A Laboratory Comparison of Managers' Investment Decision Making Behaviour with the Decisions Recommended by Real Options Theory

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Dedication

To my parents.

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Former Student: Professor, this is
the same examination you gave to
my class when I was a student
twenty years ago. Don't you ever
change the questions?
Professor: The questions don't change -
just the answers.

Anonymous quote in Thomas E Copeland and
J Fred Weston (1988), p 401

Wovon man nicht sprechen kann, darüber muß man schweigen.

Ludwig Josef Johann Wittgenstien, Tractatus Logico-philosophisus,
London, 1992

Abstract

This thesis applies a behavioural methodology to study managerial decisions involving real options. It is designed to contribute to the non-commodity strand of the real options literature, to the human information processing literature, and to the implementation research literature.

We set up, and test, hypotheses concerning three research questions. We examine firstly whether, and to what degree, decision makers decide on hypothetical investment projects in accordance with the NPV-rule or with the real options framework, secondly, how far the normative (European, non dividend-paying) real option model is relevant to the "real world" investment situations it tries to model, and thirdly whether, and in which way, there are differences in valuation behaviour and in the attitudes relevant to real options between different subgroups of respondents in the sample.

We asked 82 experienced managers from various functions, business levels, and industries to value case studies which were in effect real options on growth. We compared these empirical valuations with theoretical values derived from the basic Black-Scholes option pricing model (which produces values identical to those from (properly specified) decision tree analysis (DTA)).

Respondents tend to overvalue most of the real options, but they correctly value or undervalue some of the options. Overall, the respondents tend to vary their (biased) valuations in line with the variations prescribed by theory, i.e. increases in moneyness, volatility, and maturity all tend to produce increases in the valuations, with a few interesting exceptions.

In a questionnaire survey, respondents showed high levels of agreement with various statements needed as assumptions in the real option model. They also accepted as realistic most of the parameter settings used in the experiment.

Respondents from the oil industry and the pharmaceuticals industry overvalue the case studies least, and so are most rational. These industries are already using real options in capital budgeting, which suggests that direct or indirect familiarity with the theory may improve valuations.

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Declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute of learning.

The Author

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1. INTRODUCTION

1.1 Introduction

This thesis applies a behavioural methodology to study managerial decisions involving real growth options. It has been argued that the classical Net Present Value (NPV)-rule is inappropriate for valuing these investments because it does not properly capture management's flexibility to change certain investment projects while they are under way. The real options framework can value this flexibility by capitalising on its similarity with the flexibility inherent in financial options. In the real options framework financial option pricing theory (OPT) is used to evaluate investments in non-financial, i.e. real assets, which provide flexibility. Growth options, in particular, are investments in real assets which create opportunities to make or not make for follow-up investments depending on how markets evolve in the future.

1.2 Research purpose

The purpose of the present research is to answer three interrelated research questions.

Firstly, we will investigate whether, and to what degree, decision makers value hypothetical investment projects containing growth options in accordance with the NPV-rule or with real options theory (and/or any additional factors) ("Correspondence"). Secondly, we will examine how far the normative (European, non-dividend paying) real options model is relevant to the "real world" investment situations it tries to model ("Relevance"). Thirdly, we will examine whether there are any differences in valuation behaviour and attitudes towards real options between the different subgroups in our sample ("Acceptability").

1.3 Justification for research

Many capital budgeting authors (e.g. Dixit and Pindyck, 1994) assert or assume consistency between management's intuition and the real options framework. Such claims are made mainly for the "option to wait" and for "growth options". We will focus on growth options. For example, Kemna (1991) observed that the intuitions of a group of Shell staff members, who were unfamiliar with the theory, seemed consistent with the theoretical option values and with the sensitivities of these values to changes in the option model parameters. This suggests that managers already act according to the new theory without having been taught it. Similarly, Kester (1984) gives anecdotal evidence for the consistency of real options models as applied to growth options with the managers' "gut feeling" for strategic investment opportunities. Also referring to growth options, Barwise et al. (1987) point out that "managers make the correct decisions but are not (yet) able to explain them in the language of finance and economics. This corresponds to an opinion in Myers (1984) that the option value of growth and intangibles is not ignored by good managers, even when traditional financial techniques miss them and that these are brought in as "strategic factors", dressed in "non-financial clothes". The present study sets out to systematically test this alleged correspondence of managers' intuition and growth options.

Moreover, the present study aims at adding to knowledge in two other areas. Firstly, it is designed to contribute to the human information processing literature by examining decision makers' (laboratory) investment decision making behaviour in terms of a new normative model, real options theory.

Finally, on a more applied level, the present study forms an inquiry into the applicability of a particular part of the real options framework (growth options modelled as non dividend-paying, European options) to corporate investment decision making. At this level, the researcher can help to assess how far the new technique can aid companies' strategic decision making. If consistency between managers intuition and the real options framework exists, it should be straightforward for companies to implement a formal theoretical framework that is already followed (consciously or subconsciously) by their managers. If the theory and managers' perceptions prove inconsistent, it would have to be considered, given the real options framework's theoretical superiority over the traditional (qualitative) analysis of the strategic dimension of investment proposals, whether it is worth introducing (not an issue in the present research), and if so, how best to implement it (e.g. which subgroups of managers are most reluctant, require most training in real option theory etc.).

1.4 Research methodology

The research methodology we will use has two main strands.

The first strand of the research methodology is deductive, and uses an experimental design. In the experiment managers decide on the values of a set of investment case studies containing growth options. We compare their valuations with a European, non dividend-paying real options model. This strand of the research is Bayesian in that it assumes, and tests, a normative model of human decision behaviour.

The second strand of the research methodology has both inductive and deductive features. It is concerned with how far managers perceive realism in the investment situations described in the experiment which were designed to be realistic examples of growth options. By examining the realism of the case studies, at the same time we examine how far the normative, European, non dividend-paying real option model, which was used to design the case studies is relevant to the "real world" situations it tries to model. In order to evaluate this, we tried to gain a picture of respondents' perceptions of the "real world" of their own investment decisions, which could be compared with the structure and assumptions of the model. The research technique used was a descriptive questionnaire survey on the occurrence of growth options in the respondents' company, on the perceived realism of the assumptions underlying real options theory in general and on the specific model in particular, on the perceived realism of the option parameter settings in the case studies, and on the process of investment decision making in the respondents' company.

1.5 Summary of major findings

As pointed out above, we examined three research questions ("Correspondence", "Relevance", and "Implementation").

The first research question ("Correspondence") is whether, and to what degree, decision makers decide on hypothetical investment projects in accordance with the NPV-rule or with the real options framework (whose values are identical to those by a (properly specified) decision tree analysis (DTA)).

Regression analyses of the empirical case study valuations on the theoretical option values showed that overall, the theoretical values and the empirical valuations over the A- and B-sequences of case studies do not differ significantly. This can be considered as evidence for the claim that managers (at least under laboratory conditions) can decide according to the real options framework without having been taught it (but their valuations are considerably higher than the NPV of the case studies and the empirical slope is not significantly different from either the theoretical slope or the zero slope).

From the implementation research and human information processing literatures (HIP) we identify seven behavioural factors, among them risk-fondness, which could account for differences in the empirical case study valuations by different subgroups in the sample.

A possible explanation of the detailed pattern of over- and undervaluation in the A-sequence is that respondents place too much weight on the time value of the option (driven ultimately by volatility) and too little weight on the intrinsic value of the option (which corresponds roughly to the NPV of the follow-up project).

Follow-up investment opportunities (growth options) seem to be valued highly, as is apparent from the valuations of the case studies, in which they are explicitly presented. On the other hand, managers report it hard to identify follow-up investment opportunities in their own, real world investments.

Empirical valuations for the sequence of case studies where volatility was varied ("B-sequence") were very noisy. However, respondents, in their perception of volatility, are apparently not holding the traditional view that volatility (variance) is bad for an investment. A formally expressed volatility, as presented in the case studies, may be a concept most managers are not (yet) used to, but volatility, as associated with the concrete variable of longer time horizons, does increase the valuation of the option in the direction required by theory.

The second research question ("Realism") is how far the normative (European, non-dividend-paying) real option model is relevant to the "real world" investment situations it tries to model. Our subjects report that growth options do actually arise in practice. In general, the assumptions of our special real options model (European, non dividend-paying) are perceived as quite realistic.

Oil managers show a high degree of openness towards real options, and laboratory valuations closest to the theoretical option values. Commercial managers are more open towards the real options approach than financial managers, and also show higher laboratory valuations (but then are less rational (from a real options perspective) in the present laboratory context). This might be due to the fact that they use their "gut feeling", not financial tools, for the decisions. It is unclear whether "openness" towards real options implies more rational valuations (in real option-terms) or not.

Managers willing to look at a pioneer and a follow-up project as two separate projects show higher (laboratory) valuations, and managers desiring additional data show lower (laboratory) valuations.

The third research question ("Acceptability") is whether, and which way, there are differences in valuation behaviour, and in attitudes towards real options between different subgroups in the sample, as defined by our nine so called grouping variables. This resembles a question frequently raised in information systems (IS) implementation research. The grouping variable that is most influential over the empirical case study valuations is Sector. This means that among all the criteria used to classify the respondents, the respondents classified as being from the capital goods sector on the one hand, and from the consumer goods sector on the other hand, are most likely to decide differently on a case study. "Sector" summarises the grouping variable "Industry", which proves to be the second most important grouping variable. As for the different individual industries, the oil industry and the pharmaceuticals industries overvalue the case studies least (and therefore show the most rational valuations (in real option terms)). These industries are also already partly using the real options framework in capital budgeting. The brewing industry shows the highest (and least rational) valuations.

The next most important grouping variable is (Business) Experience, more of which makes decision makers more optimistic, less rational, and as a group more unanimous. The same is true for another important grouping variable, Position, except that Position does not significantly affect rationality. These grouping variables could both stand for seniority, and imply high self-confidence and more shared experience.

To conclude from their valuation behaviour the subgroups which might require comparatively little training in real option theory are financial managers (when compared to commercial managers) and managers currently formally involved in investment decision making (when compared to those who are not). Subgroups which should be relatively receptive to training in real option theory are managers with a business degree and managers with a degree plus an additional qualification. Subgroups that might show most resistance to (training in) real option theory are managers in the consumer goods sector, experienced managers, directors, and managers who work in a company's headquarters.

1.6 Limitations of the study

(1) Due to the fact that the investment case studies had to be intelligible to a broad audience of general managers in a short period of time, the research was limited to simple growth options. Compound options, or multiple, interacting options could not be economically described in simple investment case studies.

(2) An obvious limitation of the study is the unknown generalisability of the results. This concerns mainly the experimental results. By using a "quasi-experiment" rather than a "true experiment", and cautious interpretation based on complementary personal interviews and questionnaire survey, an attempt was made to minimise this problem.

(3) Another limitation of the research design stems from the fact that each respondent only valued a subset (normally three case studies) from the 14 case studies. This makes it problematic to draw conclusions across all 14 case studies. In some stages of the analysis, analysing the valuations across all 14 case studies was simply not possible because the statistical procedures required data entries for all possible combinations of dependent and independent variables (e.g. multivariate ANOVA). These analyses could only be performed for blocks of responses (i.e., for each set of three case studies separately). The question of whether the results obtained for different blocks could validly be compared, will be discussed in chapter 5.

