "Engineers like to deal with units and this is the number." (R2);

> "The biggest problem we've got is that fact that we are deterministic. We've always got to have some case to build action." (D);

and,

> "I'm sure this must be a consistent observation. We do all this beautiful simulation of the distributions but people still want one figure. You could say to them, "The range is this, or your expectation is this at various probability levels, you've got say 40% chance of finding this and then you know 30% chance of finding this larger figure and so on." You know a nice little cumulative distribution. People don't look at it. They want one number, "What's the mean? What's the expected value?" So sometimes I question why we do it because people just land on one number." (H).

Furthermore, several interviewees reported that their managers do not see any value in using decision analysis. These respondents believed that this situation is exacerbated because there is no empirical study indicating that using decision analysis techniques adds value to organisations. Some of the respondents also reported that the decision–makers in their organisation do not understand the concept of decision analysis and indeed perceive it to be a threat. This is well described by the contributors from companies S and C:

> "Decision trees or EMVs, when viewed as traditional end of project recommendations, show what decision should be made. There is no discretion required. Here you have a process that is providing the answer to the problem; what is the role of the high level decision-maker; all can see what the answer is – this is a very real threat to the decision-maker." (S3);

and,

> "People think [here] that by using [a] probabilistic approach you are actually throwing out the essence of the business" (C)

The manager interviewed at company N confirmed these observations:

> "Blind faith is a better technique [than any decision analysis techniques] because then you are the boss." (N2)

Such perceptions of decision analysis are closely aligned to the rational model (Harrison, 1995), operational research (French, 1989) and to the first definitions of decision analysis proposed in the 1950s and 60s (Raiffa, 1968). These managers believe that decision analysis is a purely normative tool, which removes discretion by dictating choice. Such definitions do not emphasise the distinctive features of decision analysis that distinguish it from the rational model. These misconceptions affect the way decision analysis is used by organisations in two ways. Each will be discussed below.

- The misconceptions cause divisions and communication difficulties in organisations between those that understand the capabilities of decision analysis and those that do not. Often this is between those producing the analysis and the decision-makers. This situation is exacerbated and perpetuated since often in companies the decision-makers are not involved in the process of generating the analysis. They are often only presented with summary decision criteria. This has three implications. Firstly, it means that managers are not educated sufficiently in decision analysis to question the analysis. This could result in them accepting a flawed project and which will subsequently fuel their distrust of decision analysis. Secondly and more likely, it means that the decision-makers ignore, or reduce the emphasis on, the analysis which, in turn, affects the motivation of employees to compile the analysis and means that managers do not become educated in decision analysis techniques. According to one respondent:

> "It's very interesting in those discussions how much importance [is given to the analysis], because he [the decision-maker] doesn't really grasp, I don't believe, what's going on here. So you know you do all that work and you go to him, and it comes back down to, "Well, what do you think?"…and he has his preferred advisors. So it comes down to sometimes what his preferred advisors think who might not wholly understand what is going on down at the probabilistic level either, or have not have been involved. So there's an awful lot of input here from the people who have the trust of the leader…The decision-makers don't get it. They go on opinion. They also go on the people who they trust the best. That is very clear here….Now we still do this [decision analysis] but it might not carry one bit of weight if people who are the opinion holders if you like - the trustees, the most trusted employees - if they don't buy it." (F)

The issue of trust is discussed in more detail below. The third effect of decision-makers lack of involvement in generating the analysis is that it means that the decision-makers' preferences, beliefs and judgements are not captured and included in the analysis which must contribute to any inherent reluctance to accept its recommendations.

Some companies have attempted to overcome these difficulties by introducing a structured process for gaining management input to the decision-making process. These companies are typically the larger organisations where employees are not personally known to the decision-maker. This practice encourages communication between analysts and decision-makers. Consequently, it improves the efficiency of the process in numerous ways, not least, by ensuring that the assumptions that the analyst has underlying the analysis are consistent with the decision-makers' opinions. This ought to result in fewer projects being rejected that reach the end of the analysis process. It should also improve managers' understanding of, and attitude toward, decision analysis.

In small companies, there are usually fewer opportunities and the levels of trust tend to be higher since employees are usually known to the decision-maker. The decision-makers are more naturally involved in the process and hence, generally, companies do not think it necessary to have formal management "buy-in" to the analysis process. This is well illustrated by one respondent:

> "…And the other thing I guess in our organisation is that we have direct access to all decision-makers. I mean we [are], in terms of people, really quite small. I mean I can call up the president and CEO. He'll call me if I'm the person who can answer a particular thing. He won't go through the president over here or the general manager of the department. He'll just give me a buzz. He knows my extension and you know it might be, "What percentage interest do we have in such and such a license?" or, "What do you think of this?" or, "Do you know anybody in such and such a company?" The lines of communication are so much easier. … I mean he's coming over here in a couple of weeks and he'll come in and sit down and he'll make it very clear to the individuals. [He'll say,] "Look this is what I want to see. I loved that project you did before but I'm sorry I had to turn it down but, really, this is what bothered me about it," or, "I'm glad we did that and keep going and bring me another one like that.".…You know we all speak the same kind of language." (A)

- There appears to be a relationship between management's attitude toward decision analysis and company culture. In companies where managers believe decision analysis is valuable, the culture is "numbers-driven". In those organisations where the decision-makers do not perceive decision analysis to be important, the decision-making culture is "opinion-driven". This will be labelled relationship one here. This relationship is directly related to three other trends that are observable in the interview data. These will be outlined here.

Compare the following:

> "We are a numbers oriented company. The boss wants to see numbers and he wants to see numbers justified." (N1);

and,

> "Joe Bloggs down the corridor likes it a lot you know gives it 6 out of 10 and we would like to do it. And that's the decision" (A).

Evidently then, there is a relationship between the use of decision analysis and the culture of the organisation. In companies where the culture is "numbers-driven", more decision analysis techniques tend to be used than in organisations with "opinion-driven" cultures. This will be referred to here as relationship two.

In "opinion-driven" companies when decision analysis techniques are used, they tend to be poorly implemented and supported. In companies that are "numbers-driven", decision analysis techniques tend to be well supported and their use encouraged. This will be referred to as relationship three.

Furthermore, there is a relationship between the formalisation (note, formalisation does not imply sophistication) of the analysis and the level of employee satisfaction with the process. Typically, in those companies where the procedure for using decision analysis techniques is well defined, respondents generally felt the analysis worked well. In others, where the process is less well defined, the analysis often has numerous gaps and, generally, levels of dissatisfaction with the approach are high. In these companies, the analysis process is often gone through only to satisfy bureaucratic procedures. This will be labelled relationship four. In larger companies, there is more of a need for formalisation for evaluating prospects firstly to allow the relative ranking of opportunities and, secondly, because, as Langley (1995 p64) noted:

> "…the more strategic power is shared among people who cannot quite trust each other, the more formal analysis may become important."

The author stresses that this observation does not imply that formal analysis should be perceived as purely political tool in such cases, but simply that it has a dual role in decision-making in large organisations:

> "When used for gathering information, [formal analysis] may help determine and improve the substance of decisions directly, as most of the literature indicates. But it can also help bind individuals' decisions together to create organisational decisions through communication, direction and control, and symbolism. The second, political role should not be automatically despised. On the contrary, when different organisation members do not necessarily have the same goals or the same information sources, analysis helps to improve decisions indirectly by ensuring that ideas are thoroughly debated and verified, and that errors in proposals are detected before implementation." (Langley, 1995 p64).

Moreover, because of their size, such organisations are also more likely to have individuals and departments using their own approaches. More management involvement promotes consistency. To this end, some companies have also introduced a peer review system. It is well described by this respondent:

> "The process we use for discussing risk is what we call peer review. This is a shared learning exercise. We will take the people who work the prospect and essentially self-audit. It's not a process where management sits in judgement because very often managers are generalists not specialists, especially in the UK. We get the people who work the prospect, and a group of their peers from within the organisation. Recently we brought people from Australia and Gulf of Mexico to consider some projects we were thinking of developing in Angola. So, we actually spent a lot of money for that peer review process. The people we brought in, we brought some technical experts for some specific technologies and we brought some geoscientists who were working a similar play in a different basin in the Gulf of Mexico – so they have a great knowledge to bring to bear on the situation and subsequent decision-making. Then we went through risking session." (K)

Companies vary significantly in the extent to which their decision-makers rely on the analysis in making their final decision. Whilst most companies *require* decision analysis to be undertaken for investments above their cost threshold, the extent to which the final decision is *influenced* by the data, appears to be contingent on the four interdependent relationships outlined above.

In companies where managers are convinced about decision analysis, the culture is "numbers-driven", the use of decision analysis is encouraged, formalised and well supported, and employees are generally satisfied with their companies' investment appraisal process. Then the decision-maker relies on the results from the analysis to make decisions. This is not to say that the decision is taken solely based on the analysis. Decision-making will always be ultimately an act of judgement. However, since the decision-maker has been involved in generating the analysis, then its results are unlikely to contradict his/her subjective judgement about the particular investment opportunity. At the very least though, the analysis informs the decision. If the analysis suggests that a project is not viable, and the decision-maker still wants to go ahead, because of some bias or feeling that he/she has not been able to articulate and include in the analysis, they are doing so well informed about the potential consequences.

In companies where managers are unconvinced about the value of decision analysis, the company is largely "opinion-driven" and the use of decision analysis is not formalised or encouraged. Decisions in these companies are perceived by the employees of the organisation to be influenced more by opinion and "feeling" than numerical analysis:

> "…And if you go through a structured decision process and you calculate an EMV and it is highly negative but your guts say this is a good thing to do…you've then got two choices … you can then go back and fiddle the numbers or you can just overrule the result and say that this is strategically good for us." (D);

and,

> "…I have seen …bidding strategy meetings held with senior management where you would come forward with all of these [decision analysis] evaluations and there the psychology in the meeting would override many times the logic that had been developed using these probabilistic numbers. Somebody likes something and suddenly the money would double. I saw that many times." (G).

The observations above have been summarised in table 6.1.

MANAGEMENT UNDERSTAND DECISION ANALYSIS	MANAGEMENT DO NOT UNDERSTAND DECISION ANALYSIS
The decision analysis approach used by the company is formalised. Often manuals are available to employees. The manuals detail how the limitations and gaps in the techniques (for example, the distribution shapes to be used in Monte Carlo simulation) are to be overcome.	The decision analysis that is conducted is likely to be lacking in definition, structure and sophistication. Employees are given no direction as to how to deal with the limitations of the analysis techniques.
Decision analysis software available throughout the Organisation.	Restricted access to decision analysis software.
Employees know the decision policy used by the company.	Employees do not know the decision policy used by the company.
Consistent definitions of risk and uncertainty.	No company definitions of risk and uncertainty. Definitions change within and between organisational functions.
All employees have the ability to understand and communicate probabilistically.	Employees prefer to communicate deterministically.
Good communication between the departments compiling the analysis.	Poor communication between the departments compiling the analysis.
Motivation to conduct analysis is high.	Motivation to conduct analysis is low.
Decision analysis perceived to be a useful tool for quantifying risk and uncertainty.	Decision analysis perceived, particularly by management, to be a threat.
Each prospect is subjected to peer review.	There is no peer review system for prospect evaluation.
Decision analysis is part of the organisation's culture.	Decision analysis is not part of the organisation's culture.
Employees trust the results of the analysis.	Employees do not trust the results of the analysis.
Every employee required to attend training in decision analysis.	There is no training in decision analysis.
Management committed to decision analysis.	Management not convinced by the value of decision analysis.
Management involved in generating the analysis.	Analysis conducted low down organisation. Management only presented with decision-making criteria.
Management likely to follow the decision alternative suggested by the analysis.	Management less likely to follow the decision alternative suggested by the analysis. They believe their judgement in superior to the analysis.

Table 6.1: *Organisations' use of decision analysis*

This table investigates the different ways decision analysis is used by organisations in the upstream. It distinguishes between use of decision analysis where managers understand decision analysis and the use of the techniques when managers do not. Of the sampled companies, none exhibit all of the attributes of either column. Most are placed somewhere on a continuum between the two extremes. The table clearly highlights that decision-makers' attitudes towards decision analysis are one of the main determinants of an organisation's use of decision analysis techniques. As such, the decision-makers' attitude toward decision analysis can be identified as one of the factors that directly causes the gap between current theory and current practice in use of decision analysis in investment appraisal decision-making by the upstream oil and gas industry. This assertion is supported by a similar observation from Kunreuther and Shoemaker (1980):

> "When decision theory analysis is viewed as a multi-stage model for rational choice among alternative options, its impact on organisational theory and managerial behaviour tends to be less than might have been hoped for or expected." (Thomas and Samson, 1986 reproduced in French, 1989 p177)

This section has provided an overview of the investment appraisal decision-making process in the upstream. In particular it has highlighted that:

- There is a relationship between the culture of the organisation and the decision-maker's perceptions of decision analysis;
- there is a relationship between the use of decision analysis and organisational culture;
- there is a relationship between the culture of the organisation and the extent to which decision analysis is encouraged;
- there is a relationship between the level of formalisation of the investment appraisal process and employees' satisfaction with the process; and
- the actual decision (the "is") generally, only deviates from that recommended by decision analysis models (the "ought"), when the analysis is poorly implemented, unsophisticated and the decision-makers are unconvinced of the value of decision analysis.

It has also suggested that at least part of the reason for the gap between practice and capability is that:

- There are theoretical gaps in some of the techniques (for example, the lack of prescription in Monte Carlo simulation of the shape of the probability distribution to be used to model the reservoir parameters of reservoir rocks of similar lithology and water depth);

- decision-makers' perceptions of decision analysis are closely aligned to the earlier definitions of decision analysis and decision-makers' perceive decision analysis to be a threat; and
- decision-makers are not convinced of the value of decision analysis.

The section has also indicated that current situation is exacerbated since there has been no study conducted that has found a link between use of decision analysis and good organisational performance.

6.4 A MODEL OF CURRENT PRACTICE

The observations expressed in the previous sections are captured here by a model of current practice in investment appraisal in the upstream oil and gas industry. The model presented has been modified and developed by abstracting from the insights into decision-making at different levels within operating companies gained from the research interviews discussed in sections 6.2 and 6.3, and is informed by the behavioural decision theory literature which was presented in Section 2.4 of Chapter 2. Variations of the model have been shown to interviewees and the version that is presented here has been acknowledged by employees in the oil and gas industry to be an accurate description of current practice in investment appraisal. The respondents from Companies C and D said of the latest version:

> "I think you're right. You've basically captured it." (C);

and,

> "I saw this diagram and I can see a lot of what I've come across in here" (D)

In this section, the current version of model will be presented. The model is two-dimensional. The axes of the model will be explained and justified using quotes from the research interviews. The interviewed companies will be plotted on the two-axes. These results can then be interpreted and this confirms many of the observations made in section 6.3. In particular it highlights the need for a study to investigate the relationship between the use of decision analysis and organisational performance.

The x-axis in the model relates to the number of decision analysis techniques used for investment appraisal decisions. The quotes from the interviews presented above clearly indicate that there is variation in the number of decision analysis tools used by companies for investment appraisal decisions. Some are aware of all the techniques identified in Chapter 5 and use, at least partially, most of them. Some use very few. This is well illustrated by the following respondents:

> "I don't think that I can say we use any of those techniques" (A);

and,

> "Decision analysis is not a common thing in this company. It's not a standard that we all have to do for each decision." (B)

The y-axis of the model presented in this section indicates the proportion of investment decisions that are made in each company using decision analysis techniques. Some organisations do not use decision analysis at all even on the most basic investment decisions to which the techniques have been applied in the literature for many years:

> "We have no structured, scientific, way of evaluating [prospects]" (A).

Others appear to use decision analysis on a limited number of decisions:

> "The drill-no drill type decision I would say we use decision analysis techniques a lot for. I think when you are talking about real strategic decisions, like do I make this acquisition, I think you are much further up the qualitative end of things" (K)

In other companies, decision analysis is much more commonly used. As the following exchange between the researcher and one of the interviewees from company N indicates:

> Interviewer: "On what kind of decisions does your organisation use decision analysis techniques?"

> Interviewee: "Well, really, just about everything we do from decisions about drilling prospects through to development decisions and decisions about production."
>
> Interviewer: "On what kind of decisions does your organisation not use decision analysis techniques?"
> Interviewee: "There's none." (N1)

It is important to realise that on the y-axis that the proportion does not indicate a strict dualism. Judgement and individual interpretation, gap filling in the absence of complete information, and assumptions are required even when many tools are used:

> "You dip into that side and you come back and do some more numbers and then you dip back into that side and I think that is the way it has to go because you cannot prove mathematically that there are 15 million barrels in the ground in a discovery. You have to interpret the information you have got. And that interpretation eventually comes down to a judgement of somebody which is fair and square on this side…Because you keep asking questions and ultimately you get down to what somebody's view is – somebody's interpretation of a reservoir model or whatever, to which you can say no more than that is my interpretation, that is my feeling, my view of what the thing looks like." (N1);

and,

> "We like to think the thing is structured. We like to think there's an ordered trail of how we got to the decision. And we like to think, or some people like to think, they are completely quantifiable. But I think it is hard to get something that is absolutely hard quantifiable, because we are dealing with a subjective process. Because we are don't know all the answers – we don't even have all the questions." (D)

Moreover, in all companies:

> "Ultimately decisions are taken on judgement." (N2)

The two axes are measured along ordinal scales.

Plotting the interviewed companies on these two axes, using the information obtained in the semi-structured research interviews, then produces the model shown in figure 6.1. The pattern obtained in figure 6.1 confirms the observations made in section 6.3. Firstly, it clearly supports the perception that organisations begin to use decision analysis techniques on routine, operational decisions before introducing the techniques corporation-wide. Secondly, it provides complementary evidence that as companies introduce more techniques, they tend to use the techniques on more decisions, some of which can be regarded as strategic. This implies that in companies that use many decision analysis techniques, the decision-makers are, if not actually using the techniques themselves, at least involved in the generation of the analysis and in the interpretation of its results. This confirms the identification of managerial attitude to decision analysis as a key factor in determining the use of decision analysis techniques. Thirdly, in the model there are clearly three groups of companies (each groups is a different colour in the figure). This appears to confirm that organisations are choosing not to modify which techniques they use or how they use them, preferring instead to stay within their group. Possible reasons for this were identified in section 6.3. These include the decision-maker's perception of decision analysis, which is coloured by the lack of any empirical evidence that indicates that using decision analysis is positively associated with organisational performance.

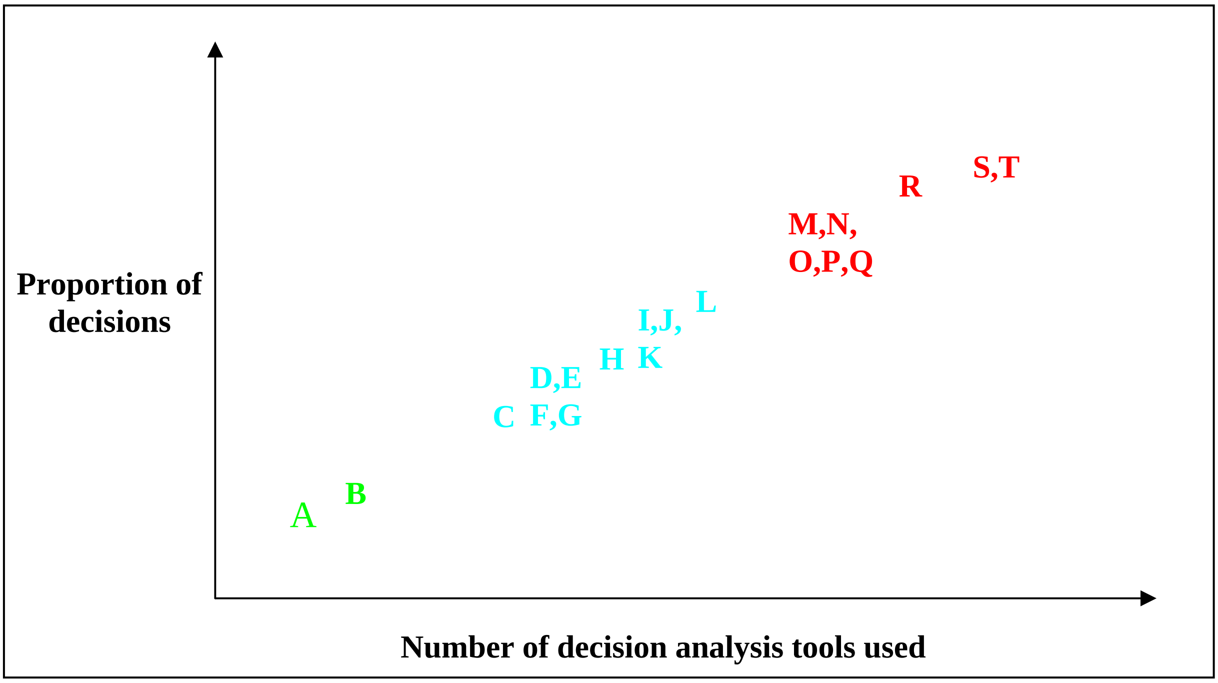

Figure 6.1: *A model of current practice*

6.5 Conclusion

By drawing on the interview data and the insights gained from the behavioural decision theory literature, the discussion in this chapter has established which techniques upstream companies use for investment appraisal. This has indicated that the gap identified by earlier research between theory and practice in decision analysis still exists. This indication of current practice will be used in Chapter 7 to produce a ranking of the companies according to the sophistication of the decision analysis tools they use for investment decision-making. In the current chapter a model of investment appraisal in the upstream was produced. Using this model reasons for the existence of the gap between practice and capability were proposed. In particular, it was suggested that managers are unconvinced about the value of decision analysis since there is no evidence that use of the techniques leads to more successful investment decision-making. Consequently, organisations do not adequately resource the introduction and use of the methods and managers regard the results as spurious and pay limited attention to them in their investment appraisal decision-making. Therefore, the following chapter, focuses on the third research question by using the indication of current practice produced here to investigate the relationship between the use of decision analysis techniques in investment appraisal decision-making and organisational performance in the upstream oil and gas industry.

Chapter 7

The relationship between the use of decision analysis in investment appraisal decision-making and business success: a non-parametric analysis

7.1 INTRODUCTION

This chapter will focus on answering the third research question by exploring the relationship between the use of decision analysis in investment appraisal decision-making and business success in the upstream. Organisational performance is complex, multi-dimensional and fundamental to strategic management theory and practice (Venkatraman and Ramanujam, 1986). Most researchers consider performance the ultimate test of new concepts and theories (Keats, 1988; Schendel and Hofer, 1979). It is contended in this chapter that the use decision analysis techniques and concepts in investment appraisal decision-making is a source of competitive advantage among operating companies active in the upstream oil and gas industry in the UKCS. This hypothesis is investigated in this chapter using non-parametric statistical tests.

The chapter begins by establishing the type of study that will be carried out. It then draws on the discussions of Chapters 5 and 6, to construct a ranking scheme. Chapter 5 used the decision theory and industry literatures to present the range of decision analysis techniques and concepts available to upstream companies for investment appraisal and in Chapter 6, it was established which of these tools and ideas companies choose to use in investment decision-making and why. In this chapter, using Chapter 6 as the main data source, each of the upstream companies interviewed, are ranked according to their knowledge and use of each of the techniques presented in Chapter 5. Measures are then selected that are indicative of upstream organisational performance and companies are ranked again this time according to the performance criteria. Hypotheses are proposed for statistical testing. Once the statistical tests have been conducted, the results are analysed and discussed. The theoretical contribution of the research to the debate between behavioural decision theorists and decision analysts, the implications for practitioners especially to managerial perceptions of decision analysis, the limitations of the current study and areas for future research will be discussed in Chapter 8.

7.2 THE TYPE OF STUDY

Most statistical techniques can be applied in different situations that vary in the degree of experimental control the researcher has and in the type of conclusion that can be drawn (Leach, 1979 p20). The distinction, however, is at the level of designing and carrying out the experiment, and not at the level of data analysis (Leach, 1979 p21). Hence, this chapter begins by looking at the two most common types of study and explores which is the most appropriate to use to investigate the relationship between the use of decision analysis tools and concepts and organisational performance.

In the first situation, the researcher takes a random sample of companies who use decision analysis and a second sample that do not. The performance of each is then monitored, and the researcher notes whether those organisations that use decision analysis score more highly than those companies that do not. In this situation, the use of decision analysis techniques and concepts is an attribute of each company taking part in the study; it is inseparably attached to each of the companies. With such a study, it is not possible to establish a causal relation between the use of decision analysis tools and concepts and organisational performance but only that there is an association between them. Thus, if a difference is found between the two samples, the researcher is not entitled to say that using decision analysis techniques and principles makes organisations perform better. It is quite possible in such a study that the association could be caused by other traits or environmental factors that predispose an organisation that uses many decision analysis techniques and concepts to perform better. In fact, it is not even possible in such a study to rule out the possibility of good organisational performance causing organisations to use more decision analysis tools and concepts. Such studies are known as correlational studies.

In the second situation, the researcher controls the number of decision analysis techniques and concepts used by organisations. The degree of usage of decision analysis tools and ideas is a treatment rather than an attribute. The researcher takes a random sample from the population of interest and randomly assigns each company to one of two groups. The members of one group are given sophisticated and numerous decision analysis techniques and concepts to use, and the others given relatively unsophisticated and few decision analysis tools and ideas. After a certain amount of time using their tools and concepts, the organisations' performance is noted. Then, even if there were, for example, certain traits that cause companies to utilise many and sophisticated decision analysis techniques and to perform well, these would balance out by the random assignment of the companies to the two treatments. In this case, if the users of sophisticated and numerous decision analysis techniques and principles performed well, then this would indicate the use of decision analysis as the cause. Thus, in the second situation, the researcher would be entitled to draw causal conclusions, while in the first they would not. This type of study is known as an experimental study (Leach, 1979, pp19-20).

In this case, an experimental study is impossible. This would involve finding a group of companies in the upstream who would be willing to be assigned at random to either using decision analysis techniques or concepts or not, on a long-term basis. Given the intensity of the competition between the organisations that operate in the oil industry, one group of companies (and their shareholders) are not likely to accept that the other group may experience better organisational performance for any length of time! Given this, the current research will be correlational and will aim to establish if there is an association between organisational performance and use of decision analysis techniques and concepts. Following Leach (1979 p19), the use of decision analysis tools and concepts will be labelled the explanatory variable and organisational performance the response variable. Leach (1979 p20) argues that provided the researcher acknowledges that when an explanatory variable is handled as an attribute, the researcher cannot conclude that any variation in the explanatory variable "explains" variation in the response variable, it is permissible for the label to be used in correlational studies.

In the following two sections, data will be compiled and presented that indicates first, organisations' use of decision analysis tools and concepts and second, business performance. In section 7.4, the statistical discussion will resume and the statistical tests will be chosen based on the types of data that have been gathered.

7.3 RANKING COMPANIES BY USE OF DECISION ANALYSIS TOOLS AND CONCEPTS

In Chapter 5 the range of decision analysis techniques and concepts that are available to upstream companies for investment appraisal were presented. Chapter 6 indicated which of these tools and ideas companies choose to use and why. In this section, the two preceding chapters are used as input to construct a ranking scheme which grades companies according to their use of decision analysis techniques and concepts, with the higher-ranking positions being given to those companies that use a larger number of decision analysis techniques and ideas. This ranking together with the performance measures ranking compiled in the following section, will be statistically analysed in section 7.5.

The techniques and concepts presented in Chapter 5 comprise the toolkit currently available to the upstream decision-maker. They vary in complexity from basic DCF techniques to the more obscure option and preference theories. Some of the ideas have been applied to the industry in the literature for many years, others only relatively recently. Whilst for most of the tools there is software available making it possible to automate their use, for a few there is no software package manufactured, making manual manipulation the only option. Such factors have affected the implementation of the techniques in companies. However, Chapter 6 provided evidence of other influences, which are perhaps stronger, which have also affected organisations' uptake and use of decision analysis techniques. In particular, in each company, the top management's attitude towards decision analysis and the corporate culture appear to affect the extent to which decision analysis techniques are used. Chapter 6 confirmed the findings of earlier studies by Schuyler (1997) and Fletcher and Dromgoole (1996) by providing evidence that there is a gap between practice and capability in the extent to which the upstream industry use decision analysis techniques and concepts. However, it also indicated that individual companies vary in the extent to which they contribute to this gap. Whilst some companies might have no knowledge of a particular tool or concept, in others its use may well be commonplace, and the technique or idea may be regarded as a main component of the organisation's investment appraisal process. Following these observations, it is possible to rank companies according to the extent of their usage of decision analysis tools and philosophies. In the ranking, companies that use many decision analysis tools and ideas will score more highly than those organisations that choose not to use decision analysis.

The decision analysis techniques and concepts are listed below. For ease of presentation the tools and ideas are described roughly according to their level of complexity (and, hence, ease of implementation), sophistication of output and extent to which their usefulness to the industry is acknowledged in the literature. For each technique and concept, an indication is given of how the companies will be graded and ranked on this criterion. Where necessary a brief outline of the tool or idea is also provided. Techniques/concepts 8-13 used the same scoring system for ranking companies. This is explained in the discussion of tool 13.

1 **Quantitative analysis.** This is used here to refer to the calculation by analysts of decision-making criteria such as payback, rate of return (Buckley, 2000) or discounted profit to investment ratio (Higson, 1995). The calculation of these criteria are recognised by many analysts to be the most basic type of investment appraisal companies can undertake since the measures are simple to calculate, include no explicit recognition of the existence of risk and uncertainty and hence, their output is primitive (for example, Newendorp, 1996). Two points will be assigned to companies that calculate these criteria routinely in their investment appraisal process. One point will be given for partial implementation, and zero for non-usage.

2 **Holistic view**. Chapter 5 indicated that for companies to make 'proper' decisions it is essential that they adopt a holistic view of the total cumulative net effect of the consequences of the decision currently under consideration. For example, for any upstream investment decision, there must be an estimate of the timing and cost of the abandonment of the facilities and the cost and timing implications of any environmental protection measures that may need to be taken. For a full discussion refer to Ball and Savage (1999). The need for upstream organisations to adopt a holistic perspective is well documented (Simpson *et al.*, 2000; Newendorp, 1996) and simple to achieve. Those companies that adopt a holistic view of the total cumulative net effect of the consequences of the decision being

taken will be assigned two points. The companies that recognise the necessity to do so but mostly do not will be given one point. No points will be given to companies that do not recognise the need to take a holistic perspective.

3 **Discounted cash flow techniques**. As discussed in Chapter 5, the timing characteristics of upstream projects are such that there is an historical average, in the North Sea, of about seven years between initial exploration expenditure and commitment to develop, with another three or four years to first production and then twenty years of production revenues before abandonment expenditure. Recognition of this, and of the time value of money, means that DCF techniques (see, for example, Brealey and Myers, 1996) must be used by upstream companies. DCF is relatively easy to conduct, its usefulness to the upstream well documented and the output it produces simplistic. Two points will be assigned where companies use DCF techniques routinely in their investment appraisal process and have appropriate training for employees in how to use the tool. One point will be given for partial implementation, and zero for non-usage.

4 **Risk and uncertainty**. In Section 2.2 of Chapter 2 the literature review indicated that there are numerous definitions of risk and uncertainty presented in the literature and that the conceptualisation that decision-makers adopt affects the method of coping that they (and their organisation) adopts. Clearly, then companies ought to have corporate definitions or, at least, a tacit organisational understanding of the terms risk and uncertainty, which are complementary to their approach to investment appraisal. Risk and uncertainty have received much attention in the industry literature and numerous definitions proposed for organisations to select from. The definitions ought to be easily applied via training or workshops.

Companies will be assigned two points if they have organisation-wide definitions or understandings, of the terms that fit with their approach to investment appraisal. One point will be given if they have any definitions or tacit understanding at all and no points will be allocated if the company has no definition or understanding of the concepts of risk and uncertainty.

5 **Monte Carlo for prospect reserves.** Chapter 5 provided a discussion of the benefits of using risk analysis via Monte Carlo simulation to generate a probabilistic estimate of recoverable reserves. Simulation has been applied to reserve evaluation in the literature for many years and software now exists to make this process relatively simple. The output produced by the simulation is a probability distribution of the recoverable reserves. Organisations that adopt this approach for prediction of recoverable reserves are explicitly recognising the existence of risk and uncertainty in these estimates. Companies will be given two points if they routinely use Monte Carlo simulation to generate estimates of prospect reserves. One point will be assigned to those organisations that occasionally used the technique and no points will be allocated for non-usage.

6 **p10, p50 and p90 reserve cases for economic modelling.** Three reserve cases should be used as input into their economic modelling since they are representative of the best, worst and most likely outcomes.

Those companies that use the three reserve cases specified above will be assigned two points. Where organisations occasionally use the three cases but usually only use one reserves case for economic modelling, the company will be given one point. When the economic models are purely constructed on one reserves case, these companies will be given no points.

7 **EMV via decision tree analysis.** The value of calculating an EMV through a decision tree is widely acknowledged in both the industry and decision theory literatures. Two points will be assigned to companies that use decision tree analysis to calculate an EMV routinely in their investment appraisal process and have appropriate training for employees in how to construct decision trees and calculate EMVs. One point will be given for partial implementation, and zero for non-usage.

8 **Probabilistic prospect economics.** Since, firstly, the technology exists for automated probabilistic economics, and secondly, it is widely documented that economic variables are volatile, companies ought to be producing probabilistic prospect economics. However, producing probabilistic prospect economics can

be complex since there are many economic variables to consider with many dependencies between them. The necessity to produce probabilistic prospect economics is receiving increasing attention in the industry literature (for example, Bailey *et al.*, in press; Simpson *et al*, 1999; Lamb *et al.*, 1999; Snow *et al.*, 1996) and the output that is produced explicitly recognises the existence of risk and uncertainty in economic estimates.

9 **Probabilistic production reserves.** Following the same rationale as 8, companies ought to be explicitly recognising the risk and uncertainty in estimating production reserves by using probabilistic analysis.

10 **Probabilistic production economics.** Follows from 8 and 9.

11 **Portfolio theory**. Markowitz has shown how a diversified portfolio of uncertain opportunities is preferable to an equal investment in a single opportunity, or restricted portfolio of opportunities, even if the diversified portfolio contains projects that are more risky than any other project in the restricted portfolio. Authors such as Ball and Savage (1999) have taken this concept and applied it to the upstream oil and gas industry, showing how diversification in terms of geographic or geological setting, in product pricing mechanism (gas versus oil), production profile timing, political environment, and the avoidance of specific niches can, when the alternatives have a negative correlation, have a positive impact on the risk/reward balance of the company's investments. It is clear, then, that when considering an incremental investment, its impact on the total portfolio should form an important factor in the decision-making.

Portfolio theory has been applied to the upstream industry in the literature for several years and whilst the concepts are relatively simple the mechanics of the technique are complex. This makes implementation more difficult. There is software produced to automate its use.

12 **Option theory**. There are four significant characteristics of most of the decisions taken in the upstream. These are: they form part of a multi-stage decision process (figure 5.1); they are, to a large extent, irreversible; there is uncertainty associated

with most of the input parameters to the decision analysis; and a decision-maker can postpone the decision to allow the collection of additional data to reduce risk and uncertainty. These characteristics mean that traditional DCF techniques can be modified through the application of option theory (see, for example, Dixit and Pindyck, 1998 and 1994) to assign credit to an opportunity for being able to assess and to avoid the downside uncertainty involved in a decision by aborting or postponing that decision until certain conditions are met. Many companies having been doing this to a limited extent, perhaps without realising that it represented the application of option theory, through the use of decision trees. The simple representation given by the decision tree in figure 7.1, illustrates the benefit of minimising expenditures by realising that a discovery may be too small to be economic and exercising the option of limiting investment to exploration and appraisal seismic and drilling, and waiting until commercial considerations (price, costs, taxes) change and the field becomes economic, or not developing at all, rather than developing at a loss. Dixit and Pindyck (1994) outline more rigorous mathematical techniques for assessing the option value of the uncertainty in an investment over which one has the ability to delay commitment, but the principle is the same.

The value of applying option theory to the oil industry has still to be proven. It has only recently begun to attract significant attention within the industry literature and there is no software currently available to automate its use.

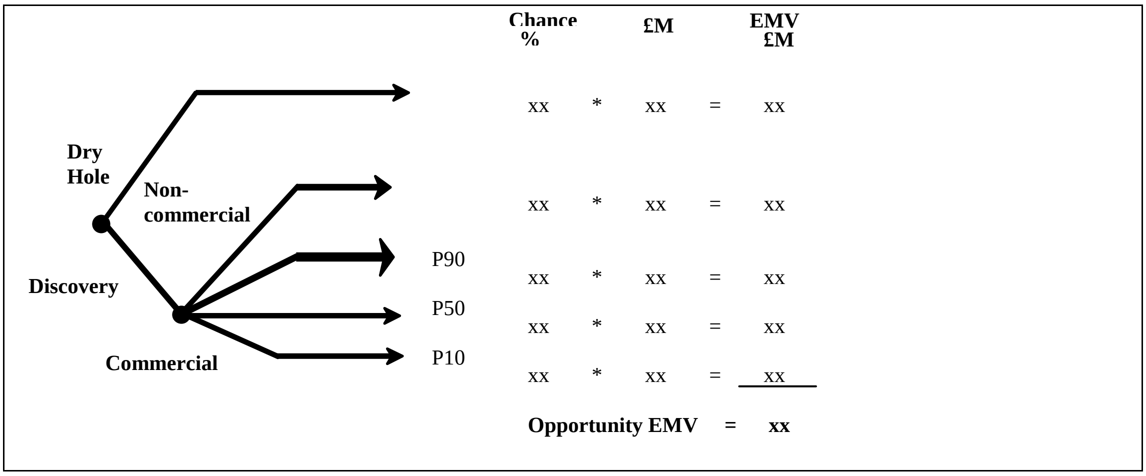

Figure 7.1: *A decision tree*

13 **Preference, or utility, theory.** As indicated in Chapter 5, this aspect of decision-making recognises the fact that companies (or, indeed, decision-makers within companies) do not all have the same attitude towards money. For example, a smaller company will be much less able to sustain losses than a larger company, and will therefore be much more wary of risky projects with downside risks that could bankrupt the company.

Whilst preference theory has been widely applied to the industry in the literature, its value is questionable. There are difficulties in obtaining preference curves and in the construction of corporate preference curves. There is, however, some software available to automate the technique.

For techniques 8-13, two points will be assigned where the technique is used routinely in organisations for investment appraisal and appropriate training is given to staff. One point will be allocated for partial implementation and zero points for non-usage.

14 **Qualitative and quantitative input.** Chapter 6 showed that few, if any, decisions are based solely on quantitative analysis. It seems that decision-makers usually ultimately lack the faith to act purely on the basis of the quantitative output. In such cases qualitative influences, such as habit, instinct, intuition or imitation of others, are also used. Whichever, the reasons for disregarding quantitative analysis, or amending it, are to do with judgements of judgements, where the original judgements are inputs to quantitative analysis and the judgements of judgements pertain to strength of belief. Companies ought to have a systematic method for documenting and critically examining or calibrating their qualitative input. This would ensure transparent decision-making in alliances and partnerships.

Much of the decision theory and industry literature fails to acknowledge the need for organisations to manage the qualitative and quantitative interface. There is no commercial software available that allows qualitative factors first, to be transparently included in the generation of the quantitative analysis, second, to be explored and modelled. Through recently established collaborative relationships, the major players (CSIRO, Merak, Gaffney-Cline & Associates, Wood Mackenzie and DNV) are now working together in an attempt to deliver to the upstream decision-maker such software.

In the company ranking, organisations that manage the qualitative/quantitative interface explicitly perhaps by using soft methods (for example, through simple multi attribute rating techniques) will be assigned two points. One point will be allocated to organisations that acknowledge the existence of both quantitative and qualitative inputs to the decision-making process but do not try to manage their interaction overtly. No points will be given to companies that do not recognise nor manage the qualitative and quantitative input to the decision-making process.

This list represents the collection of decision analysis tools and concepts presented in Chapters 5 and 6. The techniques and ideas do not represent alternatives but rather a collection of analysis tools and principles to be used together to encourage more informed decision-making. The organisation that utilises the full spectrum of these techniques and ideas is perceived to be adopting a transparent approach to decision-making that manages the full range of qualitative and quantitative aspects of the process.