(4) A different limitation is that due to the limited sample size (n = 82) and due to the very unequal numbers of participants from the different companies, the analysis in the present study could not be performed for individual companies, rendering largely irrelevant the information gathered in the interviews that was company-specific but not industry-specific. Conversely, it appears to be problematic to generalise from only one participating company in the aerospace and brewing industries to these industries as a whole, even if these companies can be regarded as "typical" companies in their respective industries.

(5) Another potential problem was the fact that the textual (non-quantitative) aspects of the case studies differed more or less strongly across all 14 case studies. In addition to the quantitative option model parameters that were varied from case study to case study, the variations in these textual aspects might have caused variations in valuation behaviour between the case studies.

(6) Of course, generalisations from the present research are limited to the population from which the sample was drawn. We limited the target population of the study to managers in non-financial and for-profit organisations. We also exclude, for example, decision makers who have no business experience. This is because our objective in the present study is not to detect differences in "option rationality" between business people and non-business people, but to gain a picture of the current option rationality of influential business people in order to identify the applicability and scope of real options theory to current investment decision making.

(7) Finally, sample bias is a potential limitation. It seemed likely that there was sample bias in the form of the respondents' being particularly receptive to the real options framework, and being partly self-selected on this basis.

1.7 Organisation of the thesis

The thesis is organised in seven chapters.

The following chapter, Chapter 2, reviews the four areas in the academic literature that are most relevant to the present study, namely the real options literature, human information processing research and behavioural economics, implementation research, and the empirical studies on capital budgeting. The gap in the literature that this thesis attempts to fill is identified.

In Chapter 3, we discuss theoretical issues in valuing real growth options.

Chapter 4 defines the three research questions and develops the research design. The research methodology applied in the present study is a combination of an experiment with a questionnaire survey. The research instrument and the procedure of data collection are described. The three research questions are operationalised into twelve research issues for which testable hypotheses are set up.

Chapters 5 and 6 contain the statistical analysis (hypothesis tests and complementary "diagnostic checks"), with Chapter 5 focusing on the analysis of the case study valuations (experiment) and Chapter 6 focusing on the analysis of the questionnaire data (survey). Finally, in Chapter 7, we discuss and interpret the statistical findings in the light of our research questions. We consider the implications of the findings for the real world, and draw conclusions.

2. LITERATURE REVIEW

2.1 Introduction

This literature chapter serves the purpose of reviewing the literatures relevant to the topic of the present study, namely the literature on real options, the human information processing and behavioural economic literatures, the implementation research literature, and the empirical studies on capital budgeting. In each section, we first explain how the respective literature relates to the present research. Secondly, we review the most relevant articles of the respective literature. We conclude each section by explaining the way in which the present research can contribute to the respective literature.

2.2 The real options framework

This section on the real options framework for capital budgeting starts with critiques of traditional discounted cash flow (DCF) analysis, in particular the net present value (NPV) rule. (Another DCF method, decision tree analysis, will be discussed in Chapter 3). Next, real option theory in general, and the growth options concept in particular, are introduced. The growth options concept in real option theory represents the normative theory against which managers' behaviour is being compared (at least attemptedly) in the present research.

2.2.1 Critiques of traditional capital budgeting

The interest in real options in the capital budgeting literature emerged in the early 1980s against a background of dissatisfaction by corporate practitioners, strategists and some academics with traditional investment decision techniques (cf. Trigeorgis 1993a). Critics inside the practitioner literature maintained that standard discounted cash flow (DCF) criteria, such as the net present value (NPV) rule, often undervalued investment opportunities, leading to myopic decisions, and eventually loss of competitive position. The reasons given for this in the practitioner literature are that the NPV framework has inherent limitations when it comes to valuing important strategic considerations and to taking into account management's flexibility to adapt to unexpected market developments by revising their original decisions (Kaplan and Atkinson, 1989).

Hayes and Garwin (1982) report that both the capital invested per labour hour and the share of GNP devoted to net new investment in the private sector of the US economy declined between 1972 and 1982. The authors dismiss each of the three types of explanations for underinvestment that were most popular at the time: managerial theories (e.g. managerial pressures causing myopia, the reliance on short-term profitability measures in multidivisional organisations, the limited time younger, aspiring managers are spending at any one job, pressure from the financial community), environmental theories (e.g. inflation, high taxes, or regulations), and financial theories, which favour mergers and acquisitions over direct investment. They argue that the true reason for receding investment is that the techniques that are being used in investment decision making, namely discounted cash flow (DCF) analysis, have profound conceptual weaknesses and are, in certain critical ways, biased against investment.

Hayes and Garwin argue that DCF analysis has "wobbly legs" in that some of the assumptions it rests upon, namely the cash generating rate (i.e. profitability), the deterioration rate (i.e. the rate of erosion in the earnings-generating power of the company's total capital stock) and the hurdle rate are theoretically not clear and have practically often been (mis)-estimated in such a way as to make direct (re-)investment seem less and less desirable. Finally, they identify "blind spots" in DCF analysis, for example absurd decisions in cases when projects have different life-times. For example, they maintain that narrow use of the present-value criterion will almost always recommend expanding facilities already in place, rather than building a new plant in a different location, because in the first investment, investment cost is normally much less, and the returns are more immediate. They give examples where a series of such decisions - each sensible on its own - had led to outmoded dinosaurs of plants. Hayes and Garwin conclude that using DCF analysis is viewing the future through a reversed telescope and can lead a company to seriously "short-change" its future.

Hodder and Riggs (1982) argue that DCF analysis is not inherently biased against long-term investments, but only often misapplied. They identify three critical issues in the implementation of these techniques that they think are ignored: the effects of inflation (particularly in long-lived projects), the different levels of uncertainty in different phases of a project (they point out that risk often declines in later phases of a project, while excessive risk-adjustments are maintained) and management's own ability to mitigate risk (for example by diversification). Despite backing DCF analysis as a logical and consistent framework for comparing cash flows occurring at different times, they also describe situations with asymmetry or skewness of the payoffs (which constitutes a parallel to the asymmetry of payoffs inherent in a financial option). Hodder and Riggs give an example where there is a 30% chance that the third phase of a project will be worth $299 million, but not a symmetric chance of losing $299 million. This is because the company will discontinue the project when faced with low product demand. Thus the expected value for phase 3 of the project of $136 million is $43 million above the most likely estimate of $93 million. They point out that traditional NPV analysis would consider only the most likely cash flow estimates and ignore the asymmetry of the pay-offs. In this way, traditional NPV understates the project's true value in situations in which future management actions can improve profits or limit losses.

Myers (1984) gives an example in which NPV analysis is deemed inappropriate (and which will form the basis of the case studies used in the present study). A firm invests in a negative-NPV project in order to establish a foothold in an attractive market. Thus a potentially valuable second-stage investment is used to justify the immediate project. Myers points out that estimating cash flows for both stages, and using discounted cash flow to calculate the NPV for the two stages together would not be appropriate. Investing in stage 1 purchases an intangible asset: a call option on stage 2. Conventional discounted cash flow does not value such options properly. Myers maintains that given DCF's inappropriateness in some situations, from a theoretical point of view, a mixture of DCF analysis and option valuation models would be adequate. He classifies investment projects into four groups and discusses the role DCF analysis (and real option analysis) can play for each.

Firstly, in the valuation of safe flows, for example from financial leases, DCF is the appropriate approach. Secondly, DCF is readily applicable to "cash cows", (i.e. to relatively safe businesses held for the cash they generate, rather than for strategic value) and it also works for "engineering investments", such as machine replacements, where the main benefit is reduced cost in a clearly-defined activity. Thirdly, in the valuation of businesses with substantial growth opportunities or intangible assets, DCF is less useful. DCF will tend to understate the option value attached to growing, profitable lines of business. Finally, Myers maintains that DCF is no help at all for pure research and development or intangible assets, since the value of these intangible assets is usually almost entirely an option value.

Aggarwal (1991) suggests that traditional capital budgeting procedures have generally ignored the valuation of options created the continuing management of an investment after the initial accept/reject decision. He maintains that such options are valuable whether or not they are exercised and should be included in the benefits of an investment. He claims that the active management of an investment can add value beyond what can be assessed when the investment is first proposed or approved.

Kulatilaka and Marcus (1992) discuss when and why conventional DCF approaches fail and give an example in which such approaches undervalue managerial flexibility. In the example, the turbines of a large electric power plant can be fired with either a gas burner or an oil burner, or, at some additional cost, a flexible boiler which can switch between gas and oil depending on current cost conditions for oil and gas. They show that different results are reached depending on whether the decision is based on expected cash flows, given only future oil prices are uncertain, or on cash flows that are expected to be flexible in the future depending on uncertain future cost conditions for both oil and gas. While in the former case the oil-fired plant is best, in the latter case the flexible technology dominates both oil and gas technologies. With the flexible technology, cost savings from a low oil price fully redound to the firm, and when oil prices are high, increases in energy costs are limited by the ability to switch to a gas boiler. Thus, in contrast to the cash flows from the other technologies, the expected cash flow of the flexible boiler is actually a function of oil price volatility, even when this volatility is symmetric around the mean price. Kulatilaka and Marcus conclude their example by noting that given the *option* to choose the better energy source one may try to exploit the analogy between this "real option" and financial options to obtain pricing algorithms. They note that while in some cases conventional DCF analysis is adequate, it will fail when future cash flows are conditional on future decisions and that those decisions cannot be made without reference to a valuation function for the project given the various alternatives under consideration.

In a theoretical article, Trigeorgis (1993a) argues that the NPV rule cannot properly capture management's flexibility to adapt to new economic conditions, and to revise later decisions in response to unexpected market developments. He points out that in traditional NPV analysis implicit assumptions concerning certain scenarios of cash flows are made, and, under each scenario, management's passive commitment to a certain operating strategy is presumed (i.e. to initiate a project immediately and to operate it continuously at a fixed scale until the end of its expected useful life). He maintains that conversely, in actual business situations, characterised by change, uncertainty, and competitive interactions, cash flows are certain to differ from what management expected initially. Trigeorgis suggests that given the arrival of new information so that uncertainty about market conditions and future cash flows is being gradually resolved, management may often be in a position to alter its operating strategy, thus capitalising on favourable future opportunities or mitigating losses. Examples of such alterations of operating strategy include deferring, expanding, contracting or abandoning a project at different stages during the life of the project. Trigeorgis points out that the management's flexibility to adapt its actions in the future in response to altered market conditions, in comparison with management's initial expectations (under passive management), increases an investment opportunity's value by improving its upside potential while limiting its downside losses (asymmetry of an investment situation containing real options).

The real options approach to capital budgeting suggested by Trigeorgis (i.e. using financial option pricing theory (OPT) to value ("real") capital budgeting projects) draws on the structural similarity between certain investment projects and financial options. Trigeorgis claims that the real options approach has the potential to conceptualise and quantify the value of flexibility from active management. This value can be decomposed into a collection of real options (such as options to defer, contract, shut down, abandon, expand, default or to switch inputs or outputs) embedded in an investment opportunity, with the underlying asset being the gross value of the expected operating cash flows.

2.2.2 Real Option Theory

Since the first articles on real options appeared in the early 1980s, real option theory has found its way into many commonly used textbooks on corporate finance and capital budgeting (e.g. Brealey and Myers, 1991, Copeland and Weston, 1988, Bierman and Schmidt, 1990 and Copeland et al, 1990). Apart from that, three advanced textbooks focusing exclusively on real options have appeared (Dixit and Pindyck, 1994, and Trigeorgis, 1995 and 1996).

In what follows, first four empirical studies on real options are reviewed. Afterwards, theoretical real options approaches to various capital budgeting problems are discussed. All real options studies discussed will be summarised in table 2.1 at the end of section 2.3.