	COMPANY																			
CRITERIA	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**
Quantitative analysis	green	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red
Holistic view	green	green	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red
Discounted cash flow	green	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red
Risk and uncertainty definitions	blue	blue	blue	blue	green	blue	blue	green	blue	red	green	blue	red	blue	red	green	red	green	green	green
Use Monte Carlo for prospect reserves	blue	blue	green	red	red	red	red	red	red	red	red	green	red	red	red	red	green	red	red	red
Take p10,p50,p90 reserve cases	blue	blue	green	blue	blue	blue	green	blue	green	blue	blue	green	green	red	red	green	green	red	red	red
Calculate an EMV, via decision tree analysis	blue	blue	green	red	green	red	blue	red	red	red	red	red	red	red	red	red	green	red	red	red
Use Monte Carlo for prospect economics	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	green	blue	green	blue	blue	green	blue
Use Monte Carlo for production reserves	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	green	blue	blue
Use Monte Carlo for production economics	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue
Portfolio theory	blue	blue	blue	blue	blue	blue	green	blue	green	blue	green	red	green	blue	green	green	green	red	green	green
Option theory	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	green	blue	green	blue	green	green	blue	green	green
Preference theory	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	green	green	blue	blue	green	blue	blue	green
Qualitative and quantitative	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	green	green
TOTAL	**3**	**5**	**9**	**10**	**10**	**10**	**10**	**11**	**12**	**12**	**12**	**13**	**15**	**15**	**15**	**15**	**15**	**16**	**17**	**17**

Table 7.1: *Ranking of companies by use of decision analysis techniques and concepts (red=2 points, green=1 point and blue=0 points)*

Using Chapter 6 as the main data source, the companies that were interviewed were ranked according to the criteria specified above. The result of this ranking is shown in table 7.1. The red squares are used to indicate where companies were assigned two points; the green squares one point and blue no points. For each of the techniques and concepts, where there were numerical ties according to the criteria detailed above, the tie was broken on the basis of other material from the interviews, which was not available for every company (and therefore, not included as an overall rank measure). For example, the tie between companies S and T was broken on the basis that company T applied decision analysis software company-wide whereas in organisation S access to such software was restricted. The gap between practice and capability identified in Chapter 6 is shown explicitly in the table.

The following section proposes the criteria that will be used to measure organisational performance. These measures together with table 7.1 will be used in section 7.5 for the statistical analysis of the association between organisational performance and use of decision analysis techniques and concepts.

7.4 RANKING COMPANIES BY ORGANISATIONAL PERFORMANCE

In this section, financial measures will be selected that are indicative of organisational performance in the upstream. The upstream shares with other industries such as the pharmaceutical and aeronautics industries specific characteristics that make assessing performance particularly challenging. Hence, financial criteria that are not typically associated with organisational performance are more pertinent in this case. There are also other unique measures, which indicate success in the oil industry. These will be included in the assessment of organisational performance in the upstream.

Papadakis (1998) comments that despite the fact that performance is the most critical and frequently employed variable in strategy research (for example, Hambrick and Snow, 1977), its theoretical aspects have not been adequately developed and tested (Keats, 1988). Compounding this, measuring organisational performance in different industries, and even in different samples, presents distinct challenges. Consequently, previous researchers studying the decision-making process have used various and different criteria to assess organisational performance (Venkatraman and Ramanujam, 1987; Dess and Robinson, 1984). Following this trend, the current study uses a variety of measures to assess organisational performance. The choice of these criteria is limited by two factors; firstly, by the data that is available. Some oil companies appear to report extensively whereas others only publish that which they are required to do by law. Furthermore, despite the trend toward using non-financial measures (such as customer acquisition, retention and satisfaction, employee satisfaction and organisational learning (Chang and Morgan, 2000; van de Vliet, 1997; Halley and Guilhorn, 1997; Management Accounting, 1997; Lothian, 1987; Harper, 1984) to measure company performance, such criteria are either inappropriate for the upstream companies under investigation since several are integrated oil companies with both upstream and downstream business and hence issues of customer acquisition are irrelevant, or are not widely reported by the oil companies. Secondly, the selection of measures is restricted because investment decision-making in the oil industry is unique. Recall, from Chapter 5 that the oil industry's investment decisions are characterised by a long payback period. In the case of exploration and development decisions, this time-period can be up to fifteen years. Therefore, to some extent, companies' performances now are dependent on decisions taken many years ago when the industry did not routinely use decision analysis (Section 6.3 of Chapter 6). So to investigate the relationship between the use of decision analysis and oil companies' business success, it is important that measures are selected that reflect the effect of recent decision-making. In the oil industry, this is best acknowledged by measures that indicate the successfulness of recent exploration decisions. This includes, for example, Wood Mackenzie's estimate of a company's total base value which is calculated by the values of commercial reserves, technical reserves (as defined by Wood Mackenzie) and the value of currently held exploration and Wood Mackenzie's assessment of its potential.

Therefore, the following criteria will be used in this study to be indicative of organisational performance in the upstream. Each measure is reviewed below with particular attention being focussed on the conclusions that the researcher will be able to draw by using the criterion.

- **The volume of booked reserves or proved reserves (PR).** Proved reserves are reserves that can be estimated with a reasonable certainty to be recoverable under current economic conditions. Current economic conditions include prices and costs prevailing at the time of the estimate. Proved reserves must have facilities to process and transport those reserves to market, which are operational at the time of the estimate or there is a reasonable expectation or commitment to install such facilities in the future. In general, reserves are considered proved if the commercial producibility of the reservoir is supported by actual production or formation tests. In this context, the term proved reserves refers to the actual quantities of proved reserves and not just the productivity of the well or reservoir (Society of Petroleum Engineers *et al*., 2000). For the company performance ranking, the volume of proved reserves will be used as a proxy for the size of the organisation and as an indicator of recent, past results in investment decision-making.
- **Wood Mackenzie's estimate of each company's total base value (TBV).** As indicated above, Wood Mackenzie calculate this measure by summing the values of a companies' commercial reserves, technical reserves and the value of currently held exploration and an assessment of its potential. For the organisational performance ranking, this measure is particularly attractive as it explicitly includes an assessment of the success of recent, past investment decision-making. However, Wood Mackenzie only publish an estimate of each company's U.K. TBV complied from UKCS data. This is an obvious weakness as some companies choose not to operate in mature basins like the UKCS or are scaling down their operations due to the high costs involved in operating in the U.K. (Section 3.3 of Chapter 3). Currently, however, no other group of analysts produces a similar measure reflecting worldwide TBV (or an equivalent criterion that reflects the value of recent exploration). Acknowledging then the weakness of the measure, but recognising there is no alternative criterion, this research will use the U.K. TBV produced by Wood Mackenzie in combination with other criteria that are indicative of worldwide performance.
- **Return on equity (ROE)**. ROE is defined as the equity earnings as a proportion of the book value of equity. It is a measure of overall performance from a stockholder's perspective and includes the management of operations, use of

assets and management of debt and equity. ROE measures the overall efficiency of the firm in managing its total investments in assets. In the context of the upstream, this measure does not include the effects of decisions taken in the recent past. (In fact, the opposite since although the measure acknowledges the monetary investment of recent decisions, the long payback period means that returns have not yet been earned). The measure is included in the performance ranking for comparison with the criteria that do reflect the effects of recent decision-making and as an indicator of the results of past investment decision-making.

- **Market capitalisation (MC).** MC is defined to be the total value of all outstanding shares in sterling. It is used in the performance ranking as a measure of corporation size.
- **Number of employees (NOE).** The NOE is used in the performance ranking as a relatively coarse indicator of both past success and anticipated future success in selecting and gaining access to the best investment opportunities.
- **Price earnings (PE) ratio**. The PE ratio relates the market value of a share to the earning per share and is calculated by:

$$\text{Price earnings} = \frac{\text{Market value per share}}{\text{Earnings per share}}$$

  The ratio is a measure of market confidence concerning the future of a company. In particular, it is used in the performance ranking as an indicator of growth potential, earnings stability and management capabilities. The higher the price earnings ratio, the greater the market believes is the future earning power of the company. This measure does not explicitly include the effects of decisions taken in the recent past but it is used here for comparison with the criteria that do.
- **Prudential Securities ranking (PSR).** In 2000, Prudential Securities carried out an energy industry benchmarking study that used nine variables to rank the major oil companies. The variables which they considered were: production incomes, quality of earnings, cash flow, production and replacement ratios (excluding abandonment and disposal), finding and development costs (excluding abandonment and disposal), discounted future net cash flows, upstream returns, adjusted production costs and depreciation, depletion and amortization expenses.

> Some of the measures above, such as proved reserves, are influenced by the size of the organisation, since PSR is based on financial measures, small and large companies can be compared and hence it provides a useful indication of business success which independent of organisational size.

Where possible the data used to calculate each measure will be based on the latest figures released by companies. In the case of the U.K. TBV criterion, the data used will be based on Wood Mackenzie's latest estimates produced in April 2000. For the ROE, 1998 figures will be used, as these are the most recent complete data set available. Previous strategy research (for example, Goll and Rasheed, 1997; Grinyer *et al.*, 1988; Papadakis, 1998) averaged performance criteria over a five year period, to decrease the chance of a one-year aberration distorting the results. Whilst in general this is good research practice, in this case this is not appropriate since this would involve aggregating criteria across time periods where decision analysis was not used routinely by the majority of the participants (Section 6.2 of Chapter 6).

All the measures described above, with the exception of the U.K. TBV, are indicative of each company's worldwide performance yet, typically, the respondents were employees working within U.K. offices. However, the researcher does not perceive this to present a problem since each interviewee was specifically asked to comment on the techniques that they were aware that their organisation used to evaluate investment opportunities worldwide and how they perceived these tools and the overall process to work organisation-wide. Therefore, the researcher is confident that the observations from the interviewees are not significantly biased by their place of work and that it is acceptable to rank the companies using measures indicative of worldwide performance.

Most of the companies included in the analysis have both up and downstream operations. Since very few of the companies differentiate between the two in their publication of financial data some of the measures chosen (for example, MC, PE and NOE) reflect organisational performance in both areas. Since, arguably the downstream business is dependent on successful decision-making in the upstream, this is only of slight concern. However, the criteria that reflect only upstream performance (PR, TBV and PSR) will be given more attention.

The companies that were interviewed were ranked according to the performance criteria selected above. (The data gathered to construct this ranking came from a variety of web sites: Prudential Securities (http://www.prudentialsecurities.com), world vest base (http://www.wvb.com), wrights investors service (http://www.wsi.com/index.htm), financial times (http://www.ft.com), hoover's on line business network (http://www.hoovers.com) and datastream, http://www.datastreaminsite.com.). The results of this ranking are presented in table 7.2. (Companies are listed worst-best performers, top-bottom for each criterion). Data for some categories and companies is incomplete because the information proved impossible to locate. The ranking is used in the following sections as an indication of organisational performance.

TBV	MC	PR	NOE	ROE	PE	PSR
C	D	A	C	D	D	I
D	P	D	P	P	N	B
P	A	J	D	E	J	N
G	E	E	A	N	I	O
B	N	N	E	K	N	T
K	B	K	N	A	B	M
I	I	B	S	G	A	L
F	S	I	I	L	T	R
T	J	S	G	S	M	S
N	T	T	J	I	E	
S	M	P	T	C	O	
O	R	L	B	T	K	
L	O	R	K	B	R	
R		O	M	M		
			O	J		
			R	R		
			L	O		

Table 7.2: *Ranking of companies by performance criteria (Companies are listed worst-best performers, top-bottom for all criteria)*

7.5 PROPOSING THE HYPOTHESES AND SELECTING THE STATISTICAL TESTS

This section uses the discussion in section 7.2, the company ranking constructed in section 7.3, and the organisational performance ranking compiled in the preceding section, to ascertain which statistical tests are the most applicable to use to investigate the relationship between the use of decision analysis and organisational performance. The appropriate null and alternative hypotheses are proposed for empirical testing.

The choice of statistical test is always complex and governed, primarily, by the type of data available and the question being asked (Leach, 1979 p21). Researchers must assess whether their data are ordinal or categorical, independent or related and pertain to one sample or several samples. By exploring these issues, statisticians such as Leach (1979 p22) argue, researchers ought to be able to at least reduce their choice of statistical test.

In the current study, whilst for the ranking of companies by their use of decision analysis techniques and concepts, categorical and ordinal data are available, when these data are expressed categorically there are many ties in the data. For some of the performance measures, it is only possible to access ordinal data.

The data in each ranking are independent. This claim can be substantiated in two ways. Firstly, in the oil industry, the performance of one company is not significantly influenced by the success of another. All companies are subject to the fluctuations of the oil price and to the vagaries of depositional environment. Secondly, in Chapter 6 it was shown that companies do not significantly influence each other to adopt new techniques or concepts. The investment appraisal approach that is adopted in the company is more likely to be affected by internal organisational factors such as management's perception of decision analysis and the corporate culture than the techniques or approach used by other companies.

In this case, the explanatory variable, the organisations' use of decision analysis techniques and concepts, has multiple levels and hence, the problem should be regarded as a "several sample" problem.

This process highlights three tests as being applicable in this case: Kendall's test for correlation, Spearman's test for correlation and the Kruskal Wallis test. First, consider the two correlation tests. Since the two tests rarely produce different results (Leach, 1979 p192) and the researcher is familiar with the Spearman correlation test, it will be used here. The procedure for carrying out the Spearman test for correlation is outlined in Appendix 3. The null and alternative hypotheses that will be tested using the Spearman test for correlation for each performance measure are:

$H1_0$: There is no or a negative relationship between the ranking of sampled companies with respect to the performance measure under investigation and the ranking of the sampled companies with respect to decision analysis sophistication in investment appraisal.

$H1_1$: There is a positive relationship between the ranking of sampled companies with respect to the performance measure under investigation and the ranking of the sampled companies with respect to decision analysis sophistication in investment appraisal.

The Kruskal Wallis test is a direct generalisation of the Wilcoxon Rank Sum test to three or more independent samples. The test attempts to decide whether the samples of scores come from the same population or from several populations that differ in location. It assumes that the data are independent and ordinal. The procedure for carrying out the test is outlined in Appendix 4. Since PR and TBV are two of the criteria which are most indicative of the results of recent, past investment decision-making (section 7.4), Kruskal Wallis tests will only be carried out on them (there is insufficient data for a Kruskal Wallis test for PSR). The null and alternative hypotheses to be tested will be:

$H2_0$: The TBV (or PR) of each company is independent of the decision analysis sophistication rank achieved by each company

$H2_1$: The TBV (or PR) of each company come from populations that differ in location according to the rank achieved by each company in the assessment of decision analysis sophistication.

If a significant result is achieved with this test for either or both of the criteria the locus of the difference will be identified by carrying out multiple comparisons using the Wilcoxon Rank Sum test. This test is also outlined in Appendix 4.

The following section investigates these hypotheses by calculating the appropriate test statistics.

7.6 RESULTS

In this section, the results of the statistical tests are presented and the null hypotheses are accepted or rejected as appropriate.

The Spearman tests for correlation were carried out and the results are presented in table 7.3. Inspection of this data indicates that 4 of the 7 criteria provide statistically significant relationships, at a level of 5% or less. Highly significant positive correlations are produced between the performance criteria TBV and PR, and use of decision analysis tools and ideas. There is also a strong significant positive correlation between MC and PSR, and the use of decision analysis techniques and concepts. There are only weak positive correlations between the categorisation of decision analysis and the rankings of ROE and PE and neither is significant at any level. Therefore, the null hypotheses ($H1_0$) for MC, TBV, PR and PSR can be rejected and the alternative hypotheses ($H1_1$) accepted. For PE and ROE, it is not possible to reject the null hypotheses ($H1_0$).

VARIABLE	SPEARMAN CORRELATION COEFFICIENT	LEVEL OF SIGNIFICANCE
PR	R=0.701, n=14	P<0.005
MC	R=0.538, n=13	P<0.05
TBV	R=0.655, n=16	P<0.005
NOE	R=0.3823, n=17	P<0.1
ROE	R=0.252, n=17	N/A
PE	R=0.296, n=13	N/A
PSR	R=0.6, n=9	P<0.05

Table 7.3*: Spearman correlation coefficients between performance variables and use of decision analysis*

For the Kruskal Wallis test for PR the test statistic K is calculated to be 8.1428. There are 2 degrees of freedom and hence this is significant at the 5% level. The null hypothesis ($H2_0$) for PR can then be rejected and, by implication, the alternative hypothesis ($H2_1$), that there are differences between the samples, accepted. To determine the locus of this difference, multiple comparisons are made using the Wilcoxon Rank Sum test, with the null hypothesis each time being that the samples were from the same population, and the alternative hypothesis being that the samples were from several populations that differ in location. The Wilcoxon Rank Sum test indicates that those companies that are ranked in the top ten in the sophistication of decision analysis ranking all have similar PRs. However, their PRs are significantly bigger than those companies that were placed between 11 and 14 in the decision analysis sophistication ranking. (All calculations are shown in Appendix 4).

Carrying out the Kruskal Wallis test for TBV in exactly the same way produces similar results. The test statistic K is equal to 7.37. There are 2 degrees of freedom and therefore this is significant at the 5% level. The null hypothesis ($H2_0$) can then be rejected and, by implication, the alternative hypothesis ($H2_1$), that there are differences between the samples, accepted. To determine the locus of this difference, multiple comparisons are made using the Wilcoxon Rank Sum test, with the null hypothesis each time being that the samples were from the same population, and the alternative hypothesis being that the samples were from several populations that differ in location. The Wilcoxon Rank Sum test indicates that those companies that achieved a mid-low decision analysis ranking position (i.e. between 6^{th} and 16^{th}) do not have different TBVs from each other. However, their TBVs are lower than those companies that achieved higher positions in the decision analysis ranking (in the top 5).

The majority of the empirical results then, suggest that there is a positive link between the use of decision analysis and organisational performance. The lack of a statistically significant positive correlation between the use of decision analysis and ROE and PE ratio is not unexpected. As indicated in section 7.4, these two measures are both indicative of historical decision-making and hence, decision-making when decision analysis was not routinely used by many upstream companies (Section 6.3 of

Chapter 6). However, the Spearman correlation coefficients for TBV and PR, the two criteria that are most indicative of upstream performance and that also take into account recent decision-making and, hence, decision-making using decision analysis, were significant at the 0.5% level. In the case of PR and TBV, the Kruskal Wallis and Wilcoxon Rank Sum tests confirmed that those companies that use sophisticated decision analysis methods were more likely to have high TBVs and high PRs. The statistically significant positive correlation between PSR and use of decision analysis indicates that the relationship is independent of the size of the company. Hence, the researcher is confident in asserting that there is an association between the use of sophisticated decision analysis techniques and organisational performance. The following section discusses these results within the context of the decision theory and organisational performance literature.

7.7 DISCUSSION

From these results, it is evident that there is an association between successful companies and the use of sophisticated decision analysis techniques and concepts. However, before discussing this association further, it is important to acknowledge that the nature of the study prevents the researcher from concluding that use of decision analysis alone improves organisational performance. Indeed some writers such as Wensley (1999 and 1997) would argue that business success cannot under any circumstances, be ascribed to any one variable since its determinants are too complex for such a simple explanation. Moreover, it will be impossible to ascertain, whether using decision analysis tools precipitates business success or if it is once success is achieved that organisations begin to use decision analysis techniques and concepts. However, despite these limitations, it is possible to draw the following conclusions from the current study. Firstly, it is clear that the decision process matters and secondly, and fundamentally, that decision analysis can be extremely valuable to the upstream oil and gas industry in investment appraisal decision-making and, arguably therefore, to other industries with similar investment decisions. Managers have the power to influence the success of decisions, and consequently the fortunes of their organisations, through the processes they use to make crucial decisions. By drawing on the literature review of Chapter 2, the following paragraphs contextualise the results of the statistical tests.

Section 2.5 of Chapter 2 identified two areas of empirical literature on the relationship between the decision-making process and effectiveness. The first demonstrated relationships between features and types of strategic planning and firm performance. In particular the research to date has tended to focus on the effects of comprehensivess/rationality and formalisation of the decision-making process on the performance of the company. Chapter 2 also established that use of decision analysis implies comprehensiveness/rationality and formalisation of the decision-making process. Hence, the results of the previous section appear to corroborate the stream of research that suggests that either high levels of performance produce enough resources to help organisations make more rational decisions, or that more rational decisions may lead to better performance (Jones *et al.*, 1993; Smith *et al.*, 1988; Dess and Origer, 1987; Grinyer and Norburn, 1977-78). By implication, then, the findings seem to refute the research that suggested that superior performance may lower the extent to which organisations engage in rational/comprehensive, formalised decision-making (Bourgeois, 1981; Cyert and March, 1963; March and Simon, 1958).