We will first discuss an unpublished exploratory survey on real options in a general capital budgeting context (focusing on decision-makers in companies) by an anonymous author (1995). The present research can be seen as a more detailed approach dealing with similar questions as this study, and focusing on growth options. After that, we will shortly summarise three empirical tests (based on capital market data) of specific real options models, those of Paddock et al. (1988), Gibson and Schwartz (1990), and Quigg (1993).

Another empirical study, linking a firm's growth opportunities and its systematic risk (Chung and Charoenwong, 1991), will be reviewed in the section on growth options (section 2.3).

In the only empirical study we know of on real options in a general capital budgeting context that focuses on decision-makers in companies, an anonymous (1995) author conducted a questionnaire survey among 44 senior managers from FT-SE 100 companies on the perceived frequency with which various real options occurred in a respondent's capital expenditure projects, what organisational routines applied to these situations, and the respondents' agreement with statements on the influence of the option model parameters on the value of the real option, as prescribed by option pricing theory. The anonymous author finds that real options commonly occur and, in accordance with Kemna (1991, see below), that respondents' intuitions agreed by and large with the prescriptions of real option models. On exercise price and maturity, only a few disagreed with the real option model prescriptions, on volatility over half agree with the prescriptions, and on interest rates, less than half agreed. We will report and interpret our own empirical findings on these issues concerning growth options in Chapters 5, 6, and 7.

Paddock et al. (1988) develop an options-based model that values offshore petroleum leases as a function of the market price of oil. For 21 tracts, they compare the prices computed from their model both to the government's discounted cash flow model and to industry bids. The Paddock et al and government models give very highly correlated values, but neither comes close to predicting industry bids. The highest industry bid would generally correspond to the market price, providing a comparison between real option values and transaction prices. These highest bids are more than twice the option-based and government valuations, but the mean industry bid is within the range of the alternative valuations. Paddock et al. conclude that decision makers may on average be rational in option pricing terms. They point out that the reason for the highest bid to exceed the theoretically correct expected tract value might be a "winner's curse", i.e. the phenomenon identified in the behavioural economics literature that winners of an auction usually end up paying more than the "fair" price. Paddock et al.'s conclusions represent a precedent to the conclusions of the present study, in that decision makers are found by and large "option rational", with certain features of their decision making behaviour being explained using findings from behavioural economics.

The next two studies represent a parallel line of inquiry to the present study in that they test the "option-rationality" of capital markets, which are assumed to be efficient.

Gibson and Schwartz (1990) develop and empirically test a two-factor model for pricing financial assets (futures, options on futures and oil-linked bonds) and for pricing real assets contingent on the price of oil (oil lease contracts, oil reserves, etc.). The factors employed are the spot price of oil and the instantaneous convenience yield. They estimate the parameters of the model using weekly oil futures contract prices from January 1984 to November 1988, and assess the model's performance out of sample by valuing futures contracts over the period November 1988 to May 1989. The model performs well in valuing short term contracts such as futures. Secondly, the two-factor model is able to explain the "intrinsic" difference in price volatility between spot and futures contracts.

Quigg (1993) examines the empirical prediction of a real option-pricing model using data on 2700 land transactions in Seattle. Quigg finds empirical support for a model of land price that incorporates the value of the option to wait to develop land. The option model operates with both stochastic development costs and stochastic prices of the underlying asset and has explanatory power for predicting transactions priced above the asset's intrinsic value, (i.e., the value of the underlying asset minus the exercise price of the option). In Quigg's sample, market prices reflect a mean premium (difference between the intrinsic value and the option model value, divided by the option model value) for the option to wait to invest of 6%. The implied volatility (standard deviation of the random walk) for property prices is estimated to range from 18 to 28% per year. Quigg concludes that the option model used has high explanatory power for predicting transaction prices. Decision makers in real estate may therefore be acting rationally in option pricing terms.

The above four studies are exceptional in being empirical. Their broad implications are that individual decision makers in companies and financial markets in general show some "option rationality". Most articles in the real options literature are conceptual and still await empirical testing. Trigeorgis (1993a), in his review of the real options literature, identifies articles on six distinct types of real options, namely growth options, the option to wait, the "time to build" option (staged investment), the option to alter operating scale (e.g. to expand, to contract, to shut down and restart), the option to abandon, and the option to switch (e.g., outputs or inputs). The last three options can be summarised as "operating options" because they mainly arise in an ongoing operations (e.g. manufacturing or resource extraction) context. Judging both from the volume of publications on each of the above real option types, and from opinions expressed in the general capital budgeting literature, the option to wait and the growth option seem to stand out in their importance for general capital budgeting. Due to time constraints on the part of our participants, in order to reach our desired level of detail of analysis, in the empirical part of the present study, we had to focus on only one type of real option. In the absence of previous published empirical studies on real options in a general capital budgeting context, we decided to focus on the real option type potentially most important for general capital budgeting, namely the real growth option. (For the reasons why we chose to neglect the option to wait, see section 3.4.1.1).

Applications of the above first six types of real options to various investment contexts are discussed in the remainder of this section. Articles on real asset investments containing growth options will be discussed in the next section (section 2.2.3).

Following Sick (1989), in our discussion of the first six types of real options mentioned above, we first consider models for "commodity like" assets which have observable market prices and then consider models for industrial projects whose market prices are more and more difficult to observe.

In cases where a relevant track record of historical data exists, the underlying uncertainty of a real option situation can be observed and quantified relatively easily. It is then relatively straightforward to apply real option analysis. Therefore, in the beginning, real option analysis was focused on investment situations in industries that face quantifiable risks which can be traded in a market. These are mainly producers of standardised commodities such as oil, minerals, and agricultural products.

To cope with the high degree of uncertainty attached to the output prices of mining and other natural resource projects, Brennan and Schwartz (1985) apply the techniques of continuous time arbitrage and stochastic control theory. Thus, they not only value such projects but also determine the optimal policies for developing, managing, and abandoning them.

McDonald and Siegel (1986) study the optimal timing of investment in an irreversible project where both the benefits from the project and the investment cost follow continuous-time stochastic processes. They derive an optimal investment rule and an explicit formula for the value of the option to invest, assuming that options to invest are owned by many well-diversified investors. In simulations, McDonald and Siegel demonstrate that the option value can be significant and that for reasonable parameter values it is optimal to wait until expected benefits are twice the cost of capital.

Morck et al (1989) solve the classical problem of the duration of an investment in forestry resources (i.e., when to cut down the trees) using a contingent claims approach. They value the forestry resources as a function of (1) stochastic prices and inventories, and (2) an asymmetric, optimal production policy that incorporates the option to halt timber production temporarily. The model developed gives rise to a non-linear partial differential equation that must be solved by numerical methods.

The investment situations that next attracted the attention of real option theorists were in industries with well-traded, but not-so-standardised commodities, such as real estate. In real estate, historic price data are available, but there are many variables like location, size, density, and quality that make it difficult to relate the available prices to a standard piece of property.

Titman (1985) develops a model for pricing vacant land in urban areas. He demonstrates that the range of possible building sizes provides a valuable option to the owner of vacant land. The fact that increased uncertainty has apparently led to a decrease in building activity in the current period is explained in the model by the option's becoming more valuable as uncertainty about future prices increases. Part of this intuitive model was later empirically tested in the above mentioned study by Quigg.

Triantis and Hodder (1990) apply contingent claims pricing to valuing flexible production systems: they study the effects of product mix flexibility on the value of a firm's manufacturing programme. They allow for multiple products and a production capacity constraint. The underlying assumption for their model is that the contingent claim (i.e., the manufacturing programme) can be replicated by existing securities, thus permanently risk neutral valuation. The proposed procedure is then to use an equivalent martingale valuation for each European option in order to manufacture an optimal product mix during a given period.

Trigeorgis (1993b) examines the nature of real operating option interactions (interaction of the options to defer, abandon, contract, or expand investment, and to switch use). He attempts to show that the presence of subsequent options can increase the value of the underlying asset for earlier options, while exercise of prior real options may alter the size of the underlying asset (e.g. in case of expansion or contraction) and hence the value of subsequent options on it. Trigeorgis points out that on theoretical grounds, the combined value of a collection of real options may differ from the sum of the individual option values. For example, the incremental value of an additional option, in the presence of other existing options, is generally less than the value of that option on its own, and this effect increases the more options there are present.

Thirdly, real option theory can be applied to investment situations involving totally new products. Here, it is hard to use historic data to measure risk. Companies have to develop risk (and cash flow) estimates internally, and the outcome of the analysis will in general be sensitive to their assumptions. This is the case for investments in research and development (Majid and Pindyck, 1987) and for many strategic investments (see next section).

Majid and Pindyck (1987) note that many investment decisions are made sequentially. Moreover they emphasise that the rate at which construction proceeds is usually flexible and can be adjusted with the arrival of new information. To value such investments and to derive optimal decision rules, they use contingent claims analysis. In simulations, Majid and Pindyck determine the effects of time to build, i.e., the time that passes while a project is underway, opportunity cost and uncertainty on the optimal decision.

Finally, we may note that the literature to date appears to include only three PhD theses on real options, all being theoretical. Tourinho (1976) applies option pricing theory to the valuation of natural resources, Trigeorgis (1985) tries to link option valuation and strategic investment decision making theory and Herbelot (1992) uses option valuation techniques to determine companies' environmental policies.

This summary of theoretical real option models has shown that various complex decision-making situations are analysable using the real options framework. Due to the requirement, in the present study, for a set of case studies to be intelligible to a sample of general managers in a short period of time, the most basic option pricing model, the Black-Scholes (B-S) model, was used as the basis for the case studies.

2.2.3 Growth options

The theory on growth options forms the normative framework which we attempt to use in the present study. To conclude from published articles, real growth options have been the most analysed of all types of real options (see Trigeorgis 1993a). In contrast to the operating options discussed in the previous section, which complement existing quantitative capital budgeting techniques, growth options seem to break entirely new ground in that they allow management to analyse quantitatively certain strategic aspects of investment projects, which previously had only been evaluated qualitatively. This opinion is reflected in several of the articles summarised below (especially Kester, 1984 and Myers 1984). (The option to wait also seems to introduce a new aspect into capital budgeting, but for reasons discussed below in section 3.4.1.1, the present study, did not focus on the option to wait).

Various proponents of the practitioner literature on (strategic) capital budgeting (e.g. Kester, 1984), some authors of finance textbooks (Brealey and Myers, 1991, Shapiro, 1994, Dixit and Pindyck, 1994, summarised in Dixit and Pindyck, 1995) and various authors in the finance and strategy literature (Trigeorgis, 1993a, Kemna, 1993, Trigeorgis and Kasanen, 1991) all suggest that managers do or should think of investment opportunities as options on the company's future growth. The common point in these literatures is to describe many "early investments" (e.g. major expansion in an existing market, entry into a new market, acquisitions or strategic alliances, R&D programmes, and investment in an IT network/infrastructure) as prerequisites or early links in a chain of interrelated projects. The authors mentioned above all point out that, considered in this way, the value of these investments derives mainly not from their expected directly measurable cash flows, but rather from the fact that they unlock future growth opportunities (e.g., a second-generation product or process, access to a new market, strengthening of a company's core capabilities).

The idea of a real growth option goes back to Myers (1977), who suggests that a firm's value arises from a mixture of the assets already in place and the firm's opportunities to grow. The growth opportunities can be looked upon as call options since their realisation depends on discretionary future investment by the firm. The future investment decision in turn depends on the net present value of each opportunity as it evolves in the future. In future unfavourable states of nature the firm will not invest. According to this theory, part of the value of a firm is accounted for by the present value of its options to make further investments only on (expectedly) favourable terms. A firm's assets' contribution to the firm's value has therefore two dimensions: an asset in place provides an income now plus an option to invest more in future, whose value depends on future states of the market and resulting discretionary investment by the firm.