The second area of empirical research identified in Section 2.5 of Chapter 2 related to the impact of consensus on organisational performance. It was argued in that chapter that use of decision analysis encouraged communication and helped to build consensus amongst organisational members. As such the findings of section 7.5 appear to confirm the research of Bourgeois (1981) and Dess (1987) and others (Hambrick and Snow, 1982; Child, 1974) who suggested that either business success leads to higher levels of consensus, or that high levels of consensus encourage better organisational performance. Simultaneously, the results seem to dispute those of Grinyer and Norburn (1977-78) and others (Schweiger *et al.*, 1986; De Woot *et. al.*, 1977-78) who found evidence of a negative correlation between consensus and performance, and those of Wooldridge and Floyd (1990) who found no statistically significant relationship at all.

7.8 CONCLUSION

In conclusion, the results from the current study provide some insight into the association between performance and the use of decision analysis in investment appraisal. The analysis presented above shows strong positive correlations between the use and sophistication of decision analysis techniques and concepts used and various measures of business success in the upstream. This is consistent with the proposition that sophistication in the use of decision analysis in investment appraisal decision-making is a source of competitive advantage in organisations that operate in the oil and gas industry. The theoretical contribution of this research to the debate between behavioural decision theorists and decision analysts, the implications for practitioners especially to managerial perceptions of decision analysis, the limitations of the current study and areas for future research will be discussed in the following chapter.

Chapter 8

Conclusion: between “extinction by instinct” and “paralysis by analysis”

8.1 INTRODUCTION

This chapter will draw on those that precede it to answer the research questions posed in the first chapter of this thesis. It will demonstrate how, through the utilisation of qualitative methods and statistical analysis, the current study has produced research that has made a valuable contribution firstly, to the decision theory and oil and gas industry literatures and secondly, to oil industry practitioners.

By drawing on the insights gained through the conduct of the literature review, research interviews and data analysis stages of the current study, the chapter begins by answering each of the three research questions in turn. The main conclusions of the research are then contextualised in the decision theory and oil industry literatures. This highlights how the research has contributed to one of the current debates in these literatures by providing evidence of a link between the use of decision analysis in investment appraisal decision-making and good organisational performance. Implications of the study and recommendations to practitioners follow. The chapter concludes by identifying directions for future research.

8.2 THE RESEARCH QUESTIONS REVISITED

In Chapter 1 the three research questions that the current study aimed to examine were proposed. Focussing on each question in turn in this section these questions and their motivation will be examined. Attention will be concentrated on how, through the utilisation of the combination of qualitative methods and statistical analysis, the research presented in this thesis can be used to answer these questions.

The first research question aimed to establish which of the decision analysis techniques presented in the decision theory and industry literatures, are the most appropriate for upstream oil and gas companies to utilise in their investment decision-making. This question was motivated by the recognition that there are many decision analysis techniques and concepts presented in the decision theory and industry literatures. Some of these have been applied to the upstream in the industry literature since the early 1960s. A few have only recently began to attract attention. Still others have yet to be considered in the context of the upstream. However, previously in the decision theory and industry literatures, authors had tended to describe the application of a single technique to either a real or hypothetical decision situation (Hammond, 1967; Swalm, 1966). Whilst such accounts provide useful insights, they also implied that using particular decision analysis technique in isolation, would provide the decision-maker with best possible perception of the risk and uncertainty associated with a decision. Yet, as indicated in Chapter 5, in reality, each tool has limitations (Lefley and Morgan, 1999), some that are inherent, others which are caused by a lack of information or specification in the literature. As such, the knowledge that the decision-maker can gain from the output of one tool is limited. Therefore, a combination of decision analysis techniques and concepts should be used. This would allow the decision-maker to gain greater insights and, hence, encourage more informed decision-making. Some writers had recognised this and presented the collection of decision analysis tools that they believed constituted those that decision-makers ought to use for investment decision-making in the oil and gas industry (for example, Newendorp, 1996). However, as indicated above, new techniques, such as option theory, have only recently been applied to the industry and clearly, these previously presented approaches required modification.

The research presented in this thesis addressed this first question by drawing on the decision theory and industry literatures to ascertain which decision analysis tools are the most appropriate for upstream oil companies to use for investment appraisal decision-making. This involved firstly, identifying the whole range of techniques that are available and, secondly, deciding which of these are the most appropriate for upstream investment decision-making. This meant careful consideration of factors such as the business environment of the upstream and the level and type of information used for investment decision-making in the industry.

Through this process, the research identified the following decision analysis techniques as particularly useful for upstream investment decision-making: the concepts of expected monetary value and decision tree analysis, preference theory, risk analysis, portfolio theory and option theory. Then by drawing again on the decision theory and industry literatures, and also on insights gained at conferences and seminars, a 9-step investment decision-making process was presented. This provided an illustration of how these tools can be used together in the particular decision situation where an upstream company is considering whether to drill an exploration well in a virgin basin at an estimated cost of £10 million. The approach was summarised in figure 5.12 and this is reprinted here.

1. Assess the chance of success based on historic statistics and analogues of other basins and plays with similar geological characteristics.
2. Use sensitivity analysis to determine the critical reservoir parameters.
3. Conduct a probabilistic analysis of reserves using Monte Carlo techniques. If necessary, perform a further sensitivity analysis here by altering the shapes of the probability distributions assigned to the reservoir parameters and changing the nature of the dependencies between the variables.
4. Extraction from the probabilistic output of the reserves calculation of some deterministic samples –for example, p10, p50 and p90 (high, mid, low cases).
5. Use sensitivity analysis to determine the critical economic parameters.
6. Perform a probabilistic economic analysis for each deterministic reserve case using Monte Carlo techniques. If necessary, perform a further sensitivity analysis here by altering the shapes of the probability distributions assigned to the economic factors and changing the nature of the dependencies between the variables.
7. Using influence diagrams draw the decision tree.
8. For each reserve case, recombine the chance of success estimated in step 1 and the economic values generated in step 6, through a decision tree analysis to generate EMVs.
9. Use option theory via decision tree analysis and assess the impact on the EMV.

Figure 5.12: *A 9 step Approach to Investment Appraisal in the Upstream Oil and Gas Industry*

Variations of the approach could be used for development decisions, any production decisions and for the decision of when to abandon production and how to decommission the facilities. Versions of it could also be used in other industries with a similar business environment to the oil and gas industry, for example, the pharmaceutical or aerospace industries. In these businesses, investment decisions are similar in scale to the oil industry with the high initial investment without the prospect of revenues for a significant period and are also characterised by high risk and uncertainty.

The second research question focussed on two issues. First, it aimed to establish which of the decision analysis techniques that the researcher had identified to comprise current capability in answering the first research question, upstream oil and gas companies actually choose to use to make investment decisions. Second, it sought to understand how these tools are used in the process of organisational investment decision-making.

Previous studies into the usage of decision analysis techniques had suggested that there was a gap between current practice and current capability (for example see studies by Arnold and Hatzopoulous, 1999; Carr and Tomkins, 1998; Schuyler, 1997; Buckley *et al.*, 1996 Fletcher and Dromgoole, 1996; Shao and Shao, 1993; Kim, Farragher and Crick, 1984; Stanley and Block, 1983; Wicks Kelly and Philippatos, 1982; Bavishi, 1981; Oblak and Helm, 1980 and Stonehill and Nathanson, 1968). It appeared that whilst the literature described some very sophisticated investment appraisal tools, companies were choosing to use only the most simplistic. However, most of the earlier studies had tended to utilise quantitative methodologies and, as such, these works had only been able to provide an indication of how widely used a particular decision analysis technique was (for example, Schuyler, 1997). They had not provided any insights, based on behavioural decision theory, into the reasons why some techniques fail to be implemented and others succeed, and, more importantly, which techniques perform better than others do (Clemen, 1999). In adopting a qualitative methodology, the current study was able to address these issues.

Earlier qualitative research into organisational decision-making had neglected the role of decision analysis. Several studies had focussed on the existence of formalisation and rationality in decision-making (for example, Papadakis, 1998; Dean and Sharfman, 1996) but few had explicitly examined the use, and usefulness, of decision analysis in investment appraisal. Fewer again had examined cases where the decision situation is characterised by a substantial initial investment, high (absolute) risk and uncertainty throughout the life of the asset and a long payback period, features that are common in, though not unique to, the petroleum industry. Typically, where such research had been undertaken, it had usually been conducted within one company usually by an employee of that organisation (for example, Burnside, 1998) and had often not been published due to commercial sensitivity. There had been only one previous qualitative study researching the use of decision analysis in the oil industry (Fletcher and Dromgoole, 1996). However, this study had only focused on the perceptions and beliefs of, and decision analysis techniques used by, one functional area within organisations in the upstream. As such its findings could only be regarded as indicative rather than conclusive. In contrast, the current study integrated perspectives from individuals from a variety of backgrounds within organisations. In doing so, the research was able to produce a description of current practice in investment decision-making in the oil industry that was informed from the perspectives of the main participants in the process.

The current study indicated that for exploration decisions, most companies use Monte Carlo simulation to generate estimates of prospect reserves. They then run their economic models on only one reserve case. Typically, Monte Carlo simulation is not used for economic analysis. In production decision-making, the majority of companies only use deterministic analysis. Option, portfolio and preference theories are hardly used at all by any firm. Comparing this approach with the 9-step approach outlined in figure 5.12 and reprinted above, confirms the suggestions of earlier empirical research, and establishes that there is a gap between current theory and current practice in the quantitative techniques used for investment appraisal in the upstream.

The research interviews were then used to provide insights into the reasons for the gap between current practice and capability. It appears that there are relationships between decision-makers' perceptions of decision analysis, company culture and the extent to which decision analysis is used for investment appraisal decision-making. In companies where managers are convinced about decision analysis, the culture is "numbers-driven" and decision analysis is used extensively. In companies where managers are unconvinced about the value of decision analysis, the company is largely "opinion-driven" and the use of decision analysis is not formalised or encouraged.

These ideas were then captured in a model of current practice. The x-axis in the model relates to the number of decision analysis techniques used for investment appraisal decisions. The y-axis of the model indicates the proportion of investment decisions that are made in each company using decision analysis techniques. Plotting the interviewed companies on the two axes then produces the model shown in figure 6.1 and reprinted here. The pattern obtained suggests that organisations begin to use decision analysis techniques on routine, operational decisions before introducing the techniques corporation-wide. Secondly, it provides evidence that as companies introduce more techniques, they tend to use the techniques on more decisions, some of which can be regarded as strategic. Thirdly, in the model there are clearly three groups of companies (each group is a different colour in the figure). This suggests that organisations are choosing not to modify which techniques they use or how they use them, preferring instead to stay within their group. Possible reasons for this include the decision-makers' perception of decision analysis, which are affected by the lack of any empirical evidence to indicate that using decision analysis is associated with good organisational performance.

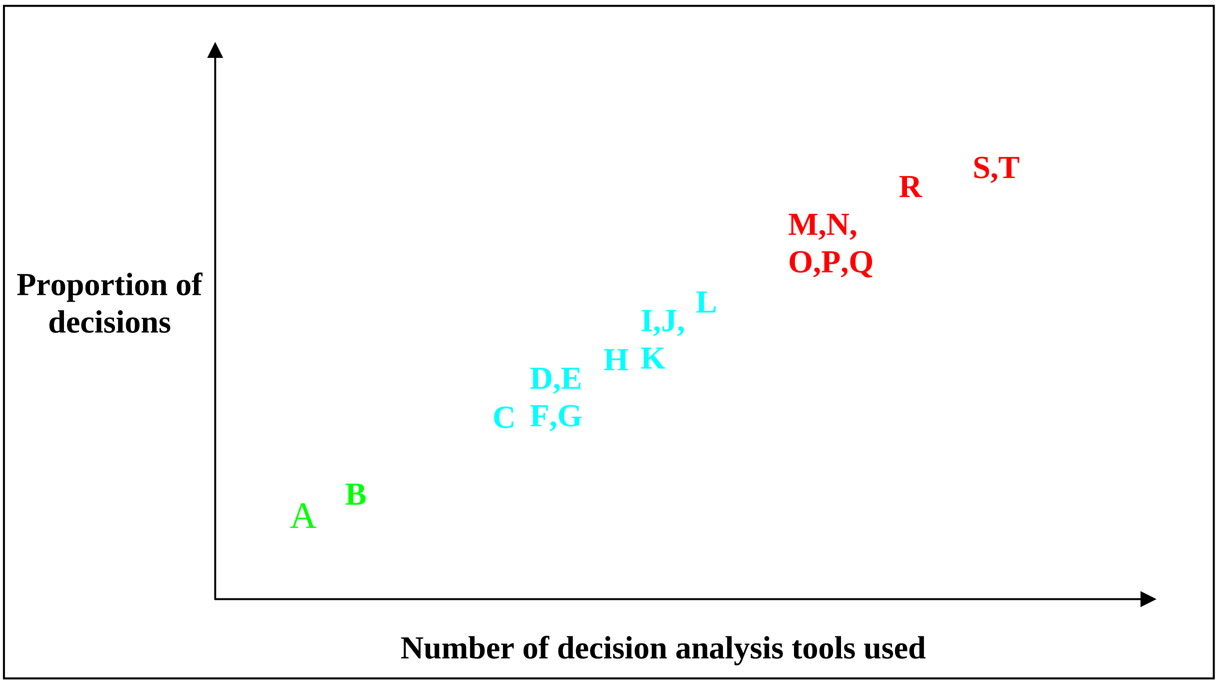

Figure 6.1*: A model of current practice*

This leads into the third research question that this thesis aimed to address, which was to establish if there is a link between the techniques organisations use for investment appraisal and good decision-making in the upstream oil and gas industry. This question was motivated by the recognition that despite over four decades of research undertaken on developing decision analysis methods, on understanding the behavioural aspects of decision-making, and on the application of decision analysis in practice, no previous research had been able to show conclusively what works and what does not (Clemen, 1999). Some studies in behavioural decision theory had evaluated the effectiveness of individual decision analysis techniques (for example, Aldag and Power, 1986; John *et al.*, 1983; Humphreys and McFadden, 1980) and Clemen and Kwit (2000) had investigated the value of a decision analysis approach in Kodak, but, crucially, no earlier study had shown that use of decision analysis techniques could actually help organisations to fulfil their objectives.

Qualitative methods again were chosen as the most appropriate to evaluate the effectiveness, or otherwise, of using a decision analysis approach in organisational decision-making in the oil industry. Using the results from the second stage of the research, a ranking of the companies according to the number and sophistication of the techniques and concepts they used, was produced. The research assumed that any value added to the company from using a decision analysis approach, including "soft" benefits, would ultimately affect the bottom-line. This meant that it was possible to investigate the relationship between the ranking of organisations by their use of decision analysis generated by the qualitative study and good decision-making statistically, by using criteria that are indicative of organisational performance in the upstream. The majority of the results produced suggested that there is a positive association between the use of decision analysis in investment appraisal and good organisational performance in the upstream oil and gas industry.

This section has shown how the empirical research presented in this thesis can be used to answer the three research questions proposed in Chapter 1. The following section will examine how the work produced in this thesis contributes to the existing academic and industry literature. In section 8.4, the implications of the study for practitioners will be investigated.

8.3 THEORETICAL CONTRIBUTION

This section will demonstrate how the research presented in this thesis can be seen to have generated a robust set of findings that have contributed to the one of the current debates in the decision theory literature.

As indicated in Chapter 2, the decision theory literature is comprised of behavioural decision theory and decision analysis. Simplistically, decision analysis is the label given to a normative, axiomatic approach to decision-making under conditions of risk and uncertainty. By using any one, or a combination, of decision analysis techniques, the decision-maker is provided with an indication of what their decision ought to be based on logical argument. Conversely, the behavioural decision theory literature shows that people are not always coherent or internally consistent. They do make inconsistent patterns of choices and their inferences can be exploited (Clemen, 1999), particularly under conditions of risk and uncertainty.

There is a tendency in the decision theory literature for decision analysts and behavioural decision theorists to become embroiled in a somewhat circular argument over the use and benefits of decision analysis. Tocher (1976 and 1978 reprinted in French, 1989) and other behaviouralists argue that people do not behave in the manner suggested by decision analysis and, in particular, do not adhere to the underlying assumptions of the decision analysis approach, namely those of rationality and maximising behaviour. Harrison (1995 p90) writes:

> "…the assumptions underlying maxisimising behaviour are faulty. Objectives are not fixed. The known set of alternatives is always incomplete because it is impossible to obtain perfect information and human beings cognitive limitations preclude serious consideration of a large number of alternatives. Many of the variables that must be considered in any attempt at maximisation are not easily quantified. Therefore, a precise preference ranking of the firm's objectives or its alternatives that will maximise outcome is most unlikely."

In a special edition in 1991 of the Harvard Business Review *The logic of business decision-making*, Etzoni (1991 p41) commented:

> "Decision-making was never as easy as rationalists would have us think. Psychologists argue compelingly that even before our present troubles began, human minds could not handle the complexities that important decisions entailed. Our brains are too limited. At best, we can focus on eight facts at a time. Our ability to calculate probabilities, especially to combine two or more probabilities – essential for most decision-making – is low… Moreover, we are all prone to let our emotions get in the way – fear for one. Since all decisions entail risks, decision-making almost inevitably evokes anxiety."

Additional limitations on maximising behaviour become apparent in considering the human predicament of decision-making. Shackle (1974 p1) eloquently articulates this in the following quote:

> "If choice is originative, it can be effective, it can give thrust to the course of things intended to secure its ends. In order to secure its ends, choice must apply a knowledge of what will be the consequence of what. But the sequel of an action chosen by one man will be shaped by circumstance, and its circumstances will include the actions chosen now and actions to be chosen in time to come by other men. If, therefore, choice is effective, it is unpredictable and thus defeats, in some degree, the power of choice itself to secure exact ends. This is the human predicament…Decision is not, in its ultimate nature, calculation, but origination."

If, as Shackle indicates, decision-making is not founded on calculation, the assumptions underlying decision analysis are untenable. As such Tocher and other opponents would rather operate with no model at all than utilise a model that is in conflict with how people actually act and think:

> "…any theory which is worth using predicts how people will behave, not how they should, so we can do our mathematics." (Tocher, 1976 reprinted in French, 1989 p140)

Decision analysts response to such criticisms is that they acknowledge that utility functions and subjective probability distributions do not provide valid models of decision-maker's actual preferences and beliefs (French, 1989). They argue that their intention is not to describe the decision-maker's beliefs and preferences as they are; it is to suggest what they ought to be, if the decision-maker wishes to be consistent. French urges that the "is" should not be confused with the "ought", and decision analysis only suggests how people ought to choose. Decision analysis, he argues, is normative not descriptive analysis. Keeney and Raiffa (1976 pvii) adopt a similar stance:

> "…[decision analysis is a] prescriptive approach designed for normally intelligent people who want to think hard and systematically about important real problems."

Krantz *et al.* (1971) describe decision analysis to be:

> "…normative principles defining the concept of rational behaviour rather than a description of actual behaviour". (cited by Tocher, 1978 reprinted in French, 1989 p151)

They go on to say:

> "…We want to stress that subjective probabilities are means of describing rational behaviour. Nothing more! They cannot be used as estimates of the

objective probability of an event or the credibility of a statement or the corroboration of a theory." (cited by Tocher, 1978 reprinted in French, 1989 p151)

But to critics such as Tocher such a defence is weak and referring to the above quote from Krantz, Tocher writes:

"This sums up my attitude to the utilitarians; I am irritated by their arrogance – they will tell me how I ought to think regardless of the evidence of how people actually think or take decisions." (Tocher, 1978 reprinted in French, 1989 p151)

Figure 8.1 shows the relationships between these two areas of the decision theory literature. Recently, researchers have realised that to unite the two seemingly diametrically opposite views, empirical research needs to establish if there is a relationship between the use of decision analysis and successful decision-making (Clemen and Kwit, 2000; Clemen, 1999). Clemen (1999 p2) believes that:

"…such research could connect the … existing areas into a truly unified body of literature"

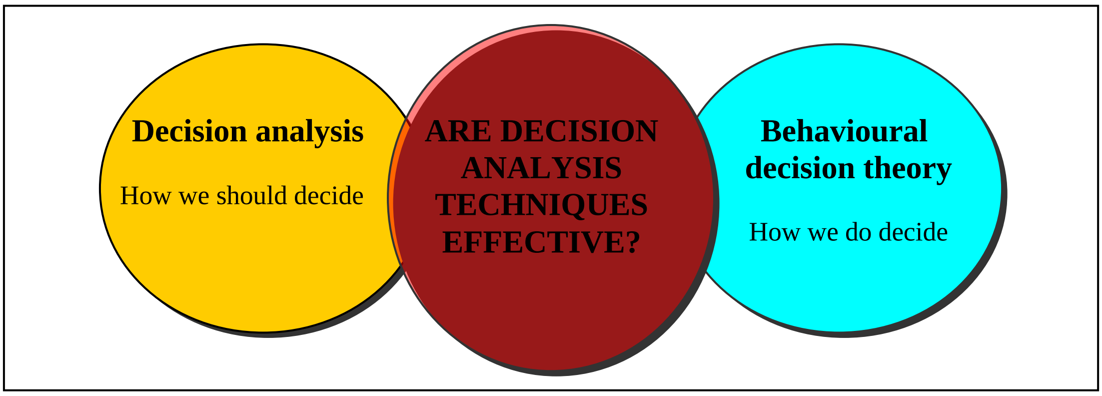

Figure 8.1: *The relationship between decision analysis and behavioural decision theory (adapted from Clemen, 1999)*

However, as indicated above in section 8.2, such studies have been slow to appear, doubtless because of the threat they represent to decision analysts:

"Asking whether decision analysis works is risky. What if the answer is negative? The contribution will clearly be scientifically valuable, but many individuals – consultants, academics, instructors – with a vested interest in decision analysis could lose standing clients, or even jobs." (Clemen, 1999 pp23-24)

The research presented in this thesis then can clearly be seen to provide a useful contribution to the theoretical debate, by establishing the existence of such an association in the upstream oil and gas industry.

8.4 IMPLICATIONS OF THE STUDY FOR PRACTITIONERS

The findings presented in this thesis clearly have implications for practitioners in the oil industry. These will be analysed in this section.

By answering the first research question, the study has provided an indication of which decision analysis techniques are the most appropriate for upstream companies to use for investment appraisal and indicated how these tools can be used together. Companies can use this as a template to modify their own investment appraisal approach. The model of current practice produced by answering the second research question, showed which tools companies in the upstream use. This will allow organisations to compare their processes with the rest of the industry and make any appropriate modifications. This model also permitted the researcher to identify best practices in those companies that currently use decision analysis (summarised in figure 8.2) and these should be communicated to companies through publications in industry journals such as *Journal of Petroleum Technology*.

- The decision analysis approach used by the company is formalised. Often manuals are available to employees. The manuals detail how the limitations and gaps in the techniques (for example, the distribution shapes to be used in Monte Carlo simulation) are to be overcome.
- Decision analysis software available throughout the organisation.
- Employees know the decision policy used by the company.
- Organisations have consistent definitions of risk and uncertainty.
- All employees have the ability to understand probabilities and communicate probabilistically.
- Good communication between the departments compiling the analysis.
- Motivation to conduct decision analysis is high.
- Decision analysis perceived to be a useful tool for quantifying risk and uncertainty.
- Each prospect is subjected to peer-review.
- Decision analysis is part of the organisation’s culture.
- Employees trust the results of the analysis.
- Every employee is required to attend training in decision analysis.
- Management are committed to decision analysis.
- Management are involved in generating the analysis.

Figure 8.2: *Best practices in organisations’ use of decision analysis*

By providing evidence that decision analysis contributes positively to organisational performance, the current study ought to promote interest in decision analysis tools and concepts. This should result in more organisations using decision analysis, and some companies using the more sophisticated decision analysis techniques and ideas. Clearly then the research presented in this thesis ought to be seen as a vehicle for narrowing the gap between current practice and current capability in the use of decision analysis by the upstream oil and gas industry. However, this will only occur if, simultaneously, decision-makers recognise that decision analysis is not a threat, that it does not dictate answers, nor does it usurp decision-makers and remove choice and neither could it ever aspire to do so. Numerous decision analysts (for example, French, 1989; Keeney and Raffia, 1976) stress that decision analysis is not a means whereby the decision-maker is replaced by an automatic procedure. Newendorp (1996 p7) observes in his book on decision analysis that:

> "We will unfortunately not be able to develop a single "handy-dandy" formula which will cure all the evaluation problems relating to capital investment decisions."

The basic presumption of decision analysis is not to replace the decision-maker's intuition, to relieve him or her of the obligations in facing the problem, or to be, worst of all, a competitor to the decision-maker's personal style of analysis, but to complement, augment, and generally work alongside the decision-maker in exemplifying the nature of the problem (Bunn, 1984 p8). Keeney (1982) commented

> "Decision analysis will not solve a decision problem, nor is it intended to. Its purpose is to produce insight and promote creativity to help decision-makers make better decisions." (Goodwin and Wright, 1991 p4)

Yet, currently decision-makers, in the upstream, at least, appear to fear that implementation of decision analysis, will be accompanied by a diminishing role for decision-makers. Clearly, decision-makers need to be educated in the conception of decision-analysis. Only then will organisations fully adopt decision analysis.

8.5 FUTURE RESEARCH

Whilst conducting the research underpinning this thesis, one of the most difficult tasks for the researcher was to recognise that every interesting issue uncovered could not be explored. As such, whilst contributing to the theoretical debate and providing useful advice to practitioners, the current study has also highlighted several areas for future research. These will be discussed in this section.

Firstly, as highlighted in Chapter 5, there is a need for several studies to investigate the issues surrounding Monte Carlo analysis. One study needs to establish the shape of the input distributions that ought to be used to represent the reservoir parameters, in a field of specified lithology and depth, in a Monte Carlo simulation to generate an estimate of the recoverable reserves. A further study is required to explore the nature of the dependencies between these variables. The data necessary for such a study is due to be published next year by the Geological Society in a book titled *Oil and Gas fields of the United Kingdom Continental Shelf* edited by Jon Gluyas *et al.*. The need for these studies is particularly pertinent since most companies are using Monte Carlo analysis to generate estimates of recoverable reserves at the prospect level. Similar studies also need to be conducted to investigate these issues for economic variables. However, the economic data that are necessary for such research are regarded by most companies to be strictly confidential. Consequently, such research is unlikely to be undertaken in the near future.

Further work is also needed to understand the complexities of option theory and its application to the upstream. The growing interest from the industry should ensure that this occurs. The researcher expects to see more companies using the technique on individual investment appraisal cases in the next couple of years. Software companies such as Merak are interested in integrating the technique into their existing packages and this should aid its introduction to the industry.

One of the most interesting areas that the researcher had to acknowledge was beyond the scope of this thesis were issues of tacit knowledge and the extent to which organisations and decisions are dependent upon it, and decision-makers reliance on gut feelings and experience. Firstly, understanding such issues, and secondly, researching them, requires specialist skills in areas, for example, such as organisational psychology. Following similar observations, in March 1999 the Departments of Management Studies and Economics at the University of Aberdeen identified a researcher with the appropriate background to undertake such research. This Ph.D. is due for completion in March 2002.

Future research should concentrate on further examination of the link between use of decision analysis and organisational performance. The current study focussed on those oil companies active on the UKCS, a comparative study could be undertaken in companies active in other areas. Following presentation of a paper based on Chapter 7 of this thesis at a recent Society of Petroleum Engineers conference in Japan, JNOC (Japanese National Oil Company) are considering conducting a similar study in Japan. The study could also be replicated in other industries with a similar high risk/high reward environment, such as pharmaceuticals or aeronautics. CSIRO are currently considering funding such research.

These studies could perhaps adopt longitudinal research designs. Previous research (for example, Papadakis and Lioukas, 1996; Rajagopalan *et al.*, 1993), suggests that organisational performance is a function of a diverse collection of factors. Cause-effect relationships are, at best, tenuous and a broader conceptualisation of effectiveness that incorporates both process and performance measures, is now appropriate (Goll and Rasheed, 1997). Using longitudinal research designs, researchers would be able to gain a greater understanding of the causal relationships between the decision process and organisational performance by studying how connections between context, process and outcome unfold over time (Papadakis, 1998). This would minimise the possibility of reverse causality among the main variables (Van de Ven, 1992; Leonard-Barton, 1990). Consequently, longitudinal research methods would increase researchers' confidence in the causal interpretation of the findings (Hart and Banbury, 1994; Chakravarthy and Doz, 1992).

8.6 CONCLUSION

This thesis has highlighted that decision analysis should not be perceived to be providing a dictatorial straitjacket of rationality (French, 1989). Rather it should be seen to be a delicate, interactive, exploratory tool which seeks to introduce intuitive judgements and feelings directly into the formal analysis of a decision problem (Raiffa, 1968). The decision analysis approach is distinctive because for each decision, it requires inputs such as executive judgement, experience and attitudes, along with the “hard data”. It helps decision-makers to tread the fine line between ill-conceived and arbitrary investment decisions made without systematic study and reflection (“extinction by instinct”) and a retreat into abstraction and conservatism that relies obsessively on numbers (“paralysis by analysis”) (Langley, 1995). The thesis has demonstrated that such an approach contributes positively to organisational performance in the upstream oil and gas industry.

APPENDICES

APPENDIX 1: INTERVIEW SCHEDULE

Roles and responsibilities

Assure respondents that all answers will be treated as confidential, that information disclosed in the interview will be kept securely at the university and that in the final research report, the real names of people and companies will not be used.

1. What is your job title? (Make note of company)

____

2. Typically, what decisions does this mean you are responsible for making?

____
____
____
____
____

3. Do you think that two decision-making processes exist in organisations?

Yes ☐ No ☐ Don't know ☐

If so, ask for more explanation and examples.

____
____
____
____

a) In your company what percentage of decisions are regarded as operational/procedural? What are the characteristics of an operational decision?

- 0-20%
- 20-40%
- 40-60%
- 60-80%
- 80-100%

b) What type of decisions in your organisation are classified as operational and why? How are operational decisions made? What is the input? Who is involved?

____

c) What type of decisions in your organisation are classified as strategic and why? How are strategic decisions made? Who is involved?

Risk and uncertainty

4. What do you mean by risk?

5. What do you mean by uncertainty?

6. Are these interpretations consistent with company-wide definitions of these terms?

Yes ☐ No ☐ Don’t know ☐

If not, what are the company interpretations of risk and uncertainty?

RISK

UNCERTAINTY

7. Are there different interpretations of these terms depending on functional department, job title etc?

Yes ☐ No ☐ Don't know ☐

If so, ask for details on differences:

____
____
____
____

8.
a) Do you think it is necessary for companies to develop specific training to help individuals and teams discuss risk and uncertainty?

Yes ☐ No ☐

b) Has your company developed any such training or vocabulary?

Yes ☐ No ☐ Don't know ☐

Either way, ask for more details:

____
____
____
____
____

9.
a) Do you think it is necessary for organisations to develop definitions of the risks it faces?

Yes ☐ No ☐

b) Has your organisation developed such definitions?

Yes ☐ No ☐ Don't know ☐

If so, ask what are they are and how these were communicated to employees?

____
____
____
____
____

10. What decision-making criteria are used in your company?

- NPV (Net present value)
- EMV (Expected monetary value)
- DPI (Discounted Profit to Investment ratio)
- IRR (Internal rate of return)
- ROR (Rate of return)
- Don't know
- Other (give details below)

____

____

____

____

____

11.In your company, are projects ranked in terms of risk and reward?

Yes ☐ No ☐ Don't know ☐

12. Has the ability to better understand and manage risk and uncertainty allowed your organisation to assume higher levels of risk?

Yes ☐ No ☐ Don't know ☐

13. Are projects able to be stopped based on assessment of the risks and rewards?

Yes ☐ No ☐ Don't know ☐

14. Has your company done anything specific in hiring personnel, or developed reward and recognition practices to encourage consideration of risk and uncertainty in decision-making?

Yes ☐ No ☐ Don't know ☐

Decision-making techniques and software tools

15. Does your organisation use specific tools and processes to analyse and understand risk and uncertainty in decision-making?

Yes ☐ No ☐ Don't know ☐

If so, what tools do you use, what stage/level in the decision-making process are they used and how effective are they in this position?

____
____
____
____
____
____
____

16. Which, if any, of the following techniques are you aware of?

- Monte-Carlo
- Decision Trees
- Scenario Planning
- Portfolio Theory
- Juniper
- Option theory
- Analytic hierarchy process
- Preference theory
- None

17. Are you aware of any other techniques not listed above?

Yes ☐ No ☐

If so, ask for further details:

____
____
____
____

18. What is your opinion of these techniques? Rank them on a 0 to 5 scale.
(0 is least useful and 5 is the most useful)

	increasing effectiveness and efficiency →					
Monte Carlo	0	1	2	3	4	5
Decision Trees	0	1	2	3	4	5
Scenario Planning	0	1	2	3	4	5
Portfolio Theory	0	1	2	3	4	5
Juniper	0	1	2	3	4	5
Option Theory	0	1	2	3	4	5
Analytic hierarchy process	0	1	2	3	4	5
Preference theory	0	1	2	3	4	5

19. Is any software used to aid decision-making in your organisation?

Yes ☐ No ☐ Don't know ☐

If so,
a) which software package/s is/are used and when?

____
____
____
____

b) How is/are the results of the software tool/s integrated into decision-making?

____
____
____
____

c) Do you think that this/these tool/s have increased the efficiency of the decision-making procedures in your organisation?

Yes ☐ No ☐

20. Do you think software tools, in general, assist decision-making?

Yes ☐ No ☐

21. Are decisions based primarily, on the figures output from the software packages?

Yes ☐ No ☐ Don't know ☐

22. How effective do you think your company's decision-making processes and procedures are in comparison to your main competitors?

Increasing effectiveness and efficiency →

0 1 2 3 4 5

23. Are any changes likely in the foreseeable future to your current practice?

Yes ☐ No ☐ Don't know ☐

If so, ask for further details:

____

____

____

____

Thank the interviewee for time taken to conduct interview. Note any comments.

Comments:

APPENDIX 2: PRESENTATIONS AND PAPERS

The presentations and papers that have been generated during the current study are shown below. All were produced before the researcher's marriage and hence use the researcher's maiden name of Lamb.

PRESENTATIONS

1. **Methods for Handling Risk and Uncertainty in Business Decision-making,** Department of Management Studies Seminar, December 1997
2. **Methods for Handling Risk and Uncertainty in the Upstream Oil and Gas Industry**, Uncertainty Forum, University of Aberdeen, December 1997
3. **Current Capability in the methods for handling risk and uncertainty in the upstream oil and gas industry**, presented to University of Aberdeen, Department of Management Studies Masters' students, March 1998
4. **Ph.D. Progress Presentation**, presented to Robert Johnston (a representative of CSIRO – the Ph.D. sponsors), October 1998
5. **Current Capability versus Current Practice in decision-making in the upstream oil and gas industry**, presented at the Economics and Management Studies Oil and Gas Seminar, University of Aberdeen, January 1999
6. **Research Methods**, presented to University of Aberdeen, Department of Management Studies Masters' students, March 1999
7. **Ph.D. Progress Presentation**, presented at the Postgraduate and Research Methods Forum, University of Aberdeen, May 1999
8. **Current Practice in decision-making in the upstream oil and gas industry**, presented to Conoco's International Risk and Uncertainty group, June 1999
9. **Methods for handling risk and uncertainty in mature fields**, presented at the Society of Petroleum Engineers Seminar in Aberdeen, September 1999
10. **Using decision analysis in the upstream oil and gas industry**, presented to the Department of Management Studies, December 1999
11. **Decision analysis and organisational performance: The link with success**, presented at the Economics and Management Studies Oil and Gas Seminar, University of Aberdeen, February 2000

12. **Decision analysis and organisational performance: The link with success**, presented to John Wils director of UKOOA, March 2000
13. **Ph.D. Progress Presentation**, presented to CSIRO representatives, March 2000
14. **Decision analysis and organisational performance: The future,** presented to CSIRO employees in Melbourne, April 2000
15. **The Application of Probabilistic and Qualitative Methods to Asset Management Decision-making**, presented at the Society of Petroleum Engineers Asia Pacific Conference on Integrated Modelling for Asset Management held in Yokohama, Japan, April 2000.

PAPERS

Simpson, G.S., Finch, J.H. and Lamb, F.E., 1999, Risk, uncertainty and relations between "strategic" and "within strategy" decision-making in the upstream oil and gas industry, University of Aberdeen, Department of Economics, Discussion Paper 99-1

Lamb, F.E., Simpson, G.S. and Finch, J.H., 1999, Methods for evaluating the worth of reserves in the upstream oil and gas industry, *Geopolitics of Energy*, Issue 22, Number 4, pp2-7

Simpson, G.S., Lamb, F.E., Finch, J.H. and Dinnie, N.C., 1999, The application of probabilistic and qualitative methods to decision-making in mature fields, presented at the Society of Petroleum Engineers conference on the Management of Mature Fields in Aberdeen, September 1999

Finch, J.H., Dinnie, N.C., Simpson, G.S. and Lamb, F.E., 1999, A behavioral framework for understanding decision-making as an inimitable organisational conference, presented at the EAEPE conference in Prague, November 1999

Simpson, G.S., Lamb, F.E., Finch, J.H. and Dinnie, N.C., 2000, The application of probabilistic and qualitative methods to asset management decision-making, paper submitted to Journal of Petroleum Technology.

APPENDIX 3: SPEARMAN TEST FOR CORRELATION

The Spearman's correlation coefficient is frequently used as alternative to the standard (Pearson) correlation coefficient when only ordinal data are available. Spearman's rank order correlation coefficient is mathematically equivalent to the Pearson correlation coefficient computed on ranks instead of scores. For the Spearman test, the scores on each variable must first be rank ordered with the lowest score being assigned a rank of 1. The Spearman's rank order test assumes both variables are continuous and ordinal and that the data are independent. The procedure usually followed is:

1. Select the significance level, α, and decide whether a one or two tailed test is required.
2. Rank-order the scores on each variables separately and subtract each ranking on the response variable from its associated ranking on the explanatory variable. Compute D, the sum of the squares of the resulting differences. Find n, the number of scores on either variable.
3. Compute:

$$r_s = 1 - \frac{6\Sigma D^2}{n(n^2-1)}$$

4. If n is larger than 30, use the normal approximation.
5. From the table in Appendix 5, find the relevant critical value(s) of r_s and make decision as specified at the top of the table in Appendix 5

Adapted from Leach, 1979.

APPENDIX 4 – THE KRUSKAL WALLIS AND WILCOXON RANK SUM TESTS

1. <u>KRUSKAL WALLIS TEST</u>

The Kruskal Wallis test is a direct generalisation of the Wilcoxon Rank Sum Test to three, or more independent samples. The test attempts to decide whether the samples of scores come from the same population (the null hypothesis) or from several populations that differ in location (the alternative hypothesis). It assumes that the data are independent and that the scores on the response variable consist of continuous ordinal data. The procedure usually adopted is:

1. Select the significance level, α
2. Find n, the total number of scores, and t_i, the number of scores in the ith sample. Check that $\Sigma\, t_i=n$.
3. Rank order all n scores
4. Find the sum of ranks in each sample. Denote the rank-sum of the ith sample R_i. Check that $\Sigma\, R_i=n(n+1)/2$
5. Calculate:

$$K=-3(n+1)+\frac{12}{n(n+1)}\Sigma\frac{R_i^2}{t_i}$$

6. If more than a quarter of the response scores are involved in ties, go to 9
7. If more than three samples are being compared or if any of the sample sizes is larger than 5, use the chi-square approximation in 10.
8. Find the critical value in the table in Appendix 6. Reject the null hypothesis if the obtained K is larger than or equal to the critical value. If the null hypothesis is rejected, use multiple comparisons to locate the effects. Otherwise, stop.
9. For extensive ties, find u_i, the number of scores at each particular value of the response variable and divide the value of K obtained in 5 by,

$$1-\frac{\Sigma\, u_i(u_i-1)(u_i+1)}{n^3-n}$$

10. Chi-square approximation. Where there are more than two samples, a distribution known as the chi-square distribution frequently plays a role similar to that of the normal distribution in two sampled cases in providing an approximation to the

null distribution of a test statistic. This is the case with K. The table in Appendix 7 gives critical values of the Chi-square distribution that may be used with sample sizes beyond the scope of the exact table in Appendix 6. To obtain the relevant critical value:

- Find the number of degrees of freedom, the number of samples minus 1.
- Find the relevant critical value in the table in Appendix 7. Reject the null hypothesis if the obtained K (corrected for ties as in 9 if necessary) is larger than or equal to the critical value. If the null hypothesis is rejected, use multiple comparisons to locate the effects. Otherwise, stop.