Since Myers' article, several extensions of this theory have been undertaken. Miles (1986) uses growth options to identify the real determinants of a company's systematic risk. The multiperiod capital asset pricing model (CAPM) is used to value the cash flows generated by the assets already in place and the option pricing model (OPM) is used to value growth opportunities. The beta of a firm (the firm beta) is treated as the weighted average of the beta for assets in place (the asset beta) and the beta of the growth options, where the weights are the respective market values of these two components. Through simulations, he finds that the growth option beta (the difference between the asset beta and the firm beta) depends on the profitability of future investment as estimated by the ratio of market value to replacement cost, on the quantity of future investments, and on the firm's own instantaneous return variance on assets already in place.

More recently, Chung and Charoenwong (1991) produced an empirical test of the effect of a firm's growth opportunities on its systematic risk. They use contingent claims analysis to hypothesise that the greater the proportion of a stock's market value accounted for by the firm's growth opportunities, the higher the stock risk. This is what is suggested by the fact that the firm's systematic risk can be decomposed into the risk of the assets already in place and the risk arising from the firm's growth opportunities. Chung and Charoenwong focus on growth defined as profitable future investment options rather than on growth defined as expansion of the firm's assets, sales or earnings. They point out that a firm is not a "growth firm" merely because its assets and earnings are growing over time, but only if it earns returns on its investments which are larger than its cost of capital. This is because if the internal rate of return on its projects is the same as the firm's cost of capital, a firm can increase its earnings, assets and even, via the number of shares, its markets capitalisation over time without an increase in stock price. Their empirical results for the 1979-1988 period for 482 CRSP and COMPUSTAT-listed firms show that a positive empirical relation exists between the market values of a firm's equity beta and a firm's growth opportunities in the above sense. This finding confirms their hypothesis. The study thus seems to show that the stock market as a whole assesses risk and growth opportunities in a way consistent with real option theory. Investors on the whole seem to decide rationally in terms of option pricing theory.

Kester (1984) maintains that getting approval for a new investment project is among the most difficult problems managers face, partly because of differing valuation approaches and by strategists on the one hand and quantitative analysts on the other hand. He suggests that the growth option approach can reconcile both sides and to cure this fundamental business problem. The "operating options" discussed in the previous section mainly concern operational rather than strategic issues and are consequently mainly dealt with by the quantitative analysts, not the strategists. Compared to growth options, operating options seem to have a less central role in a company's overall decision-making process.

This assessment of growth options is also reflected in Myers (1984) who states, referring to growth options, that *"(growth) option pricing methods hold great promise for strategic analysis."* (p. 135) Myers argues that the financial theory of real options can eliminate one reason for the gap between finance theory and strategic planning by dealing explicitly with the time series links between capital investments, and with the option value these links create, which has often been left to strategic planners.

Kester compares the total market value of a company's equity and the capitalised value of its current earnings stream (a perpetuity of the net cash flows forecasted for the following year) using three companies from each of five different industries in the manufacturing sector. He finds that the difference constitutes well over half of the market value of many companies' equity and about 70 to 80% for companies in industries with high demand volatility. He interprets this difference as the value of a company's growth options.

Concerning the occurrence of growth options, Kester interprets the plethora of companies making initial public offerings at high price-earnings multiples as evidence that growth options dominate the equity value of small, high-growth companies marketing innovative products. As an example, he quotes Gene tech, which went public with annual revenues of $9 million and an operating cash flow of only 6 cents per share. The market value of its equity of $262 at the initial public offering of $35 was almost entirely based on options for future growth, not on its current cash flow.

At this point it is noteworthy, that the conclusion of the aforementioned studies is ultimately that the capital market as a whole makes valid evaluations of the growth options of a company. Barwise et al. (1987) stress that in financial markets, "growth stocks", (i.e. stocks of companies that are growing faster than the market over a certain period) have always been selling on high P/E multiples. If it is true that growth stocks contain a large proportion of growth options, it can be concluded that financial markets consistently recognise the importance of future growth options. From this position it follows logically and is only a small step that companies' management should be aware of growth options, and should incorporate them into the capital budgeting process for individual projects. If growth options exist for a company as a whole, it would be most enlightening for investment analysis to track them down to individual (existing and anticipated) investment projects (or to sets of such projects). This is the logical link, between growth options as a proportion of a company's market capitalisation and growth options as contained in companies' investment projects.

Kemna (1993) presents three case studies, one of which is a case study on a growth option, developed in co-operation with the group planning and manufacturing functions in Shell's central offices. In the growth option case, the introduction of option pricing theory helped management to reformulate their investment proposal. The strategic value of the project derived from the fact that investing in a pioneer venture provided management with the opportunity to invest in future commercial ventures. Kemna concludes: *"The above cases were developed with Shell staff members, who were unfamiliar with the theory. But the basic (real option theory) outcomes and the sensitivities of these outcomes to changes in the underlying input variables, seemed consistent with their intuition."* (p. 270). This means in essence that managers already act according to the new theory without having been taught it.

Similarly, Kester (1984) gives anecdotal evidence of the consistency of real option theory as applied to growth options with the managers' "gut feeling" for strategic investment opportunities. Referring to growth options, Barwise et al. (1987) point out that *"business people often act smarter than they talk"* (p. 53) by making the correct decisions (in real option terms) but not (yet) being able to explain them in the language of finance and economics. This corresponds to the opinion in Myers (1984) that the option value of growth and intangibles is not ignored by good managers, even when traditional financial techniques miss it. According to Myers, such values may be brought in as "strategic factors", dressed in non-financial clothes.

Table 2.1 provides an overview of the articles discussed in sections on real option theory and on growth options.

Table 2.1

The real options literature

Study	Area
Empirical tests of real option models	
Anonymous (1995)	General capital budgeting
Paddock, Siegel and Smith (1988)	Offshore petroleum leases
Gibson/Schwartz (1990)	Financial and real assets contingent on oil price
Quigg (1993)	Urban land
Theoretical real option models	
I. Standardised assets with observable market prices	
Brennan/Schwartz (1985)	Mining and other natural resource projects
McDonald/Siegel (1986)	Investment timing
Morck, Schwartz and Stangeland (1989)	Investment in forestry resources
II. Not-so-standardised assets with observable prices	
Titman (1985)	Urban land
Triantis/Hodder (1990)	Flexible production systems
Trigeorgis (1993b)	Real operating options interactions
III. Totally new products whose prices are not observable	
Majid/Pindyck (1987)	Sequential investments
Myers (1977)	Growth option as part of a firm's value
Miles (1986)	Influence of growth options on a company's systemat risk
Chung /Charoenwong (1991)	Influence of growth options on a company's systemat risk
Kester (1984)	Growth options in strategic capital budgeting
Dixit and Pindyck (1994)	Real options to explain corporate hurdle rates
Kemna (1993)	Case study on growth option
Myers (1984)	Growth options capture strategic factors

Summary and conclusions so far

Although many capital budgeting authors assert or assume consistency between real option theory and management's intuition (e.g. Kemna (1991) for growth options and Dixit and Pindyck (1994) for the option to wait), this consistency has not been systematically tested so far. In order to assess how far the new technique of real option theory can aid companies' strategic decision making, it is of utmost importance to know whether the alleged consistency actually exists. If this consistency exists, it should be acceptable to managers to use the formal theoretical real options framework for assessing the strategic aspects of an investment proposal which so far had been hard to capture. In this case, training in real options would be superfluous. If theory and managers were not consistent, it would have to be examined, given real option theory's theoretical superiority over the traditional (qualitative) analysis of the strategic dimension of projects, whether real option theory was worth introducing. However, depending on the extent of the inconsistency, training in real options might by fairly difficult. It will be the main purpose of this thesis to work towards filling the gap of knowledge concerning how far management's decisions are consistent with real growth option theory.

2.3 Human information processing and behavioural economics

On the above argument, an important open question in the real options literature is whether people's intuitive judgements duplicate the "rational" model's predictions, and further, if people do not behave "rationally", how, where and why do they behave "irrationally". Precedents for research into these kinds of questions about human decision makers exist in the so-called human information processing (HIP) literature.

2.3.1 Human Information Processing

There is a large body of descriptive psychological research on human decision behaviour by "expert" decision makers. For example, Kort (1968) modelled judges' decisions in workmen's compensation cases, using several facts from the cases as cues; Dawes (1970) modelled the acceptance policy of a graduate school admissions board; Knox and Hoffman (1968) modelled the estimation by human judges of student's intelligence, using cues such as the students' academic grades and the number of college courses they attended. These descriptive studies focused on replicating the process by which a decision was reached, rather than judging the normative validity of the decision itself.

In this vein, an extensive body of research has been developed which analyses decision making in accounting settings. This research is focused either on the complex decisions required within the practice of accounting itself (e.g. in auditing), or on the role of accounting information and financial information in decisions by users of accounts (e.g. in commercial lending, management control, or financial analysis).

Relatively little of the research on human-decision making has directly dealt with decisions on strategic investments in particular (cf. table 2.2).

Following Libby and Lewis (1982), the following review of the human information processing literature will recognise four main research approaches: (1) the lens model, (2) probabilistic judgement, (3) predecisional behaviour and (4) cognitive style. The studies discussed in each category will be summarised in a table at the end of the section.

(1) Lens model research, or linear research, descriptively examines the use of information by the decision maker and its impact on decision quality. Many of these studies involve the building of statistical models to replicate human decision behaviour. These models try to identify the relative importance of different pieces of information and to assess various qualities of the decision and the decision maker. The ability of decision makers to process information and integrate it into decisions is believed to be limited (Kanaan, 1993). The following brief review of selected recent articles provides ample support for this view.

Abdel-Kalik and El-Sheshai (1980), from a laboratory sample of 28 experienced commercial loan officers, identified the relative perceived importance of 10 financial ratios in judging whether a firm will default on the payment of its debt. The ratios used by the participants and their predictions were compared with the ratios and predictions of a mathematical model. The mathematical model outperformed human judges in terms of the percentage of correct predictions. Furthermore, the lower predictive ability of the respondents was mainly due to suboptimal choice of information cues (financial ratios), rather than to erroneous processing of the chosen cues.

Lewis et al. (1988), in a related laboratory study, examined whether inefficient information choice is the main factor in decision makers' sub-optimal prediction performance. The task was to predict whether bond ratings of a city issuing municipal bonds would be increased, decreased, or remain unchanged in the year subsequent to the disclosure of some data which were provided to the participants. The participating 47 experienced municipal analysts were divided into two groups. One group received five pieces of information selected by a statistical model from a 12-item information menu, and the other group had to make the information selection themselves. The results show that the statistical model outperformed the analysts in both groups. However, these analysts who received model-selected information items did not perform more accurately than analysts who had to select the information cues themselves. When a validation sample, using a different set of data, was used, the apparent superiority of the predictive ability of the statistical model vanished. Lewis et al. conclude that the superiority of the statistical model is situation-specific whereas the analysts showed more consistency in their predictions.

Paquette and Kida (1988), for a sample of 48 financial managers, examined decision makers' prediction accuracy when faced with varying levels of (laboratory) task complexity. The participants could choose one of four different strategies to evaluate five financial ratios in order to select firms with the highest bond rating. Task complexity was varied by providing the subjects with two, five, and nine firms to compare. They found that the decision strategies that used only subsets of the available information did not result in reduced accuracy, regardless of the level of complexity. However, accuracy declined as the complexity (number of firms in the data set) increased.

Chewning and Harrell (1990) used a sample of 17 practising auditors and 67 students to test the hypothesis that individuals who appear to experience information overload reach decisions of lower quality than those who do not experience information overload. The task was to use 4, 6, or 8 financial ratios to estimate the likelihood that a hypothetical firm would experience financial distress. A group of participants who were not believed to experience information overload (group A) and a group of participants who were believed to experience information overload (group B) were formed. The consistency of the decisions taken by the participants in group B declined when the information load was increased to 8 cues, while the consistency of the decisions made by group A participants remained largely unchanged. Chewning and Harrell conclude that information overload leads to lower decision quality. As almost all participants in our study received the same number of case studies which they were allowed to consider in their own time, (differences in) information overload was not expected to influence our results.

Strawser (1990) tries to determine whether auditors' risk judgements are consistent with those suggested by the audit risk model as specified by Statements on Accounting Standards SAS 39 and SAS 47. The results of analysis of variance procedures and cue-utilisation indexes show that some of the auditors' judgements are inconsistent with the multiplicative nature of the audit risk model. Furthermore, for substandard tests of details procedures, auditors affiliated with regional and local firms (as opposed to the big six) differ from the audit risk model. This might be due to the fact that different versions of the audit risk model might be used by the big six and by regional or local companies. Strawser's study represents a precedent to the present study regarding differences in information processing/decision making between groups with different professional characterstica.

Somerville and Taffler (1995) assess the appropriateness of allocation of credit to less developed countries (LDC) by examining lenders' judgements on country risk. They use the Institutional Investors country credit ratings as indicators of banker judgement on countries' credit worthiness. In terms of their ability to predict the emergence of areas on external debt-service for the period from 1980 to 1990, it is shown that, for the sample of 54 countries, bankers are overly pessimistic about the creditworthiness of LDCs. Multivariate statistical models (discriminant and logit methodologies) have a higher overall predictive accuracy. However, they may be outperformed by banker judgement when allowance is made for the differential costs of type I and type II errors.

The examples from the Lens model research literature described here show that certain linear models are well suited to describe decision makers' decisions, or, in other words, that decision makers seem to decide rationally with respect to particular models. In general, decision makers' ability to process information and use it for decisions is clearly limited, and expert decision makers cannot in general be expected to be rational.

(2) Research on probabilistic judgement studies some type of decision for which a normatively "best" decision policy is known (or believed to exist). Such research describes and attempts to explain why human judges do or do not act in accordance with normative models of rational behaviour, namely expected utility theory and Bayes' theorem. Most

research models of the human processing of probabilistic information assume that the human judge ought to select an action which will maximise the judge's expected utility, under circumstances in which the payoff or consequence to the decision maker is conditioned upon his action choice and the occurrence of some state of nature (Libby and Lewis, 1982). The judge, or decision maker, is therefore expected to be an expected utility maximiser and a Bayesian processor of information.

Swalm (1966), applied cardinal utility theory as developed by von Neumann and Morgenstern (1947) to managers' decision making, especially in order to elicit information on their attitudes towards risk-taking. Swalm attempted to design a set of realistic case studies, that were set to 100 executives. From the results he was able to plot individuals' utility curves, indicating risk attitudes ranging from "extremely conservative" (risk-averse) over "linear" (risk neutral) to "gambler" (risk lover). Most subjects in his sample proved to be risk-averse. We will discuss the role of risk-tolerances in the present research context in the next chapter.

Snowball and Brown (1979, as summarised in Libby and Lewis, 1982) used a business context to examine bank trust officers' use of disaggregated probabilities. A business task was set which was capable of distinguishing expected value maximisation, preference for high initial stage probability, preference for high second stage probabilities and anti-expected value maximisation. The results showed that nearly two-thirds of the responses were consistent with the normative model, 18.5% preferred higher initial stage probabilities, and 11% showed a preference for higher second stage probabilities.

Nonnormative behaviour decreased as joint differences increased. Suboptimal strategies were more prevalent among those subjects with a higher disposition toward risk.

Brown (1980) used a variance investigation task to examine the opportunity cost of suboptimal behaviour. In eight situations created by manipulating a statistical parameter, cost parameters, and information levels, subjects' investigation strategies were only negligibly more costly than a Bayesian model, though not identical to it.

The Bayes framework poses considerable difficulty for empirical study, because it uses subjective probability distributions and subjective loss functions, which are in practice very difficult to measure. Consequently, Ulehla (1966) and Pitz and Downing (1967) suggested that non-optimal behaviour by the subjects of an incentive structure might be the result of a conflict between the "visible" payoff function, which was a reward given by the experimenter, and some implicit and therefore not measurable "intrinsic" preference function. This hypothesis saved the Bayes model but made it effectively untestable.

We can now compare and relate the two research approaches so far discussed (linear research and Bayesian research) to the present research. Linear research is descriptive, trying to reproduce the human judgement process by a linear statistical model. It does not normally compare the decision policies of subjects with any normatively defined optimum. The mainstream linear research tends to deal with real world decision tasks, or with close imitations of real world decision problems (Howell 1978). An extreme representative, Brunswik, asserts that decision behaviour should only be studied in real environments because these are too complex to be imitated in an experiment (Brunswik, 1952 and 1956).

Bayesian research in contrast is based on a particular normative framework for rational decision making - Bayes theorem. Bayesian research tries, for problems where Bayes' theorem seems to be relevant, to see how far human beings follow Bayes theorem. Bayesian research usually uses an experimental research design, often including specifications which are extremely unrealistic or unrepresentative of "real world" tasks (Howell, 1978).

The present research approach shares certain of its aspects with both the linear and the Bayesian approaches.

The present research follows the linear research tradition in that the case studies used in the study try to be close imitations of reality. The most telling results are expected to come from the responses by those managers who are actually in charge of strategic investment decision making their companies, such as corporate controllers, corporate treasurers, and strategic planners. A similar approach was chosen by Barona (1985) who asked British bank managers to decide on case studies describing overdraft proposition from medium-sized corporations.

On the other hand, in the chosen research design, as in Bayesian research, the decisions taken by individuals are analysed in a normative framework, namely the real options approach to strategic investment decision making. As in Bayesian research, it remains questionable whether the normative structure as read into the problem by the researcher is actually relevant to the decision makers' real world skills or tasks.

(3) Predecisional behaviour research focuses on the dynamics of problem definition, hypothesis formation and information search behaviour. This relatively new but fast growing strain of HIP research uses process-tracing techniques in order to provide a more detailed description of cognitive processes.

For example, Shields (1983) uses a predecisional research method to examine the relationships between experienced managers' demand for information, the supply of information, and judgement accuracy in order to shed light on the information-choice of accountants. His sample of managers was asked to analyse four performance reports and to make diagnostic judgements. He finds that there is a moderate level of convergence among three behavioural measures of demand, a low but statistically significant level of demand consensus, an association between supply and demand, that demand is not associated with judgement accuracy, and that judgement accuracy is an inverted-U function of the quantity of information.

(4) Research on cognitive style focuses on the impact of the personal characteristics of the decision maker on the quality of his decisions and examines the effect of information load on decision quality.

Weber (1978) examined the relationships of a personality measure (dogmatism), risk-taking propensity, and experience to the accuracy of the auditors' decisions in an audit task and the auditor's expressed degree of confidence in those decisions. Three out of 12 hypotheses showed significant results, but two in an unexpected direction. The only hypothesis confirmed by the experiment was that the extent of the audit plan decreased when risk-taking propensity increased. In the next chapter of the present study, we will use empirical findings e.g. on risk-taking propensity like Weber's to design our hypotheses.

In order to test their Skinnerian reinforcement model, Pratt and Waller (1979) had 90 evening students predict earnings based on one of three annual reports which represented three levels of stimulus complexity. The participants were classified by a personality measure, by occupation and by investment experience. A multidimensional scaling of similarity judgements, made by the subjects with respect to the information content of 12 sections of the annual report, was used to measure the conceptual organisation of information (the conceptual level). A self-report allocation of weights to the 12 report sections was used to measure information search/use. In accordance with the hypothesis, variation in the conceptual level was explained, in order, by complexity of the stimulus, by investment experience, by occupation and by personality. In correlation analysis, significant but weak links between conceptual level and perceived use of information, between conceptual level and earnings predictions and between perceived use of information and earnings predictions were found.

By adapting the human information processing perspective, the present study can be seen as taking up some of the issues introduced in each of the four categories of the human information processing body of literature namely in lens model research, probabilistic judgement research, predecisional behaviour research, and cognitive style research are summarised in the table below.

Table 2.2: Studies on human information processing

Study	Decision maker	Dependent variable	Independent variable	Results
(1) Lens model research				
Abdel-Kalik/ El-Sheshai (1980)	28 commercial loan officers	a firm's default risk	10 financial ratios	mathematical model superior to human judges
Barona (1985)	British bank managers	firms' overdraft propositions	accounting information	information use
Lewis, Patton and Green (1988)	47 municipal analysts	rating of municipal bonds	5/12 pieces of information	analysts very consistent
Paquette/Kida (1988)	48 financial managers	a firms" bond rating	4 strategies/ 5 financial ratios	complexity affects accuracy
Chewning/ Harrell (1990)	17 auditors/67 students	a firm's financial distress	4/6/8 financial ratios	effects of info. overload
Strawser (1990)	national and regional auditors	audit risk	cues of the audit risk model	auditors partly consistent
Sommerville/ Taffler (1995)	bankers' opinion	arrears on debt service of LDCs	II country credit ratings	banker judgement equals stat. model
(2) Research on probabilistic judgement				
Swalm (1966)	100 executives	corporate utility functions	investment alternatives	some weaknesses of utility theory
Snowball/Brown (1979)	bank trust officers	decision on business task	disaggregated probabilities	2/3 of responses consistent
Brown (1980)	business subjects	investigation task	statistical parameter, costs, information	subjects close to Baysian model
(3) Research on predecisional decision behaviour				
Shields (1983)	sample of managers	accounting judgements	4 performance reports	demand and supply of info.
(4) Research on cognitive style				
Weber (1978)	auditors	accuracy of audit decisions	dogmatism, risk-taking & experience	3/12 hypotheses significant
Pratt/Waller (1979)	90 evening students	predicted earnings	annual reports sections and personal data	variation in the conceptual level

2.3.2 Behavioural economics/behavioural decision research

The Bayesian strand of the HIP literature examines whether people's intuitive judgements duplicate a normative theoretical model's predictions whereas the "lens" strand tries to formulate descriptive empirical models of human decision making). Similarly, the behavioural economics/behavioural decision research literature (a good overview of this literature is Thaler, 1991) also tests theoretical models of human decision making (originally it focused on expected utility theory which is in turn founded on the axioms of choice under uncertainty by von Neumann and Morgenstern (1947)). However, additionally, it tries to identify patterns in the apparent violations (so-called "anomalies") of the theory in question. In many studies it was observed that similar "anomalies" occur over and over again (Thaler, 1991).

It was consequently concluded that taken together, empirically well corroborated "anomalies" might amount to a more accurate empirical description of human decision behaviour than the normative theory itself. The focus of the behavioural economics/behavioural decision research on anomalies is relatively new and the emerging picture of human decision making behaviour, made up of the individual phenomena identified so far, unfortunately lacks the elegance and the coherence of expected utility theory. However the separate findings have high descriptive power and mostly do not contradict each other. They are also in line with some well-established findings in experimental psychology (e.g. bounded rationality, "satisficing" rather than value-maximising, etc., cf. Simon, 1960). The findings from behavioural economics ultimately suggest that, taken together, psychological insights might explain human behaviour better than normative economic theories. In our study it is interesting to see whether, some of these phenomena will be necessary and prove useful to help to explain our empirical findings.