Adapted from Leach (1979)

2. Multiple Comparisons using the Wilcoxon Rank Sum Test

When a significant result has been obtained in the Kruskal Wallis test, all that is known is that there is some difference in location between the samples. The locus of this difference is unknown. The Wilcoxon Rank Sum test is frequently used for this purpose and the procedure generally followed is:

1. Select the per experiment significance level, α
2. Decide on c, the number of comparisons you wish to make. Normally you will wish to compare all possible pairs of samples. If there are k samples, the number of pairs will be c=k(k-1)
3. Order the k samples with respect to their average ranks (given by R_i/t_i) and write the sample names in order.
4. Using a two-tailed test carry out the Wilcoxon Rank Sum tests as follows. Using the ordering given in 4 and the table in Appendix 8, compare the left-most sample first with the right most, next with the second from the right, and so on until a non-significant result is obtained. When this happens, join the two sample names with a line. Then take the second sample from the left and compare it first with the right most, next with the second from the right, and so on until either a non-significant result is obtained or two samples are being compared that are already joined by a line. Continue in this way until all comparisons have been exhausted.

Adapted from Leach (1979)

3. The Kruskal Wallis and Wilcoxon Rank Sum tests for PR

1. Arrange the companies into groups depending on their ranking position in the sophistication of decision analysis rank. (For example, column 1<=DA<=5 contains companies that were ranked in the top 5 in the decision analysis ranking). Then note companies proved reserves under the appropriate heading. The following simple notation will be used, n will be the total number of companies, t_1 will be the number in 1<=DA<=5, t_2 will be the number in 6<=DA<=10, t_3 will be the number in 11<=DA<=14.
2. Rank the data from low to high (with rank of 1 being assigned to the company with the least proved reserves). Compute the rank sums for the three samples. This is done in the table below, where R_i refers to the rank sum of the ith group, so R_1=57, R_2=34 and R_3=14. The test statistic will need to take account of what is going on in all 3 groups to give an adequate picture of the data. Since there are different numbers of companies in some of the groups, the mean rank in each group is more informative than the rank sum. This is obtained by dividing the rank sum R_i for a given group by the number of companies in that group and is shown in the table below for each group. If the null hypothesis is true, then these three average ranks should all be relatively close together. In this case the average ranks differ, this indicates the alternative hypothesis is true.

1<=DA<=5	**6<=DA<=10**	**11<=DA<=14**
10	5	4
9	12	2
13	6	7
11	3	1
14	8	
t_1= 5, R_1=57, R/t = 11.4	**t_2=5, R_2=34, R/t=6.8**	**t_3=4, R_3=14, R/t=3.5**

3. The test statistic needs to reflect how different the average ranks are, that is it should be a measure of the dispersion of the ranks. Leach provides the proof of the formula (1979 pp149-150), here it will be take as given:

$$K = -3(n+1) + \frac{12}{n(n+1)} \sum \frac{R_i^2}{t_i}$$

4. In this case, K=8.1428

   There are 2 degrees of freedom in this case.

   It is therefore possible to reject the null hypothesis at α=0.05

5. To find the locus of the difference, use the rank sum test and choose α=0.02 as the significance level.

6. Writing the groups in order of increasing R/T:

11<=DA<=14	**6<=DA<=10**	**1<=DA<=5**
4	5	10
2	12	9
7	6	13
1	3	11
	8	14
t_1= 5, R_1=57, R/t = 11.4	**t_2=5, R_2=34, R/t=6.8**	**t_3=4, R_3=14, R/t=3.5**

7. Then comparing 11<=DA<=14 with 1<=DA<=5 gives:

p's	**q's**
5	0
5	0
5	0
5	0
P=20	**Q=0**

S=P-Q=20, which is significant at α=0.02

8. Then comparing 11<=DA<=14 with 6<=DA<=10 gives:

p's	q's
4	1
5	0
3	2
5	0
P=17	Q=3

S=P-Q=14, which is not significant at α=0.02.

9. So the result of the Wilcoxon Rank Sum for PR is, $\overline{11<=DA<=14, 6<=DA<=10}$, 1<=DA<=5

APPENDIX 5: CRITICAL VALUES OF ρ FOR SPEARMAN TESTS

Examples: For a two tailed test, with n=15 and α=0.05, reject the null hypothesis if the obtained ρ is larger than or equal to 0.521, or if it is smaller than or equal to -0.521.

Examples: For a one tailed test, with n=15 and α=0.05, if an upper tail test is required, reject the null hypothesis if the obtained is larger than or equal to 0.446. If a lower tail test is required, reject if the obtained ρ is smaller than or equal to -0.446.

	One tailed significance level, α					
	0.1	0.05	0.025	0.01	0.005	0.001
	Two tailed significance level, α					
n	0.2	0.1	0.05	0.02	0.01	0.002
4	1	1				
5	0.8	0.9	1	1		
6	0.657	0.829	0.866	0.943	1.00	
7	0.571	0.714	0.786	0.893	0.929	1.00
8	0.524	0.643	0.738	0.833	0.881	0.952
9	0.483	0.6	0.7	0.783	0.833	0.917
10	0.455	0.564	0.648	0.745	0.794	0.879
11	0.427	0.536	0.618	0.709	0.755	0.845
12	0.406	0.503	0.587	0.678	0.727	0.818
13	0.385	0.484	0.560	0.648	0.703	0.791
14	0.367	0.464	0.538	0.626	0.679	0.771
15	0.354	0.446	0.521	0.604	0.657	0.750
16	0.341	0.429	0.503	0.585	0.635	0.729
17	0.328	0.414	0.488	0.566	0.618	0.711
18	0.317	0.401	0.474	0.550	0.6	0.692
19	0.309	0.391	0.46	0.535	0.584	0.674
20	0.299	0.38	0.447	0.522	0.57	0.66

From Leach (1979)

APPENDIX 6: CRITICAL VALUES OF K FOR KRUSKAL WALLIS TEST WITH 3 INDEPENDENT SAMPLES

t_1 is the number of observations in the largest sample
t_3 is the number of observations in the smallest sample

Example: For $t_1=4$, $t_2=3$, $t_3=2$, and $\alpha=0.05$, reject the null hypothesis if the obtained K is larger than or equal to 5.33

The table may be used for any case for which t_1, t_2, t_3 are all less than six. The test is inherently two tailed.

			Significance level, α						
t_1	t_2	t_3	0.2	0.1	0.05	0.025	0.01	0.005	0.001
2	2	1	3.6						
2	2	2	3.71	4.57					
3	2	1	3.52	4.29					
3	2	2	3.93	4.5	4.71				
3	3	1	3.29	4.57	5.12				
3	3	2	3.78	4.56	5.36	5.56			
3	3	3	3.47	4.62	5.6	5.96	7.2	7.2	
4	1	1	3.57						
4	2	1	3.16	4.5					
4	2	2	3.67	4.46	5.33	5.5			
4	3	1	3.21	4.06	5.21	5.83			
4	3	2	3.44	4.51	5.44	6	6.44	7	
4	3	3	3.39	4.71	5.73	6.15	6.75	7.32	8.02
4	4	1	3.27	4.17	4.97	6.17	6.67		
4	4	2	3.46	4.55	5.45	6.08	7.04	7.28	
4	4	3	3.42	4.55	5.6	6.39	7.14	7.6	8.33
4	4	4	3.5	4.65	5.69	6.62	7.65	8	8.65
5	1	1	3.86						
5	2	1	3.33	4.2	5				
5	2	2	3.36	4.37	5.16	6	6.53		
5	3	1	3.22	4.02	4.96	6.04			
5	3	2	3.41	4.65	5.25	6	6.82	7.19	
5	3	3	3.44	4.53	5.65	6.32	7.08	7.52	8.24
5	4	1	3.09	3.99	4.99	5.78	6.95	7.36	
5	4	2	3.36	4.54	5.27	6.04	7.12	7.57	8.11
5	4	3	3.32	4.55	5.63	6.41	7.45	7.91	8.5
5	4	4	3.33	4.62	5.62	6.67	7.76	8.14	9
5	5	1	3.24	4.11	5.13	6	7.31	.7.75	
5	5	2	3.39	4.51	5.34	6.35	7.27	8.13	8.69
5	5	3	3.43	4.55	5.71	6.49	7.54	8.24	9.06
5	5	4	3.31	4.52	5.64	6.67	7.77	8.37	9.32
5	5	5	3.42	4.56	5.78	6.74	8	8.72	9.68

From Leach (1979)

APPENDIX 7: CRITICAL VALUES OF CHI-SQUARE AT THE 0.05 AND 0.01 LEVEL OF SIGNIFICANCE

Example: With α=0.05 and 4 degrees of freedom reject the null hypothesis if the critical value obtained is larger than or equal to 9.488. The distribution is inherently two tailed

	Level of significance, α	
df	0.05	0.01
1	3.841	6.35
2	5.991	9.210
3	7.815	11.345
4	9.488	13.277
5	11.070	15.086
6	12.592	16.812
7	14.067	18.475
8	15.507	20.090
9	16.919	21.666
10	18.307	23.209
11	19.975	24.725
12	21.026	26.217
13	22.362	27.688
14	23.685	29.141
15	24.996	30.578

From Levin and Fox (1988)

APPENDIX 8: CRITICAL VALUES OF S FOR THE WILCOXON RANK SUM TEST

t_1 is the number of observations in the largest sample
t_2 is the number of observations in the smallest sample

Example: For a two-tailed test, with t_1=3, t_2=2 and α=0.05, reject the null hypothesis if the obtained S is larger than or equal to 6, or if it is smaller than or equal to –6.
Example: For a one-tailed test, with t_1=3, t_2=2 and α=0.05, if an upper tailed test is required reject the null hypothesis if the obtained S is larger than or equal to 58. If a lower tail test is required, reject if the obtained S is smaller than or equal to –58.

The table may be used for any case for which t_1, t_2, t_3 are all less than six. The test is inherently two tailed.

		One tailed significance level, α					
		0.1	0.05	0.025	0.01	0.005	0.001
		Two-tailed significance level, α					
t_1	t_2	0.2	0.1	0.05	0.02	0.01	0.002
3	2	6					
3	3	7	9				
4	2	8					
4	3	10	12				
4	4	10	14	16			
5	2	8	10				
5	3	11	13	15			
5	4	12	16	18	20		
5	5	15	17	21	23		
6	2	10	12				
6	4	14	18	20	22	24	
6	5	16	20	24	26	28	
6	6	18	22	26	30	32	

From Leach (1979)

BIBLIOGRAPHY

Aldag, R.J., and Power, D.J., 1986, An empirical assessment of computer aided decision analysis, *Decision Sciences*, 17, pp572-588

Aldrich, H.E., 1979, *Organisations and environments*, Englewood Cliffs, Prentice Hall, New Jersey

Allaire, Y., and Firsitrotu, M.E., 1989, Coping with strategic uncertainty, *Sloan Management Review*, 3, pp7-16

Allais, M., 1953, Le comportement de l'homme rationnel devant le risque: Critique des postulates et aximoes de l'ecole americaine, *Econometrica*, 21, pp503-546

Allias, M., and Hagen, J., editors, 1979, *Expected utility hypotheses and the Allais paradox*, Dordrecht, The Netherlands, Reidel

Anderson, B.F., Deane, D.H., Hammond, K.R., and McClelland, G.H., 1981, *Concepts and Judgement in Decision Research*, Praeger, New York

Argote, L., 1982, Input uncertainty and organisational co-ordination in hospital emergency units, *Administrative Science Quarterly*, 27, pp420-434

Argote, L., Seabrigh, M.A., and Dyer, L., 1986, Individual versus group use of base rate and individuating information, *Organisation Behaviour and Human Decision Processes*, 38, pp65-75

Armstrong, J.S., Denniston, W.B., and Gordon, M.M., 1975, The use of decomposition principle in making judgements, *Organisation Behaviour and Human Decision Processes*, 14, pp257-263

Arnold, G.C., Hatzopoulous, P.D., 2000, The theory-practice gap in capital budgeting: Evidence from the United Kingdom, *Journal of Business Finance and Accounting*, June, volume 27, numbers 5 and 6, pp603-626

Atrill, P., 2000, *Financial Management for Non-specialists*, Second Edition, Prentice Hall, England

Bailey, B., Couet, B., Lamb. F., Rose, P., and Simpson, G., in press, Taking a Calculated Risk, *Oilfield Review*

Ball, B.C. and Savage, S.L., 1999, Holistic vs. Hole-istic E&P Strategies, SPE 57701, *Journal of Petroleum Technology*, September, pp74-84

Barley, S., 1995, Images of imaging: notes on doing longitudinal fieldwork, in Huber, G. and Huber, G. and Van de Ven, A. (editors), *Longitudinal Field Research Methods: Studying processes of organisational change*, Sage, London

Baumard, P., 1999, *Tacit Knowledge in Organisations*, Sage Publications, London

Bavishi, V.B., 1981, Capital budgeting practices at multinationals, *Management Accounting*, August, pp32-35

Baxter, M. and Rennie, A., 1996, *A financial calculus: An introduction to derivative pricing*, Cambridge University Press, Cambridge

Bechofer, F., 1974, Current Approaches to empirical research: some central ideas, in Rex, J., (editor), *Approaches to Sociology: an introduction to major trends in British Sociology*, Routledge, Kegan Paul, London

Bell, C. and Encel, S., 1978, (editors), *Inside the Whale*, Peragamon Press, Oxford

Bell, C. and Newby, H., 1977, (editors), *Doing Sociological Research,* Allen&Unwin, London

Bernoulli, D., 1738, Specimen theoriae novae de mensura sortis, translated by Louise Sommer published in *Econometrica*, volume 22, 1954, pp23-36

Bernoulli, J., 1713, *Ars conjectandi tractatus de seribus infinitis,* Basel

Bernstein, P.L., and Silbert, T.H., 1984, Keeping Informed, *Harvard Business Review*, 62(5), pp32-40

Black, F. and Scholes, M., 1973, The pricing of options and corporate liabilities, *Journal of Political Economy*, 81, pp637-554

Blair, J.D., Slaton, C.R., and Savage, G.T., 1990, Hospital Physician Joint Ventures: a Strategic Approach for Both Dimensions of Success, *Hospital and Health Services Administration*, 35(1), pp3-26

Borsch, K. and Mossin, J., (editors), 1968, *Risk and Uncertainty*, proceedings of a conference held by the International Economic Association, Macmillan, New York

Bourgeois, L.J., III, 1985, Strategic goals, perceived uncertainty, and economic performance in volatile environments, *Academy of Management Journal*, 28, pp548-573

Bourgeois, L.J., III, 1984, Strategic management and determinism, *Academy of Management Review*, 9, pp586-596

Bourgeois, L.J., III, 1981, On the Measurement of Organisational Slack, *Academy of Management Review,* 6, pp29-39

Bourgeois, L.J., III, and Eisenhardt, K.M., 1988, Strategic Decision Processes in High Velocity Environments: Four cases in the Microcomputer Industry, *Management Science*, 34(7), pp816-835

Bowman, C. and Ambrosini, V., 1997, Using Single Respondents in Strategy Research, *British Journal of Management*, volume 8, pp119-131

BP statistical review of world energy, 2000, http://www.bp.co.uk

Brealey, R.A and Myers, S.C., 1996, *Principles of Corporate Finance*, McGraw-Hill, New York

Brennan, M.J., and Schwartz, E.S., 1985, Evaluating Natural Resource Investments, *Journal of Business*, 58(5), p135

Brown, M., 1992 Thinking small about oil, *Management Today*, March, p80-84

Brunsson, N., 1985, *The irrational organisation*, Wiley, Chichester

Bryman, A., and Burgess, R.G., 1994, (editors), *Analysing Qualitative Data*, Routledge, London

Bryman, A., 1989, *Research method and organisation studies*, George Unwin, London

Buckley, A., 2000, *Multinational Finance*, 4th edition, Prentice Hall, England

Buckley, A., Buckley, P., Langevin, P., and Tse, K., 1996, The financial analysis of foreign investment decisions by large UK based companies, *European Journal of Finance*, 2(2), pp181-206

Budescu, D.V., and Wallsten, T.S., 1995, Processing linguistic probabilities, in Busemeyer, J. and Medin, D.L., (editors), *Decision-making from a cognitive perspective*, pp275-318

Bunn, D., 1984, *Applied decision analysis*, McGraw Hill, New York

Burgess, R.G., 1984a, *The Research Process in Educational Settings: Ten Case Studies*, Falmer Press, London

Burgess, R.G., 1984b, *In the Field: An introduction to field research*, George Allen and Unwin, London

Burke, L.A., and Miller, M.K., 1999, Taking the mystery out of intuitive decision making, *The Academy of Management Executive*, volume 13, issue 4, November, p19

Burnside, C.A., 1998, *Applications of Risk Analysis and Investment Appraisal Techniques in Day to Day operations of an upstream oil company*, submitted in partial fulfillment of the degree of Master of Business Administration, University of Aberdeen, unpublished.

Butler, R., 1991, *Designing organisations – A decision-making perspective*, Routledge, London

Campbell, C.J., 1997, *The Coming Oil Crisis*, Multi-Science Publishing Company and Petroconsultants, S.A.

Capon, N., Farley, J.U., and Hulbert, J.M., 1994, Strategic Planning and Financial Performance: More Evidence, *Journal of Management Studies*, 31(1), pp105-110

Carr, C., and Tomkins, C., 1998, Context, culture, and the role of the finance function in strategic decisions. A comparative analysis of Britain, Germany, the U.S.A. and Japan, *Management Accounting Research*, 9, pp213-239

Chakravarthy, B.S., and Doz, Y., 1992, Strategy process research: Focussing on corporate self-renewal, *Strategic Management Journal*, 13, pp5-14

Chang, R.Y., and Morgan, M.W., 2000, Performance Scorecards: Measuring the Right Things in the Real World, HR Magazine, August, volume 48, issue 8, p170

Chapman, L.J., and Chapman, J.P., 1969, Illusory correlation as an obstacle to the use of valid psychodiagnostic signs, *Journal of Abnormal Psychology*, 74, pp271-280

Child, J., 1974, What Determines Organisation Performance? The Universals vs. the it-all-depends, *Organisation Dynamics*, 1, pp2-18

Child, J., 1972, Organisational structure, environment, and performance: the role of strategic choice, *Sociology*, 6, pp2-21

Clemen, R., 1999, *Does Decision Analysis Work? A Research Agenda*, Furqua School of Business, unpublished, first presented at a seminar at the University of Texas, Austin, April, 1996

Clemen, R., Jones, S.K., and Winkler, R.L., 1996, Aggregating Forecasts: An empirical evaluation of some Bayesian Methods, in Berry, D., Chaloner, K., and Geweke, J., (editors), *Bayesian Statistics and Econometrics: Essays in Honor of Arnold Zeller*, pp2-13, Wiley, New York

Clemen, R., and Kwit, R.C., 2000, The Value of Decision Analysis at Eastman Kodak Company, 1990-1998, forthcoming in *Interfaces*

Cohen, M. S., 1989, A database tool to support probabilistic assumption based reasoning in intelligence analysis, *Proceedings of the 1989 Joint Director of the C^2 Symposium*, Ft. McNair, VA, June, pp27-29

Cohen, M.S., Schum, D.A., Freeling, A.N.S., and Chinnis, J.O., 1985, *On the art and science of hedging a conclusion: A cognitive approach*, Falls Church, Decision Science Consortium

Cooper, M. and Burford, S., 1999, Murchison Field: "doing things better", published in the proceedings of *Reservoir Management of Mature Fields*, SPE Aberdeen Section, 29th September

Copeland, T., Koller, T., Murrin, J., 1990, *Valuation: Measuring and Managing the Value in Companies*, John Wiley and Sons, New York City

Corbin, R.M., 1980, Decisions that might not get made, in Wallsten, T., (editor), *Cognitive Processes in choice and decision behaviour*, Hillsdale, New Jersey, Erlbaum

Cyert, R.M., and March, J.G., 1963, *A Behavioural Theory of the Firm*, Prentice Hall

Das, T.K., Gosavi, A., Mahadevan, S., Marchalleck, N., 1999, Solving Semi-Markov Decision Problems Using Average Reward Reinforcement Learning, *Management Science*, volume 45, number 4, April

Daft, R.L., 1985, Why I recommend that your manuscript be rejected and what you can do about it, Cummings, L.L., Frost, P.P. (editors), *Publishing in the Organisational Sciences*, Richard D. Irwin, Homewood, Illinois

Datastream, http://www.datastreaminsite.com

Dawes, R.M., 1988, *Rational Choice in an Uncertain World*, Harcourt Brace Jovanovich, San Diego, California