The methods of behavioural economics, like the present study, involve controlled experiments: by carefully setting up the environment that subjects face, one can find the effects of changing only one factor, leaving everything else constant. Shiller (1992) points out that it is usually impossible to do controlled experiments in actual financial markets. He concludes that his own experiments with a few undergraduates make good sense as ways to begin obtaining an understanding of the behaviour of vast markets.

Probably the best known "anomaly" (or apparent departure from rational expected utility theory) is the Allais-Paradox (Allais, 1953). In an experiment, a pair of lotteries is presented to a subject twice and each time the subject has to choose one lottery. Most of the subjects display inconsistent behaviour. This is commonly interpreted as evidence that either expected utility theory is wrong i.e. it does not correctly describe rational behaviour, or for decision makers often acting irrationally. Conversely, the discussion in Thiessen (1993), can be interpreted to argue that neither is the case (Jägle, 1993). Thiessen points out that, according to expected utility theory, one should invest time and money in acquiring and processing information as long as the resources do not yield a higher expected utility in another use. Since the experiment is not associated with a high expected utility by the subjects, they used simplifying heuristics when assessing the lotteries and therefore did not reach the normatively "right" results. (As will be argued in section 4.7, this effect is likely to arise for our results, too).

Kahneman and Tversky (1979) find that the way information for decision making is presented seems to matter for individual decision making. They ask their subjects to decide between surgery and radiation-therapy for cancer treatment, given (hypothetical) information, which is given to them in the following form (summarised in Copeland and Weston, 1988):

Survival Frame

Surgery: of 100 people having surgery, 90 live through the post operative period, 68 are alive at the end of first year, and 34 are alive at the end of five years. Radiation Therapy: of 100 people having radiation therapy, all live through the treatment, 77 are alive at the end of one year and 22 are alive at the end of five years.

Mortality Frame

Surgery: of 100 people having surgery, 10 die during surgery or the post operative period, 32 die by the end of the first year, and 66 die by the end of five years. Radiation Therapy: of 100 people having radiation therapy, none die during treatment, 23 die by the end of one year, and 78 die by the end of five years.

The information in both frames is identical, yet when given the survival frame, 18 per cent of subjects preferred radiation, while when given the mortality frame, 44 per cent of subjects preferred radiation. This constituted a significant difference. This "framing effect" was similarly strong for experienced physicians and for "statistically sophisticated" business students. We tried to bear the framing effect in mind when designing our case studies.

In the same article, Kahneman and Tversky demonstrate that subjects show a bias to want to insure against relatively small losses with high probability, rather than against catastrophic losses with low probability (which would perhaps seem more logical and is the traditional use of insurance).

Kahneman et al. (1986) elicited community standards of fairness for the setting of prices and wages by conducting a telephone survey of 195 randomly selected residents of two Canadian metropolitan areas between May 1984 and July 1985. The fairness rules they encountered were that in customer or labour markets, it is acceptable for a company to raise prices or cut wages when profits are threatened and to keep prices up when costs decrease. Conversely, it was considered unfair to exploit changes in demand by raising prices or cutting wages. Assuming that these standards of fairness influence the behaviour of firms in general, Kahneman et al. are able to explain various market anomalies.

In nine experimental tests, involving between 26 and 117 (overall 700) students at North American universities, Kahneman et al. (1990) identify what they call an endowment effect: the value that an individual assigns to an object common in everyday life appears to increase substantially as soon as that individual is given the object. Hence, preferences do not appear to be independent of endowments, as hypothesised by economic theory. (The standard assumptions of economic theory suggest that when income effects are small, differences between an individual's maximum willingness to pay for a good ("WTP") and minimum compensation demanded for surrendering the same entitlement (willingness to accept or "WTA") is negligible. Consequently, indifference curves are drawn without reference to actual endowments). For their sample, indifference curves tend to be kinked at the current endowment. They conclude that their findings support an alternative view of endowment effects and loss aversion as fundamental characteristics of preferences.

De Bondt and Thaler (1985), in their studies of market efficiency, refer to research in experimental psychology which suggests that, in violation of Bayes' rule, most people tend to "overreact" to unexpected and dramatic events (individual level) and they investigate whether such behaviour affects stock prices (market level). They find that CRSP monthly return data of NYSE common stocks for the period 1926 - 1982 are consistent with the investor overreaction hypothesis. Prices tend to rise too high if good news comes out and to fall too low if bad news comes out. Eventually, people seem to forget about the news and the stock prices come back. What is more, they found systematic price reversals. Portfolios of prior "losers" significantly outperform past winners. Five years after portfolio formation, the losing stock had earned about 25 per cent more than the winners, even though the latter were significantly more risky.

As far as the present study is concerned, these findings cast doubt on the appropriateness of any theoretical framework (including the real options framework) to describe capital markets' or individuals' behaviour. As shown for example by Paddock et al. (1988), it seems however possible to interpret empirical findings as by and large corresponding to a theoretical model (real option theory) with some distortions caused by phenomena discussed in behavioural economics (e.g. winner's curse).

Table 2.3 contains an overview of the studies discussed in this section.

Table 2.3

Overview of key studies in behavioural economics

Study	Phenomenon
Allais (1953)	Allais paradoxon
Kahneman/Tversky (1979)	Framing effect
Kahneman/Knetsch/Thaler (1986)	Fairness
Kahneman/Knetsch/Thaler (1990)	Endowment effect
De Bondt/Thaler (1985 and 1987)	Overreaction

2.4 The systems implementation literature

The (information) systems (IS) implementation literature represents a precedent regarding the attempt of the present study to identify individual differences between subgroups of respondents regarding their case study valuation behaviour and their real options-related attitudes. While the IS implementation literature uses individual differences to predict the acceptance of information systems, the present study in this way aims to specify training needs in real options.

The basic notion of implementation research is that the major deterrents to successful IS implementation are both technical and organisational issues. However, it is widely recognised that the more serious deterrent is the behavioural side. This is because the introduction of most IS causes change in the organisation, i.e. to individuals' responsibilities, to socio-political structure etc. (Krovi, 1993).

Zmud (1979) points out that among the studies on the various factors that are believed to influence MIS success (organisational, environmental, task, interpersonal, MIS staff and personal characteristics), empirical studies on the manner in which individual differences (i.e. cognitive style, personality, and demographic/situational variables) impact MIS success (regarding design, implementation and usage) are most numerous. He puts forward a model that he believes to portray the manner in which individual differences influence MIS success. In Zmud's model, individual differences affect MIS success via cognitive behaviour, attitudes of MIS user, MIS design characteristics, and a priori and posterior involvement. In his review of the implementation literature, Zmud uses his model to summarise, for each branch of the model, the existing empirical evidence.

Hirschheim and Newman (1988) first survey the IS implementation literature to identify the causes of resistance to change introduced by implementation of information systems and then try to identify these causes in their case study of an unsuccessful IS implementation. From the literature, they identify 10 broad factors:

(1) "Innate conservatism" (i.e. a reluctance to change the status quo caused by inertia), (2) "Lack of felt need" (i.e. resistance because system users have not been convinced of the merits, especially for themselves, of the change, (3) "Uncertainty" (about being transferred or about being unable to acquire new skills etc. which provokes fear in the individual), (4) "Lack of involvement in the change" (i.e. the fact that individuals have been excluded from the decision-making process associated with the change), (5) "Redistribution of resources", (6) "Organisational invalidity" (i.e. a mismatch between specific features of system design and characteristics of the existing organisation, including elements of organisational structure). The core idea here is that "resistance arises because the system does not `fit' the individuals' and groups' work patterns, or the structure of the organisation". So far, with the possible exception of (2) this seems to be the most interesting factor for the capital budgeting system implementation aspect of the present study. The other factors Zmud quotes are (7) Lack of management support, (8) Poor technical quality, (9) Personal characteristics of the designer (systems developers might have difficulties in interacting with users), and (10) "Other" factors (which all seem to be relevant to the present study), namely insufficient training, a lack of education on what to expect from the system, cognitive style, and individual characteristics of the users.

Hirschheim and Newman check for the presence of the above ten factors in their case study of a medium-sized New England insurance company which introduced a new computer system and where many of the commercial underwriters by-passed the system or used it minimally for documentation only. They find most factors present in their case study and conclude that in their case study organisational invalidation is the best explanation for resistance.

Aydin and Price (1991) use quantitative and qualitative methods to investigate the two-year process of implementing a computerised medical records information system in one health care organisation. They base their approach on Lucas' multidimensional model of information systems implementation (1981) which maintains that attitudes towards an information system are influenced by multiple contextual factors, including individual differences, system use and organisational implementation practices. Following the symbolic interactional perspective in sociology, their longitudinal case study extends previous research by proposing that membership in occupational and departmental social worlds (i.e. social context) also influences individual attitudes towards a medical IS.

Krovi (1993) conceptually applies organisational change theories as the basis for assessing the causes of resistance to IS implementation. He distinguishes between three possible levels of change (the extent of change); first order change (incremental change), middle order change and second order change (radical/transformational change). These three levels can be distinguished by the extent to which they affect: critical success factors, organisational processes, the number of individuals affected, the impact of the change on the external environment, and forces that might drive this change. The three different levels correspond to three different kinds of IS systems. Krovi points out that each level/system-kind has its own causes of resistance.

Joshi (1991) uses an "equity-implementation" model to explain sources of resistance to change. An individual's attitude toward a change depends on his or her perceptions about the associated "outcomes" and "inputs". Outcomes can be favourable (e.g. more pleasant working conditions) or unfavourable (e.g. reduced job satisfaction). An individual's input requirements can be reduced (e.g. reduced manual or cognitive effort) or increased (e.g. need to learn higher skills). If the favourable aspects of a change exceed the unfavourable ones, the change is accepted, conversely, the change is resisted.

According to the model, an individual tends to assess three different aspects of a change. At the first level, the individual looks only as the effects of the change on his or her own situation, independent of the effects on others. At the second level, the individual judges whether the effects of a change are equitably shared between the individual and the superior, according to the individual's sense of "deservingness". Finally the individual judges the effects of a change on himself or herself relative to the effects on his or her peers.

Unlike some previous models, the equity-implemenation model can be applied to any level of change or implementation, ranging from the implementation of a word processing package ("first order change") to the implementation of large integrated systems involving many users/departments.

Researchers from a variety of disciplines share a common interest in examining the effect of individual differences (cognitive, personality, and demographic/situational variables) on information processing and decision behaviour (cf. section 2.3.1 on HIP and 2.3.2 on behavioural decision research). This implementation literature and the present study share an interest to identify individual differences. They might affect on the one hand the acceptance of a new management information system and on the other hand the potential training needs for a capital budgeting system.

2.5 Empirical studies on capital budgeting

The last literature that is reviewed here is the literature of empirical studies on capital budgeting. This is in order to put the present research into a wider perspective and to see whether real option theory is compatible with descriptive procedural models of investment decision making. First, often older, survey-type research on capital budgeting methods is reviewed. Second, more recent qualitative, case study-type studies that often focus on the capital budgeting process are examined. At the end of this section, the discussed studies will be summarised in a table. We start by reviewing survey-type studies focusing on the use of the various capital budgeting techniques in companies' investment decision making.

Schall et al (1978) sent questionnaires to a major financial officer of each of the 407 largest companies on the COMPUSTAT tape. They found a trend towards use of what were at the time the more sophisticated capital budgeting techniques, with 86% of their sample firms using discounted cash flow methods, most of them combining this with a payback or accounting rate of return analysis. Project risk was usually assessed subjectively, and most firms required a higher rate of return for more risky projects.

Scapens and Sale (1981) present a survey on capital budgeting practice in 170 US and 95 UK divisionalised firms. They posed two questions: firstly whether divisional managers have responsibility for investment decisions and secondly whether ex post monitoring of capital investment decisions is practicable. They conclude tentatively that divisional managers generally may be able to influence investment decisions in their own divisions, despite the formal authorisation procedures administered by the headquarters. Concerning ex-post monitoring, they find that post-completion audits are widely used in the US.

In a more recent study, Pike (1983) included finance directors and controllers in 150 of the 208 largest UK manufacturing and retailing companies in a postal survey asking a variety of questions covering aspects of the formal capital budgeting process. Pike shows that managers attach almost the same degree of importance to systematic, highly developed formal capital budgeting systems as to the subjective, qualitative aspects. Pike finds that the level of sophistication in capital budgeting methods is negatively related to the firm's beta value.

Berry (1984) uses an open social systems approach to explain capital investment practice in one large UK nationalised industry. He highlights that his approach was focused on the explanation of phenomena encountered and does not lead to a rejection of the normative theory. He puts the normative theory on capital investment in a broader perspective by suggesting to rather see it as an approach to interpreting one element of the environment to an organisation.

Pohlman et al (1988) conducted a questionnaire mail survey on companies on the Fortune 500 listing on cash flow estimation practices. Out of the 232 respondents, a majority follows a systematic method of generating cash flow information for capital investments (i.e., company-wide procedures in preparing cash flow data are employed and additionally one person is in charge of co-ordinating or supervising the process). This is especially true for firms with higher financial risks (as indicated by a higher debt ratio). They perceive a clear indication that large corporations combine judgmental and quantitative forecasts to greatly improve their estimates. The authors highlight the relative importance of not only quantitative but also qualitative factors in corporate capital expenditure decision making.

Pohlman et al. found a positive correlation between the degree of financial risk of a company and the existence of systematic procedures of preparing cash flow data. This seems to at least partially contradict Pike's finding that the level of sophistication in capital budgeting methods is negatively related to the firm's beta value. However, Pohlman et al.'s measure of "financial risk", the company's debt ratio, is quite different from Pike's risk measure, the company's beta value. Moreover, Pohlman et al.'s procedures of cash flow estimation arise at an earlier stage of the capital budgeting process than Pike's capital budgeting methods/financial analysis. It is therefore not surprising that the two studies find different correlations between risk and capital budgeting-sophistication. Other differences between the two studies are different geographical sample regions (US vs. UK) and different industry sectors (miscellaneous vs. manufacturing and retailing). A possible interpretation of both findings is that due to the increase default risk a high debt ratio leads firms towards projecting their future cash flows very carefully, while the same companies due to the riskier projects they have to undertake (to reach the higher required return due to their higher leverage; this also implies a higher beta value) are quite sure about the projects they have to pursue and therefore do not need to apply sophisticated decision making tools.

In what follows, we review studies employing a case study-type research approach which focus on the capital budgeting process.

Based on two years of fieldwork in one single giant organisation, and following four case histories of investment projects, Bower (1970) examines the problem of strategic investment planning from the point of view of the chief executive. He argues that projects progress towards funding only if a higher-level manager "sponsors" the project and gives "impetus". Bower has observed that managers involved in strategic investment decision making inevitably consider the personal benefits of being "right" or "wrong". Their perceptions are strongly influenced by the formal organisational systems and procedures, including monitoring, evaluation and rewarding. Bower therefore argues that top managers should manage the strategic investment decision making process, not by transmitting corporate standards downwards but instead by control of the organisational context.

Barwise et al. (1987) review the literature on decision-making in large organisations and try to identify the ways in which the analysis of strategic investment decisions needs to be seen within its organisational setting. Firstly, they point out that effective product-market strategies grow from a detailed understanding of both the market and the firm's competitive capabilities. They conclude from that that investment opportunities are therefore more likely to be revealed by managers at product-market level rather than at the corporate level. Accordingly, product level and "middle" managers have a key role to play in the surfacing, analysis, and implementation of strategic investment decisions. It follows that in large, diversified organisations, any notion that strategic investment decisions are a single act of top management choice is fundamentally flawed. Secondly, Barwise et al. conclude that investment decision making is an extended process, involving many people at many organisational levels. The main roles they identify for senior managers are developing the right questions and dialogues and exerting indirect influence by recruiting and retaining key people and by designing and maintaining appropriate structures, contexts, and decision-making processes.

It is notable that the roles Barwise et al. identify for senior managers do not include the "sponsor" role which was thought to be crucial in the study by Bower. One possible explanation for these contradicting recommendations is that the different authors have different perspectives on the capital budgeting process. It is conceivable that they overstate the role in the capital budgeting process of the respective group whose perspective they adopt in their studies. Bower, in his study, declaredly adopts the point of view of the chief executive. It could be argued that Barwise et al. adopt a "middle management" perspective.

Another possible explanation for the apparent contradiction between Bower's and Barwise et al.'s recommendations regarding the role of top management in the capital budgeting process could be the time difference of 17 years between the two studies. While in 1970 autocratic management styles were widespread and endorsed by many academics, by 1987, they had been widely replaced by participative management styles (as manifest in contemporary movements, such as "empowerment").

From a review of the academic literature on the subject of capital budgeting, McIntyre and Coulthurst (1985 and 1987) develop a conceptual model of the capital budgeting process. The descriptive model includes a creation phase, a decision phase, and an implementation phase. Activities in the creation phase are the search for ideas, sources of ideas, and the screening of ideas, activities in the decision phase are the classification of proposals, proposal feasibility clearance, and proposal evaluation, and the main activity in the implementation phase is the design of the operational framework and budgetary controls and of the project post audit. Through a postal survey of 141 executives in medium-sized UK companies, they find that medium-sized companies tend to declare that they comply with the model. By comparison with previous studies they find that some of the activities of the model are more widely used in large companies than they are in medium sized companies. A likely explanation for this pattern is that more rigorous and formal methods are only justified if benefits from improved decision making outweigh the costs.

Marsh et al (1988) explore the analysis and process of strategic investment decision making in three large diversified UK companies. They confirm previous findings that strategic investment decision making is a complex lengthy process, which can be characterised as a series of stages through time, in which the earlier stages and choices can be crucial. The traditional emphasis on the "decision" or final approval stage is therefore described as possibly misplaced. Nevertheless, Marsh et al find evidence for the use of formal capital budgeting procedures in all three companies.

The articles discussed in this section are summarised in table 2.4.

Table 2.4

Empirical studies on capital budgeting

Study	Decision maker	Subject of research	Results
Survey-type studies focusing on capital budgeting techniques:			
Schall, Sundem and Geijsbeek (1978)	407 COMPUSTAT companies	capital budgeting techniques	trends towards more sophistication
Scapens/Sale (1981)	170 US and 95 UK divisionalised firms	capital budgeting practices	divisional managers in charge of investing
Pike (1983)	managers from 150 UK companies	capital budgeting process	sophistication neg. related to beta-value
Berry (1984)	conceptual article	open social systems and capital investment	systems theory complements existing normative theory
Pohlman, Santiago and Markel (1988)	232 Fortune 500 managers	cash flow estimation practices	systematic information generation
Case study-type studies focusing on the capital budgeting process:			
Bower (1970)	one giant US organisation	investment process case studies	importance of organisational context
McIntyre/Coulthurst (1985)	141 executives in medium-sized UK companies	test of conceptual model of capital budgeting process	overall compliance with the model
Barwise, Marsh and Wensley (1987)	conceptual article	decision-making in large organisations	key role of middle management
Marsh, Barwise and Wensley (1988)	3 large diversified UK companies	case studies on capital budgeting process	importance of phases before final approval stage

The present research, although not strictly in the same research tradition, should be able to complement the literature on empirical studies on capital budgeting as follows. All surveys on capital budgeting techniques discussed above ask the participating managers to indicate the techniques used in their companies. It is not possible for the researchers, however, to find out whether these techniques are properly applied in those companies. In contrast, the present research asks managers to solve investment case studies, and draws conclusions about their decision behaviour. It therefore may be able to produce richer insight into investment decision making than the aforementioned postal surveys (but less deep than the above aforementioned case-study approaches to investment decision making).

The studies in this section emphasise the fact that capital budgeting is a process within a social organisation. These studies influenced the present research towards capturing as much as possible of the diversity in an organisation and including this information into the analysis. This was accomplished by performing most statistical analyses for various subgroups of our sample, as defined by our "grouping variables". The case study-type research reports in the second part of the present section highlight the importance of qualitative factors in capital budgeting and convinced the researcher to design an additional questionnaire in order to collect vital "background" information. A direct influence of the Bowers vs. Barwise et al. debate about the roles of different organisational groups in the capital budgeting process on the present research is that the valuation responses to our case studies were examined for differences between more or less senior subgroups within our sample. However, we could not directly investigate policies, personality factors, etc.

2.6 Summary

To conclude, the consistency of real growth option models with the intuition of investment decision makers is an issue in the real options literature (e.g., Kester, 1984, Kemna, 1993). However, no empirical testing for this particular aspect exists so far, the question therefore represents a gap in the literature. Because of the fundamental importance of this question for assessing the applicability (and training needs) of real option theory for non-commodity capital budgeting (cf. e.g., Kester, 1984, Dixit and Pindyck, 1994), it is worthwhile to work toward filling this gap.

So far as research methods are concerned, precedents exist both in the so called "human information processing" literature (regarding the use of individual differences) (e.g., Barona, 1985, Swalm, 1966) and in the emerging literature in behavioural economics (regarding the importance of "behavioural factors" in addition to normative theories). It is clear that real option theory, although not yet included in major studies on the process of strategic investment decision making (e.g., Marsh et al, 1988, Carr et al, 1994), fits in, and is possibly suitable to improve the transparency of, strategic investment decision making processes at both the planning and the formal evaluation stages. Finally, the present study does not represent a contribution to, or empirical test of, specialised theoretical real option models, as only the most simple real option structure (B-S) could be used for our case studies.

3. *THEORETICAL ISSUES IN VALUING REAL GROWTH OPTIONS*

3.1 Introduction

In the literature review of the previous chapter, we identified a gap in the real options literature for an empirical investigation of management's intuitive consistency with growth option theory. Several authors maintained that management, as far as investment projects involving potential follow-up investment opportunities (i.e. growth options) were concerned, followed real options theory already without having been taught it. In the present study, we will try to evaluate this claim by asking managers to decide on hypothetical investment case studies containing real growth options and by comparing managers' empirical valuations with the theory. We designed our set of investment case studies containing growth options to be analysable using a non-dividend paying, European option pricing model (the Black-Scholes model) and of course also by conventional valuation approaches, namely the DCF/NPV approach. In this chapter we discuss critical theoretical issues important to the design of the investment case studies and to our choice of the Black-Scholes option pricing model for valuing the latter. Many of the theoretical issues discussed in this chapter are relevant not only to the case studies used in the present research, but also to using real growth options theory in practical capital budgeting in general.