Dean, J.W. and Sharfman, M.P., 1996, Does decision process matter? A study of strategic decision-making effectiveness, *Academy of Management Journal*, April, volume 39, number 2, pp368-97

De Morgan, A., 1847, *Formal Logic: The calculus of inference, necessary and probable*, London

Denzin, N.K., 1978, *Sociological Methods: A Sourcebook*, McGraw-Hill, New York

Department of Trade and Industry, 2000, *UK Energy in Brief*, http://www.dti.gov.uk

Department of Trade and Industry, 1999, *The oil and gas industry Task Force Report A Template for Change*, pp1-2

Department of Trade and Industry, 1998, *The Energy Report*, volume 2, The Stationery Office, London

Dess, G.G., 1987, Consensus on Strategy Formulation and Organisational Performance: Competitors in a Fragmented Industry, *Strategic Management Journal*, 8, pp259-277

Dess, G.G. and Origer, N.K., 1987, Environment, Structure and Consensus in Strategy Formulation: A Conceptual Integration, *Academy of Management Review*, 12(2), pp313-330

Dess, G.G., and Robinson, R.B., 1984, Measuring Organisational Performance in the Absence of Objective Measures: The case of the privately-held firm and conglomerate business unit, *Strategic Management Journal*, 5, pp265-273

DeWoot, P., Heyvaert, H., and Martou, F., 1977-78, Strategic Management: An empirical study of 168 Belgian Firms, *International Studies of Management and Organisation*, 7, pp60-75

Dixit, A.K. and Pindyck, R.S., 1998, The options approach to capital investment, in Rutherford, J. (editor), *Financial strategy: Adding Stakeholder Value*, Wiley, Chichester

Dixit, A.K., and Pindyck, R.S., 1994, *Investment Under Uncertainty,* Princeton University Press

Drury, C., 1985, *Management and Cost Accounting*, von Nostrand Reinhold, Wokingham

Edwards, W., 1954, The theory of decision-making, *Psychological Bulletin*, 41, pp380-417

Ekenberg, L., 2000, The logic of conflicts between decision making agents, *Journal of logic and computation*, volume 10, number 4, pp583-602

Eilon, S. and Fawkes, T.R., 1973, Sampling Procedures for Risk Simulation, *Operational Research Quarterly*, 24, number. 2, pp241-252

Eisenhardt, K.M., 1989, Making fast decisions in high velocity environments, *Academy of Management Journal*, 32, pp543-577

Eisenhardt, K.M. and Bourgeois, L.J., III, 1988, Politics of strategic decision-making in high velocity environments: Towards a midrange theory, *Academy of Management Journal*, 31, pp737-770

Energy Day, 2000, *Oil age leaking away*, 3rd July

Etzioni, A., 1991, Humble Decision-making, *The logic of business decision-making*, Harvard Business Review

Farquhar, P.H., 1984, Utility assessment methods, *Management Science*, 30, pp1283-1300

Feldman, M.A., and March, J.G., 1981, Information in organisations as signal and symbol, *Administrative Science Quarterly*, 27, pp171-186

Ferner, A., 1989, The Research Process in the Cross National Industrial Relations Case Study: A personal account, *paper originally prepared for a talk to doctoral researchers at the Centre for Advanced Studies in the Social Sciences*, Insituto de Juan March de Estudios e Investigaciones, 12th April

Financial Times, http://www.ft.com

Finch, J.H., and McMaster, R., 2000, *On non-parametric statistical inference in the pursuit of causal explanations*, submitted to the Cambridge Realist Workshop Reunion Conference, May

De Finetti, B, 1964, Foresight: Its logical laws, its subjective sources, in Kyberg, A., and Smoker, E., (editors), *Studies in Subjective Probability*, (essay originally published, 1937, Wiley)

Fischer, G., 1977, Convergent validation of decomposed multi-attribute utility assessment procedures for risky and riskless decisions, *Organisational Behaviour and Human Performance*, 18, pp295-315

Fischer, G., 1975, *An Experimental Study of Four Procedures For Aggregating Subjective Probability Assessments, Technical Report 75-7*, Decisions and Designs, Inc., Washington D.C.

Fischoff, B., 1982, Debiasing, in Kahneman, D., Slovic, P., Tversky, A., (editors), *Judgement under uncertainty: Heuristics and Biases*, pp422-444, Cambridge University Press, Cambridge

Fischoff, B., 1980, Decision Analysis: Clinical Art or Clinical Science, in Sjoberg, L., Tyszka, T., Wise, J.A., (editors), *Human Decision-making*, Bodfors, Doxa

Fletcher, A.J.P., and Dromgoole, P., 1996, *Current Practices of handling subsurface uncertainty*, unpublished Juniper Document MR9501/08, October

Ford, C.M. and Gioia, D. A., 2000, Factors influencing creativity in the domain of managerial decision making, *Journal of Management*, July, volume 26, number 4, pp705-732

Ford, C.M., 1989, *Creativity in managerial decision-making: An examination of factors that influence the creativity of managers' decisions*, Unpublished doctoral dissertation, Pennsylvania State University, University Park

Fredrickson, J.W., 1985, Effects of Decision Motive and Organisational Performance Level on Strategic Decision Processes, *Academy of Management Journal*, 28(4), pp821-843

Fredrickson, J.W., 1984, The Comprehensiveness of Strategic Decision Processes: Extension, Observations, Future Directions, *Academy of Management Journal*, 27(3), pp445-466

Fredrickson, J.W., and Iaquinto, A.L., 1989, Inertia and Creeping Rationality in Strategic Decision Processes, *Academy of Management Journal*, 32(4), pp516-542

Fredrickson, J.W., and Mitchell, T.R., 1984, Strategic decision processes: comprehensiveness and performance in an industry with an unstable environment, *Academy of Management Journal*, 27, pp399-423

French S., 1989, *Readings in decision analysis,* Chapman and Hall Ltd., London

French, S., 1984, From decision theory to decision analysis, in Eglese, R.W and Rand, G.K, (editors), *Developments in Operational Research*, pp77-87, Pergamon Press, Oxford

Galbraith, J.R., 1973, *Designing Complex Organisations*, Addison-Wesley, Reading, Mass.

Galli, A.G., Armstrong, M. and Jehl, B., 1999, Comparison of three methods for evaluating oil projects, *Journal of Petroleum Technology*, October, pp44-50

Gans, J.S., 1999, Limited information, the possibility of rational choice and contingent coping valuation method, *International Journal of Social Economics,* January, volume 26, number 23, pp402-414

Gigerenzer, G., 1991, How to make cognitive illusions disappear: Beyond "heuristics and biases", *European Review of Social Psychology*, 2, pp83-115

Gigerenzer, G. and Hoffrage, U., 1995, How to improve Bayesian Reasoning without instruction: Frequency Formats, *Psychological Review,* 102, pp684-704

Gill, J. and Johnson, P., 1991, *Research Methods for Managers*, Paul Chapman Publishing, London

Gluyas, J.G., Hichens, H., Evans, I.J. and Hogg, A.J.C., (editors), 2001, *Oil and gas fields of the United Kingdom Continental Shelf*, Geological Society, London

Goldstein, W.M., and Einhorn, H.J., 1987, Expression theory and the preference reversal phenomena, *Psychological Review*, 94, pp236-254

Goll, I., and Rasheed, A.MA., 1997, Rational Decision-making and Firm Performance: The moderating role of environment, *Strategic Management Journal*, 18(7), pp583-591

Goodwin, P., and Wright G., 1991, *Decision analysis for management judgement*, John Wiley&Sons Limited, Chichester, England

Gough, R., 1975, *The Effects of Group Format on Aggregate Subjective Probability Distributions, Utility, Probability and Human Decision-making,* Reidel, Dordrecht, Holland

Grandori, A., 1984, A prescriptive contingency view of organisational decision-making, *Administrative Science Quarterly,* 29, pp192-209

Grayson, C.J., 1960, *Decisions under uncertainty: oil and gas drilling decisions*, Harvard University Press, Cambridge

Grether, D.M., and Plott, C.R., 1979, Economic theory of choice and the preference reversal phenomenon, *American Economic Review*, 69, pp623-638

Grinyer, P.S., McKiernan and Yasai-Ardekani, M., 1988, Market Organisational and Managerial Correlates of Economic Performance in the U.K. Electrical Engineering Industry, *Strategic Management Journal*, 9, pp297-318

Grinyer, P.S., and Norburn, D., 1977-78, Planning for existing markets: an empirical study, *International Studies in Management and Organisation*, 7, pp99-122

Gunn, B., 2000, Decisions, Decisions, Decisions, *Strategic Finance*, volume 81, issue 7, p14

Gustafson, D.H., Shukla, Delbecq, A., and Walster, G.W., 1973, A Comparative Study of Differences in Subjective Likelihood Estimates Made by Individuals, Interacting Groups, Delphi Groups, and Nominal Groups, *Organisational Behaviour and Human Performance*, 9, pp200-291

Gutleber, D.S., Heigerger, E.M., Morris, T.D., 1995, Simulation Analysis for Integrated Evaluation of Technical and Commercial Risk, *Journal of Petroleum Technology*, December, p1062

Halley, A., and Guilhorn, A., 1997, Logistic behaviour of small enterprises: performance, strategy and definition, *International journal of physical distribution and logistics management*, July-August, volume 27, numbers 7-8, p475

Hambrick, D.C. and Snow, C.C., 1977, A contextual model of strategic decision-making in organisations, *Academy of Management Proceedings*, pp109-112

Hammersley, M., 1992, *What's wrong with ethnography?*, Routledge, London

Hammersley, M. and Atkinson, P., 1983, *Ethnography: Principles in Practice*, Longman, London

Hammond, J., Keeney, R., Raiffa, H., 1999, *Smart Choices*, Harvard Business School Press

Hammond, J., 1967, Better decisions with preference theory, *Harvard Business Review*, November-December, pp123-141

Hammond, P., 1964, (editor), *Sociologists at work*, Basic Books, New York

Harper, J., 1984, *Measuring Business Performance*, Institute of Manpower Studies Series No. 7, Gower Publishing Company Ltd., England

Harrison, E. F., 1995, *The managerial decision-making process*, Houghton-Mifflin, USA

Harrison, E.F., and Pelleteir, M.A., 2000, Levels of strategic decision success, *Management Decision*, 29th February, volume 38, number 2, pp107-118

Hart, S.L., 1992, An integrative framework for strategy making processes, *Academy of Management Review*, 17, pp327-351

Hart, S. and Banbury, C., 1994, How Strategy-Making Processes Can Make a Difference?, *Strategic Management Journal*, 15, pp251-269

Hershey, J.C., Kunreuther, H.C., and Schoemaker, P.J.H., 1982, Sources of bias in assessment procedures for utility functions, *Management Science*, 28, pp936-954

Hespos, R.F., and Straussman, P.A., 1965, Stochastic Decision Trees in the Analysis of Investment Decisions, *Management Science*, number 10, pp244-259

Higson, C., 1995, *Business Finance*, 2nd Edition, Butterworths, London

Hirst, E., and Schweitzer, M., 1990, Electric-utility resource planning and decision-making, *Risk Analysis*, 10, pp137-146

Hitt, M.A. and Tyler, B.B., 1991, Strategic decision models: Integrating different perspectives, *Strategic Management Journal*, 6, pp171-180

Hogarth, R.M., 1987, *The psychology of judgement and choice*, 2nd Edition, Jossey-Bass, San Francisco

Holmes, P., 1998, *Investment Appraisal*, International Thomson Business Press, London

Hoover’s on-line business network, http://www.hoovers.com

Hora, S.C., Dodd, N.G., and Hora, J.A., 1993, The use of decomposition in probability assessments of continuous variables, *Journal of Behavioural Decision-making*, 6, pp133-147

Hosseini, J., 1986, Decision Analysis and its Application in the Choice between Two Wildcat Oil Ventures, *Interfaces,* 16 (2), pp75-85

Howard, R.A., 1988, Decision analysis: Practice and Promise, *Management Science*, volume 34, number 6, June 1988, pp679-695

Howard, R.A., 1968, *The foundations of decision analysis*, IEEE Trans. Sys. Sc. Cyb. SSC-4, pp211-219

Hull, J.C., 1977, Dealing with dependence in risk simulations, *Operational Research Quarterly*, 28 (1), pp201-213

Humphreys, P., 1980, Decision Aids: Aiding Decisions in Sjoberg, L., Tyszka, T., Wise, J.A., (editors), *Human Decision-making*, Bodfors, Doxa

Humphreys, P., and Berkeley, D., 1985, Handling uncertainty: Levels of analysis of decision problems, in Wright, G., (editor), *Behavioural Decision-making*, Pelnum Press, New York

Humphreys, P.C., and McFadden, W., 1980, Experiences with MAUD: Aiding decision structuring versus bootstrapping the decision-maker, *Acta Psychologica*, 45, pp51-69

Hyne, N., 1995, *None technical guide to petroleum geology, exploration, drilling and production*, Penwall Publishing Company, Tulsa

Ikoku, C.U., 1984, *Natural gas reservoir engineering*, Wiley, New York

Janis, I.L., 1989, *Crucial decisions: Leadership in policy making and crisis management*, Free Press, New York

Janis, I.L., and Mann, L., 1977, *Decision-making: a psychological analysis of conflict, choice and commitment*, Free Press, New York

Jaynes, E.T., 1956, *Probability theory with applications in Science and Engineering*, No 4 in Colloquium Lectures in Pure and Applied Science, Socony-Mobil Oil Company, USA

Jeffreys, B., 1939, *Theory of probability*, Claredon Press, Oxford

John, R.S., von Winterfeldt, D., Edwards, W., 1983, The quality and user acceptance of multiattribute utility analysis performed by computer and analyst, in Humphreys, P., von Winterfeldt, D., Edwards, W., (editors), *Analysing and aiding decision processes*, pp301-319, Amsterdam.

Jones, R.E., Jacobs, L.W., and Van Spijker, W., 1992, Strategic Decision Processes in International Firms, *Management International Review*, 32, pp219-236

Kahneman, D., Slovic, P. and Tversky, A., (editors), 1982, *Judgement Under Uncertainty: Heuristics and Biases*, Cambridge University Press

Kahneman, D., and Tversky, A., 1982, The psychology of preferences, *Scientific American*, 246, number 1, p136

Kaufman, G.M., and Thomas, H., 1977, *Modern Decision Analysis*, Penguin Books, London

Kaye, D., 1995, The importance of information, *Management Decision*, volume 33, number 5, p5

Keats, B.W., 1988, The vertical construct validity of business economic performance measures, *The journal of applied behavioural science*, 24(2), pp151-160

Keeffer, D.L., and Bodily, S.E., 1983, Three Point Approximations for Continuous Random Variables, *Management Science*, 29 (5), pp595-609

Keeney, R., 1982, Decision Analysis: an Overview, *Operations Research*, 30, number 5, pp803-837

Keeney, R., 1980, Decision Analysis in the Geo-technical and Environmental Fields, in Sjoberg, T., Tyszka, T., and Wise, J.A., (editors), *Human Decision-making*, Bodafors, Doxa

Keeney, R., 1979, Decision Analysis: how to cope with increasing complexity, *Management Review*, p26

Keeney, R.L. and Raiffa, H., 1976, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, Wiley, New York

Keeney, R.L. and Raiffa, H., 1972, A critique of formal analysis in public decision-making, in Drake, A.W., Keeney, R.L. and Morse, P., (editors), *Analysis of public systems*, pp9-11, MIT Press, Cambridge

Kemma, A.G.Z., 1993, Case Studies on Real Options, *Financial Management*, 22, pp259-270

Keren, G., 1996, Perspectives of Behavioural Decision-making: Some critical notes, *Organisational Behaviour and Human Decision Processes*, 63(3), March, pp169-178

Kester, W.C., 1984, Today’s options for tomorrow’s growth, *Harvard Business Review*, March – April

Keynes, J.M, 1921, *A treatise on probability*, Macmillan, London

Kim, S.H., Farragher, E.J. and Crick, T., 1984, Foreign capital budgeting practices used by the US and non-US multinational companies, *Engineering Economist*, 29(3), pp207-215

Kimbrough, S.O., and Weber, M., 1994, An empirical comparison of utility assessment programs, *European Journal of Operational Research*, 75, pp617-633

Kleinmuntz, D.N., 1990, Decomposition and the control of error in decision analytic models, in Hogarth, R. (editor), *Insights in decision-making: A tribute to Hillel J.Einhorn*, pp107-126, University of Chicago Press, Chicago

Kleinmuntz, D.N., Fennema, M.G., and Peecher, M.E., 1996, Conditional assessment of subjective probabilities: Identifying the benefits of decomposition, *Organisational Behaviour and Human Decision Processes*, 66, pp1-15

Krantz, D., Luce, R.D., Suppes, P. and Tversky, A., 1971, *Foundations of measurement*, Volume 1, Academic Press, New York

Kunreuther, H.C., and Schoemaker, P.J.H., 1980, *Decision analysis for complex systems integrating descriptive and prescriptive components*, Working paper, Department of decision sciences, University of Pennsylvania

Laherrére, J., H., 1999, Reserve Growth: Technological Progress or Bad Reporting and Bad Arithmetic, *Geopolitics of Energy*, April

Laing, A., 1997, *Marketing in NHS Trusts: Adoption and Adaptation of Marketing Concepts in a Public Sector Setting*, unpublished Ph.D. Thesis, University of Aberdeen

Lamb, F.E., Simpson, G.S., Finch, J.H., 1999, Methods for evaluating the worth of oil and gas reserves, *Geopolitics of Energy,* April

Langley, A., 1995, Between "paralysis by analysis" and "extinction by instinct", *Sloan Management Review*, volume 35, number 3, pp63-77

Langley, A., 1989, In search of rationality: The purposes behind the use of formal analysis in organisations, *Administrative Science Quarterly*, 34, pp598-631

Laplace, P.S., 1812, *Philosophical essay on probability*, Paris, Chapter 18

Lathrop, J.W., and Watson, S.R., 1982, Decision analysis for the evaluation of risk in nuclear waste management, *Journal of Operational Research Society*, 33, pp407-418

Leach, C., 1979, *Introduction to Statistics*, Wiley, Surrey

Lefley, F., and Morgan, M., 1999, The NPV Profile: a creative way of looking at NPV, *Management Accounting*, June, volume 77, issue 6, p39

Lehmann, E.L., and D'Abrera, H.J.M., 1975, *Non-parametrics: Statistical Methods Based on Ranks*, Holden-Day Inc., San Francisco

Leonard-Barton, D., 1990, A Dual Methodology for Case Studies: Synergistic use of a Longitudinal Single Site with Replicated Multiple Sites, *Organisational Science*, volume 1, number 3, pp248-266

Leslie, K.J., and Michaels, M.P., 1997, The Real Power of Real Options, *McKinsey Quarterly*, number 3

Levin, J. and Fox, J., 1988, *Elementary statistics in social research*, fourth edition, Harper and Row,

Lichenstein, S., Fischoff, B., and Phillips, L.D., 1982, Calibration of Probabilities: The State of the Art to 1980, in Kahneman, D., Slovic, P., and Tversky, A., (editors), *Judgement Under Uncertainty: Heuristics and Biases*, Cambridge University Press, New York

Lichenstein, S., and Slovic, P., 1971, Reversals of preference between bids and choices in gambling decisions, *Journal of Experimental Pscyhology*, 89, pp 46-55

Lindman, H.R., 1971, Inconsistent preferences among gambles, *Journal of Experimental Psychology,* 89, pp390-397

Lipshitz, R., and Strauss, O., 1997, Coping with uncertainty, *Organisational Behaviour and Human Decision Processes*, 69 (2), pp149-163

Lipshitz, R., and Ben Shaul, O., 1997, Schemata and mental models in recognition primed decision-making, in Zsambok, C., Klein, G.A, (editors), *Naturalistic Decision-making*, pp292-303, Hillsdale, New Jersey, Erlbaum

Lohrenz, J., and Dickens, R.N., 1993, Option Theory for Evaluation of Oil and Gas Assets: The Upsides and Downsides, *SPE 25837*, paper prepared for presentation at the Society of Petroleum Engineers Hydrocarbon and Evaluation Symposium held in Dallas, Texas, 29-30 March

Lothian, N., 1987, *Measuring corporate performance*, The Chartered Institute of Management Accountants

MacCrimmon, K.R., and Wehrung, D.A., 1986, *Taking Risks*, Free Press, New York

MacGregor, D., and Lichenstein, S., 1991, Problem structuring aids for quantitative estimation, *Journal of behavioural decision-making*, 4, pp101-116

MacGregor, D., Lichenstein, S., and Slovic, P., 1988, Structuring knowledge retrieval: An analysis of decomposing quantitative judgements, *Organisational Behaviour and Human Decision Processes*, 42, pp303-323

Madden, T.J., Hyrnick, M.C., Hodde, J.A, 1983, Decision Analysis use to evaluate air quality control equipment for the Ohio Edison Oil company, *Interfaces*, 13(1), pp66-75

March, J.G., and Simon, H.A., 1958, *Organisations*, Wiley, New York

Management Accounting, 1997, FDs call for new criteria for measuring company performance, September, volume 75, number 8, p10

Markides, C.C., 1999, A dynamic view of strategy, *Sloan Management Review*, Spring, volume 40, issue 3, p55

Markland, J.T., 1992, Options Theory: A new way forward for exploration and engineering economics?, *SPE 24232*, paper prepared for presentation at the Society of Petroleum Engineers Oil & Gas Economies, Finance and Management Conference held in London, 26-29th April

Markowitz, H. M., 1952, *Portfolio Selection*, Wiley, New York

Mason S., and Merton, R.C., 1985, The role of contingent claims analysis in corporate finance, in Altman, E. and Subrahmanyam (editors), *Recent Advances in Corporate Finance*, Homewood, Il: Richard D. Irwin

Maykut, P., and Morehouse, R., 1994, *Beginning Qualitative Research A philosophical and practical guide*, The Falmer Press

McCaskey, M.B., 1986, *The executive challenge: Managing change and ambiguity*, Harper Business Press

McCunn, P., 1998. The balanced scorecard, *Management Accounting*, volume 75, issue 11, p40

Meehl, P.E., 1978, Theoretical risks and tabular asterisks, Sir Karl, Sir Ronald, and the slow progress of soft psychology, *Journal of Counselling and Clinical Psychology*, 46, pp806-834

Megill, R.R., 1979, *An introduction to exploration economics*, Second edition, Tulsa, Petroleum Publishing Company, p180

Megill, R.E., 1971, *An introduction to exploration economics*, First edition, Tulsa, Petroleum Publishing Company, p159

Miles, R.H., 1982, *Coffin nails and corporate strategies*, Englewood Cliffs, New Jersey, Prentice Hall

Miles, M.B., 1979, Qualitative Data as an attractive nuisance, *Administrative Science Quarterly*, 24, pp590-601

Milliken, F.C., 1987, Three types of perceived uncertainty about the environment: State, effect, and response uncertainty, *Academy of Management Review*, 12(1), pp133-143

Milne, J.J. and Chan, C.C.C., 1999, Narrative corporate disclosure: how much of a difference do they make to investment decision making?, *The British Accounting Review*, volume 31, number 4, pp439-457

Mintzberg, H., Raisinghani D., and Theoret A., 1976, The Structure of "unstructured" decision processes, *Administrative Science Quarterly*, 21, June, p246-275

Moody-Stuart M., 1999, *Prospering under uncertainty – the North Sea in evolving markets*, speech given at Offshore Europe, September 7th

De Morgan, A., 1847, *Formal logic - The calculus of inference: necessary and probable*, Taylor & Walton, London

Morgan, M.G. and Henrion, M., 1990, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, Cambridge University Press

Mowen, J.C., and Gentry, J.W., 1980, Investigation of the preference reversal phenomenon in a new product introduction task, *Journal of Applied Psychology*, 65, pp715-722

Murtha, J.A., 1997, Monte Carlo simulation: its status and future, SPE 37932, *Journal of Petroleum Technology*, 49, p361.

Myers, S.C., 1984, Financial Theory and Financial Strategy, *Interfaces*, number 14, January - February, pp126-137

Myers, S.C, 1977, The Determinants of Corporate Borrowing, *Journal of Financial Economics*, 5, November

Myers, D.G., and Lamm, H., 1975, The polarising effect of group discussion, *American Scientist*, 63, pp297-393

Nangea, A.G., and Hunt, E.J., 1997, An Integrated Deterministic/Probabilistic Approach to Reservoir Estimation: An Update, *SPE 38803*, presented at SPE Annual Technical Conference and Exhibition, San Antonio, Texas, 5-8 October

Newendorp, P.D., 1996, *Decision Analysis for Petroleum Economics*, second edition, Planning Press, Aurora Colorado

Nisbett, R., and Ross, L., 1980, *Human Inference: Strategies and shortcomings of social judgement*, Prentice Hall, Englewood Cliffs, New Jersey

Nutt, P.C., 1999, Surprising but true: Half of the decisions in organisations fail, *The Academy of Management Executive*, November, volume 13, issue 4, p75

Nutt, P.C., 1997, Better decision-making: a field study, *Business Strategy Review*, Winter, volume 8, number 4, p45

Nutt, P.C., 1993, The formulation processes and tactics used in organisational decision-making, *Organisation Science*, 4, pp226-251

Oblak, D.J. and Helm, R.J., Jr., 1980, Survey and analysis of capital budgeting methods used by multinationals, *Financial Management*, Winter, pp37-41

O'Mahoney, J., K., 1998, *Messy Methodologies: A Case Study*, Working Paper 303, Warwick Business School, University of Warwick

Odell, P., 1995, The world is running out of oil not into it, *International Energy Workshop held at the Institute for applied system analysis*, 20-22 June

Okley, J., 1994, Thinking through fieldwork, in Bryman, A. and Burgess, R.,G., editors, *Analysing Qualitative Data*, pp18-33, Routledge, London

Oransanu, J., and Connolly, T., 1993, The reinvention of decision-making, in Klein, G.A., Oransanu, J., Calderwood, R., and Zsambok, C., (editors), *Decision-making in action: Models and methods*, pp3-20, Ablex Publishing, Norwood, New Jersey

Ordonez, L., and Benson, L., 1997, Decisions under time pressure: how time constraints affect risky decision-making, *Organisational Behaviour and Human Decision Processes*, 71 (2), August, pp121-140

Orton, J., 1997, From inductive to iterative, *Scandinavian Journal of Management*, volume 13, number 4, pp419-438

Otely, D., 1997, Better Performance Management, *Management Accounting*, volume 74, number 1, p44

Otis, R.M., and Schneidermann, N., 1997, A Process for Evaluating Exploration Prospects, *The American Association of Petroleum Geologists Bulletin*, volume 81, number 7, July, pp1087-1109

Paddock, J. and Siegel, D.R., and Smith, J.L., 1988, Option Valuation of claims on real assets: The case of offshore petroleum leases, *The Quarterly Journal of Economics*, August, pp479-507

Papadakis, V., 1998, Strategic Investment Decision Processes and Organisational Performance: An Empirical Examination, *British Journal of Management*, volume 9, number 2, pp115-133

Papadakis, V., and Lioukas, S., 1996, Do early perceptions of strategic decisions influence strategic processes? An empirical investigation, *Academy of Management Best Paper Proceedings*, Cincinnati, Ohio, pp46-50

Pearce, J.A. II, Robbins, K.D., and Robinson, R.B. (Jr.), 1987, The Impact of Grand Strategy and Planning Formality on Financial Performance, *Strategic Management Journal*, 8, pp125-134

Pearson, E.S., and Tukey, J.W., 1965, Approximating Means and Standard Deviations Based on Distances between Percentage Points of Frequency Curves, *Bimetrika*, 52, number 3-4, pp533-546

Peterson, C.R., and Beach, L.R., 1967, Man as an intuitive statistician, *Psychological Bulletin*, 68, pp29-46

Pettigrew, A., 1973, *The politics of organisational decision-making*, London, Tavistock

Pfeffer, J., 1981, *Power in organisations*, Marshfield, MA: Pitman

Pfeffer, J., and Salancik, G.R., 1978, *The external control of organisations: A resource dependence perspective*, Harper and Row, New York

Phillips, L.D., 1989, Decision analysis in the 1990's, in Shahini, A. and Stainton, R., (editors), *Tutorial papers in operational research 1989*, Operational Research Society

Pike, R. and Neale, B., 1997, *Corporate Finance and Investment. Decisions and Strategies*, 2nd Edition, Prentice Hall, London.

Polyani, M., 1966, *Personal Knowledge: Toward a Post Critical Philosophy*, University of Chicago Press, Chicago

Priem, R.L., 1990, Top Management Team Group Factors, Consensus, and Firm Performance, *Strategic Management Journal*, 11, pp469-478

Priem, R.L., Rasheed, A.M.A., and Kotulic, A.G., 1995, Rationality in Strategic Decision-making Processes, Environmental Dynamism and Firm Performance, *Strategic Management Journal*, 11, pp469-478

Prudential Securities, 2000, http://www.prudentialsecurities.com/

Quinn, J.B., 1980, *Strategies for change: Logical incrementalism*, Homewood, Il: Irwin

Raiffa, H., 1968, *Decision analysis: Introductory Lectures on choices under uncertainty*, Addison-Wesley

Raiffa, H., and Schlaifer, R., 1961, *Applied statistical decision theory*, Harvard Business School Press, Massachusetts

Rajagopalan, N., Rasheed, A.M.A., Datta, D.K., 1993, Strategic Decision-making Processes: Critical Review and Future Directions, *Journal of Management*, volume 19, number 2, pp349-384

Ramsey, F.P., 1926, Truth and probability, reprinted Kyburg, H.E., and Smokler, H.E., (editors), *Studies in subjective probability*, 1963, Wiley

Rose P.R., 1987. Dealing with risk and uncertainty in exploration: how can we improve?, *The American Association of Petroleum Geologists Bulletin*, volume 71, number1, pp1-16.

Ross, D., 1997, *Portfolio management applied in the oil industry*, TNO internal report, NITG 97-293-B

Rossman, G. B., and Rallis, S.F., 1998, *Learning in the field: An introduction to qualitative research*, Sage, Thousand Oaks, California

Saaty, T.L., 1980, *The Analytic Hierarchy Process, Planning Priority Setting and Resource Allocation*, Mc-Graw Hill, New York

Savage, L.J., 1954, *The foundations of statistics*, Wiley, New York

Schafer, R.E., and Borcherding, K., 1973, The assessment of subjective probability distributions: A training experiment, *Acta Psychologica*, 37, pp117-129

Schendel, D.E., and Hofer, C.W., editors, 1979, *Strategic Management: a New View of Business Policy and Planning*, Little Brown, Boston

Schoemaker, P.J.H., 1995, Scenario Planning: A tool for strategic thinking, *Sloan Management Review*, 36(2), pp25-50

Schuyler, J.R., 1997, Best practices in project evaluation and influence on company performance, *Journal of Petroleum Technology*, August, pp818-834

Schweiger, D.M., Sandberg, W.R., and Ragan, J.W., 1986, Group Approaches for Improving Strategic Decision-making: A comparative analysis of Dialectical Inquiry, Devil's Advocacy, and Consensus, *Academy of Management Journal*, 29(1), pp57-71

Seaver, D. A., 1978, Assessing Probabilities with Multiple Individuals: Group Interaction Versus Mathematical Aggregation, *Technical Report SSRI-78-3*, Social Science Research Institute, University of South California, Los Angeles

Shackle, G.L.S., 1974, Decision: The human predicament, *Annals of the American Academy of Political and Social Science*, 412, March

Shaffir, W., B., Stepbins, R., A., and Turowetz, A., 1980, editor, *Fieldwork Experience: Qualitative Approaches to Social Research*, St. Martin's Press, New York

Shao, L.P., and Shao, A.T., 1993, Capital budgeting practices employed by European affiliates of US transnational companies, *Journal of Multinational Financial Management*, 3 (1/2), pp95-109

Shell, 1998, *Shell Brent*, 7th October, speech given at the Shell Leadership conference

Shipman, M., 1976, (editor), *The Organisation and Impact of Social Research*, Routledge and Kegan Paul, London

Siegel, D.R. , Smith, J.L., and Paddock, J.L., 1987, Valuing Offshore Oil Properties with Options Pricing Models, *Midland Corporate Finance Journal 5*, pp22-30

Siegel, S. and Castellan, N.J., 1988, *Nonparametric statistics for the behavioural sciences*, 2nd edition, McGraw-Hill, New York

Simpson, G.S., Lamb, F.E., Finch, J.H., Dinnie, N.C., 2000, The application of probabilistic and qualitative methods to asset management decision-making, *SPE 59455*, prepared for SPE Asia Pacific Conference on Integrated Modelling for Asset Management Yokohama 25-28th April

Simpson, G.S., Finch, J.H. and Lamb, F.E., 1999, Risk, uncertainty and relations between "strategic" and "within strategy" decision-making in the upstream oil and gas industry, in *Proceedings of the 4th international conference on the dynamics of strategy*, University of Surrey, pp335-358.

Singh, G. and Kinagi, G., 1987, *Risk and reliability appraisal on Micro Computers*, Chartwell-Brat, Lund

Slovic, K.G., 1995, The construction of preference, *American Psychologist*, 50, pp364-371

Smith, K.G., Gannon, M.J., Grimm, C. and Mitchell, T.R., 1988, Decision-making behaviour in smaller entrepreneurial and larger professionally managed firms, *Journal of Business Venturing*, 3, pp223-232

Smith, J.E., and McCardle, K., 1997, Options in the real world: Lessons learned in oil and gas investments, Fuqua/Duke University, Working paper, April

Smithson, M., 1989, *Ignorance and uncertainty: Emerging paradigms*, Springer Verlag, New York

Snow J.H., Doré A.G., and Dorn-Lopez D.W., 1996, Risk analysis and full-cycle probabilistic modelling of prospects: A prototype system developed for the Norwegian Shelf, in Doré A.G. and Sinding-Larsen R., eds., *Quantification and Prediction of Petroleum Resources*, NPF special publication number 61, Elsevier, Amsterdam, pp153-165

Society of Petroleum Engineers, World Petroleum Congress and American Association of Petroleum Geologists, 2000, http://www.spe.org/cda/content/0,1428,285,00.htm

Spradlin, T., 1997, *A lexicon of decision-making*,
http://www.faculty.fuqua.duke.edu /daweb/lexicon.htm

Spencer, J.A., and Morgan, D.T.K., 1998, Application of Forecasting and Uncertainty Methods to Production, *SPE 49092*, presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, 27-30 September

Stael val Holstein, C.A.S, 1971a, The effect of learning on the assessment of subjective probability distributions, *Organisational Behaviour and Human Decision Processes*, 6, pp304-315

Stael val Holstein, C.A.S, 1971b, Two techniques for assessment of subjective probability distributions: An experimental study, *Acta Psychologica*, 35, pp478-494

Stanley, M.T., and Block, S.B., 1983, An empirical study of management and financial variables influencing capital budgeting decisions for multi-national companies in the 1980s, *Management International Review*, 23 (3), pp61-72

Stonehill, A.I., and Nathanson, L., 1968, Capital budgeting and the multinational corporation, *California Management Review*, Summer, pp39-54

Swalm, R.O., 1966, Utility Theory – Insights into Risk Taking, *Harvard Business Review*, November-December, pp123-136

The Economist (US), 1998, *Oil industry: The decade's worst stocks*, volume 349, issue 8097, pp73-74

The Economist, 1996, *From major to minor*, volume 339, number 7966, May 18th, pp63-65

Thomas, H., and Samson, D., 1986, Subjective aspects of the art of decision analysis: exploring the role of decision analysis in decision structuring, decision support and policy dialogue, *Journal of Operational Research Society*, 37, pp249-265

Thompson, J., 1967, *Organisations in action*, McGraw Hill, New York

Tocher, K.D., 1978, Viewpoints, *Journal of Operational Research Society*, 29, pp179-182

Tocher, K.D., 1977, Planning Systems, *Philosophical Transactions of the Royal Society of London*, A287, pp425-441

Tocher, K.D., 1976, Notes for discussion on "control", *Operational Research Quarterly*, 27 pp231-239

Trigeorgis, L, 1996, *Real Options: Managerial Flexibility and Strategy in Resource Allocation*, Massachusetts Inst. of Technology Press, Cambridge, Massachusetts

Tversky, A. and Kahneman, D., 1981, The framing of decisions and the psychology of choice, *Science*, 211, pp453-458

Tversky, A. and Kahneman, D., 1974, Judgement Under Uncertainty: Heuristics and Biases, *Science*, 185, pp1124-1131

Uliva, J.W., 1987, Post Automation (Zip+4) Technology: A Decision Analysis, *Interfaces*, 72 (2), pp1-12

United Kingdom Offshore Operators Association, 2000a, *The Origins of Oil and Gas*, http://www.ukooa.co.uk

United Kingdom Offshore Operators Association, 2000b, *Current Reserves and Projected Life*, http:///www.ukooa.co.uk/present/harness2.html

United Kingdom Offshore Operators Association, 2000c *Economic Contribution 1999*, http://www.ukooa.co.uk

Van de Ven, A., H., 1992, Suggestions for Studying Strategy Process: A research note, *Strategic Management Journal*, volume 13, pp169-188

Van de Vliet, A., 1997, The new balancing act, *Management Today*, July, p78

Venkatraman, N., and Ramanujam, V., 1987, Measurement of Business Economic Performance: an examination of Method Convergence, *Journal of Management*, 13(1), pp109-122

Von Neumann, J., and Morgenstern, O., 1947, *Theory of games and economic behaviour*, 1st edition, Princeton

Von Neumann, J., and Morgenstern, O., 1947, *Theory of games and economic behaviour*, 2nd edition, Princeton

Von Winterfeldt, D.V., 1980, Structuring decision Problems for Decision Analysis, *Acta Psychologica*, 45, pp73-93

Wald, A., 1964, *Statistical decision functions*, Wiley, New York

Watson P., 1998, A process for estimating geological risk of petroleum exploration prospects, *Australian Petroleum Production and Exploration Association Journal*, p577 – 583.

Weick, K.E., 1979, *Sensemaking in organisations*, Sage, Thousand Oaks, CA

Wells, G.E., 1982, The use of decision analysis in Imperial Group, Journal of Operational Research Society, 33, pp313-318

Wensley, R., 1999, Product strategies, managerial comprehension and organisation performance, *Oxford Review of Economic Policy*, Spring, volume 15, issue 1, p33

Wensley, R., 1997, Explaining success: the rule of ten percent and the example of market share, *Business Strategy Review*, Spring, 8(1), p63

Weston, J.F., and Brighman, E.F., 1978, *Management Finance*, 6th edition, Holt, Rinehart and Winston, New York

Whiteside, M., 1997, Portfolio Optimisation, *Indeva Energy Consultants*, Oxon

Whitney, J. and Smith, R., 1983, Effects of Cohesiveness on Attitude Polarisation and the Acquisition of Knowledge in a Strategy Planning Context, *Journal of Marketing Research*, 20, pp167-176

Whyte, W.F., 1955, *Street Corner Society*, 2nd Edition, University of Chicago Press, Chicago

Wicks Kelly, M.E. and Philippatos, G.C., 1982, Comparative analysis of foreign investment practices by US based manufacturing multinational companies, *Journal of International Business Studies*, 13(3), pp19-42

Wildavski, A., 1988, *Searching for safety,* Transactions Publishers, New Brunswick (USA)

Wilmot, P., Dewynne, J., and Howison, S., 1994, *Option Pricing*, Financial Press, Oxford

Winter, F.W., 1985, An Application of Computerised Decision Tree Models in Management Union Bargaining, *Interfaces*, 15(2), pp74-80

Wiseman, J., 1974, The research web, *Urban Life and Culture*, volume 3, number 3, pp317-328

Wohstetter, R., 1962, *Pearl Harbour: Warning and Decision*, Stanford University Press, Stanford, CA

Wood Mackenzie, 2000, *Newsletter,* issue 37, February

Wood Mackenzie, 1999, *North West Europe Upstream Service,* May

Wood Mackenzie, 1998, *North Sea Report 272*, November

Wooldridge, B., and Floyd, S.W., 1990, The Strategy Process, Middle Management Involvement, and Organisational Performance, *Strategic Management Journal*, 11, pp231-241

World Vest Base, http://www.wvb.com

Wright Investors Service, http://www.wisi.com/index.htm

Yates, J.F. and Stone, E.R., 1992, The risk construct, in Yates, J.F., (editor), *Risk taking behaviour*, pp1-26, Wiley, New York

Yergin D., 1991, *The Prize: The epic quest for oil, money and power,* Simon and Schuster, Sydney

Zimmer, A.C., 1983, Verbal vs Numerical processing of subjective probabilities, in Scholz, R.W., (editor), *Decision-making under uncertainty*, Amsterdam