We will first define (real) growth options. After that, we describe the structure of our investment case studies, which are intended to be realistic descriptions of "real world", growth option-containing investment opportunities. Consequently, we discuss whether the option to wait should be taken into account in the valuation of the case studies. Having established the European options are a suitable model of these specific growth options, we discuss whether a dividend-paying or a non dividend-paying option pricing model should serve as the basic model for evaluating the case study investments. Some of the assumptions of real options theory e.g. that of a log-normal distribution of the price of the underlying asset are examined. We discuss the risk-neutral valuation approach of option pricing theory and compare it to the risk-adjusted valuation approach to decision tree analysis. We identify the ways in which (real) option pricing theory is able to add to this long-standing operations research technique. Finally, the option pricing model parameter settings, as used in the investment case studies, are laid out and the B-S option values for our case studies are given.

3.2 Definition of growth options

A (real) growth option is defined as a situation in which some initial investment, (a so-called "pioneer" project e.g., an R&D project, a lease on undeveloped land or oil reserves, a strategic acquisition, or an information network) is a prerequisite or link in a chain of interrelated projects, opening up future growth opportunities (a so-called follow-up project, e.g., a new generation product or process, oil reserves, access to a new market, or strengthening of core capabilities) (Trigeorgis, 1993a).

Real options theory maintains that the structure of such investments is identical to the structure underlying financial options and that consequently option pricing theory can (and should) be used for the valuation of such investments. In financial option pricing terms, a call option is a contract between two parties which gives one party, the owner of the option, the right but not the obligation to buy from the counterparty the so-called underlying asset at a predetermined so-called exercise price, over a predetermined period of time, the so-called time-to-maturity, or at a predetermined date, the so-called maturity of the option.

In real growth options terms, a company that undertakes an investment project which is a prerequisite for a follow-up project is acquiring a growth option. The company acquires the opportunity but not the obligation to invest in a follow-up project at the end of some time period.

The variables of the real growth option model and of the financial option model (for the example of a call option on a stock) are compared in Table 3.1. In the third column labelled "Prescription", we give the prescriptions of option pricing theory for the effect on the option value of increasing each specific option model parameter.

Table 3.1

Comparison of financial and real option terminology

Option parameters	Symbol	Prescription	Real asset "growth" investment project determinants
Asset price (e.g. Stock price)	S	+	Expected PV of the follow-up project's cash flows
Volatility of the asset price	σ	+	Volatility of the random walk evolution over time of the expected PV
Exercise price	X	-	The follow-up project's initial investment cost
Maturity, or life of the option	T-t	+	Time period until the follow-up project can be undertaken, or "development time"
Risk-free interest rate	r	+	Risk-free interest rate
Call option value	c		Growth option value

Note that the underlying asset for the financial option considered here is a stock, but for the real option it is a follow-up investment in some real (possible intangible) asset or project.

For a financial option, the maximum of zero and the difference between the stock price S at a given time and the exercise price X, can be defined as the intrinsic value of the option at that time (Hull, 1993): max (0, S-X)

This is the value to be gained if the option is exercised immediately. The difference between the option's full theoretical value and the above intrinsic value is called the time value of the option. (By way of analogy, in the language of real options theory, the term "intrinsic value" refers to the difference between the expected PV of the follow-up project's cash flows and the follow-up project's initial investment cost). It can be seen that the time value of a real option is maximised when the expected PV of the follow-up project's cash flows equals the follow-up project's initial investment cost, since in this condition there is the maximum possibility for the eventual value of the project to be either higher or lower than the follow-up project's initial investment cost (cf. Hull, 1993, p.165).

Growth options will not arise if the investment is a one-off investment without immediate follow-on opportunities. This is the case e.g. for routine maintenance or plant modernisation, which are still best evaluated using discounted cash flow (DCF) criteria. Accordingly, real growth options theory is complementary to traditional DCF analysis (cf. Myers, 1984).

Growth options, if defined as investments which are prerequisites for follow-up investment opportunities after a fixed and finite time, would normally be considered European options (excercisable at maturity only). Note that European options can also model the case in which the maturity of the real option lies before the end of the pioneer project, at some level of completion which is sufficiently high for the follow-up project to be started.

3.3 Discussion of the investment case studies

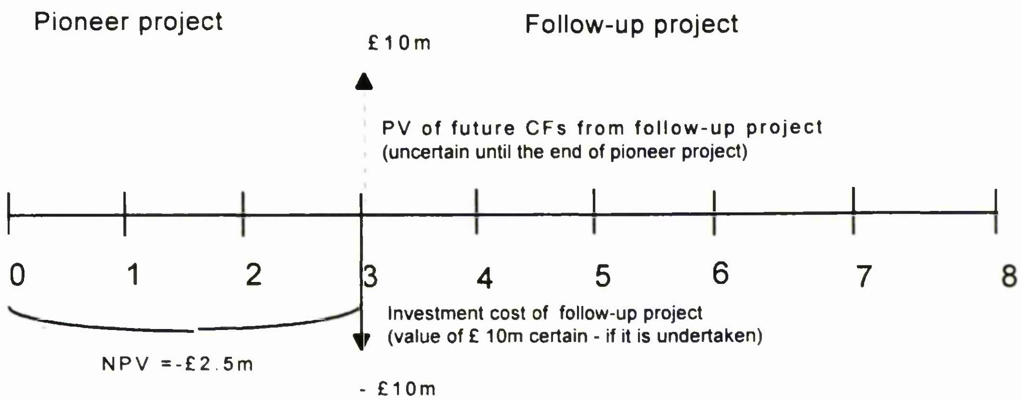
3.3.1 The common logical structure of the case studies

In all our investment case studies, a common logical structure was maintained for the textual narrative of the investment situations described. The structure we chose for our case studies was initially described by Myers (1984) and is widely quoted in the real options and capital budgeting literatures (c.f. e.g. Brealey and Myers, 1991). It is thought to be the classical example of an investment opportunity containing a growth options. Our specific parameterisation of Myers' example is as follows:

A pioneer project takes three years (in the first 12 out of 14 case studies) and leads to a negative Net Present Value (NPV, i.e. the sum of cash inflows and outflows) of - £ 2.5 m. The pioneer project generates no income but is known to open up an opportunity to invest in a follow-up project after a finite time interval This interval is assumed to be three years in all case studies except the last two (one year and five years respectively).

To undertake the follow-up project, an investment cost of £10m will be necessary at the end of 3 years (with the follow-up project having zero terminal value at the end its life-cycle of 5 years). The expected Present Value (PV) of the follow-up project's future cash flows is uncertain, although its under the current conditions expected (average) value is £10m in the last 7 investment case studies. This project structure is summarised in the diagram below.

Figure 3.1: The investment project cash flow sequence



The positions of cash flows in the diagram symbolise effective dates, but in the case studies cash flows are all described as discounted to time 0.

Note that the expected PV of the follow-up project's future cash flows is uncertain. At present, only its value as expected under current economic conditions is known. It is known that in three years time this expected value will have changed, and will lie with a certain probability within a certain range.

As an approximation, the upper and lower value of the range that the PV will lie in at the end of year 3 with about 68% probability is indicated in each case study. Of course, the indicated range is not the highest/lowest values possible. Actual values can be higher or lower than this range with a respective probability of 15%. These facts are represented in the diagram of a log-normal distribution (see Appendix 4.1). Note that we assume that at the end of year 3 only the then expected value of the follow-up project will be known.

Undertaking the pioneer project creates for the company the choice, in year 3, to undertake the follow-up project or not, depending on whether prospects for the follow-up have turned out favourable or poor up to year 3.

The fact that the future evolution of the expected PV of the follow-up project's cash flows is highly uncertain can be beneficial for the company. This is because a high PV at the end of year 3 means the company can dare to make the follow-up investment with high potential gains, whereas a low PV would only lead to a limited loss because in this case the company would not make the follow-up investment.

Note, however that even if the option is "in the money" (i.e. S>X) at maturity and will consequently be exercised, the company can still lose money because the PV of the follow-up project's cash flows can decrease again afterwards.

In the case studies, we do not give the actual risk-free interest rate. This is in order to encourage respondents to use their gut feeling when valuing the case studies (although at least those respondents who are involved in investment decision making in their companies might be knowledgeable about the current risk-free interest rate).

3.3.2 Variation of option parameters in the set of case studies

In the European, non dividend-paying option pricing model (Black-Scholes model) which we use to provide theoretical valuations for the case studies, five parameters determine the value of the option to undertake the follow-up project, namely the follow-up project's initial investment cost, the expected PV of the follow-up project's cash flows, the volatility of the expected PV of the follow-up project's cash flows, the time period until the follow-up project can be undertaken, and the risk-free interest rate.

Given the high level of detail we attempted to achieve in the study, and due to the limited available sample size and to time restrictions on the part of our respondents, the present research had to be limited to varying only a subset of these five parameters. Our choice was to vary the expected PV of the follow-up project's cash flows S, the volatility of the expected PV of the follow-up project's cash flows σ, and the time period T-t until the follow-up project can be undertaken. We focused on these particular variables and neglected to vary the follow-up project's initial investment cost x and the risk-free interest rate r for two reasons. Firstly, in order to vary "moneyness" of an option, it is sufficient to vary either the expected PV of the follow-up project's cash flows, or the follow-up project's initial investment cost. Of these, we chose to vary the expected PV of the follow-up project's cash flows. Secondly, the risk-free interest rate is an irrelevant parameter for the decision between different investment projects as it is of course the same for all projects at any one time Moreover, it is outside a company's control (and is also relatively stable, at least in real terms). Finally, as we will show in the sensitivity analysis in Table 3.3, the theoretical option value is quite insensitive to (realistic) variations in the risk-free interest rate.

In order to examine how the perceived value of the option was affected by changes in the chosen three independent variables, three sequences of case studies were designed. Over the first sequence of seven case studies (labelled A1 to A7), the expected PV of the follow-up project's cash flows S was varied. Over the sequence of the next five case studies (labelled B1 to B5), the volatility of the expected PV of the follow-up project's cash flows σ was varied, and over the sequence of the two last case studies (labelled C1 to C2), the time period T-t until the follow-up project could be undertaken was varied. Over all 14 investment case studies, we hold constant the two option parameters of the follow-up project's initial investment cost and the risk-free interest rate.

3.3.3 Discussion of the quantitative parameters of the case studies

3.3.3.1 Treatment of the NPV of the pioneer project

The pioneer project's constant negative NPV of £2.5m represents the only quantitative parameter in the case studies that is not a part of the option pricing model. In financial option terms, this amount corresponds to the price that is paid to acquire the option. The price paid to acquire an option normally reflects the value of the option on the day of the purchase, but afterwards, of course, there is no defined relationship between the (historical) price paid and the option value. If the option was sold again, this (historical) option price has to be deducted from the selling price to determine the investor's net profit/loss.

In the real option set-up of the present study, respondents were asked to indicate this net profit/loss. Consequently, to arrive at the option valuation implicit in this profit/loss, the £2.5m had to be added again. In this way, we were able to compare directly the (adjusted) empirical valuations of the case studies given by the respondents and the theoretical values suggested by real options theory:

Empirical option valuation = "Net profit/loss" + £2.5m

Note that the pioneer project's negative NPV of £2.5m is kept constant over all 14 case studies irrespective of the "moneyness" of the real option and was assumed constant over the maturity of the option, unaffected by any changes in the economic conditions.

3.3.3.2 Upper and lower bounds informing about the volatility of the PV

In order to inform the respondents of the way in which the expected PV of the follow-up project is expected to evolve over the period until the follow-up project can be undertaken, we give information in the form of the mean of the presently expected PV and the upper and lower bounds (mean plus/minus one standard deviation) within which the mean PV evolves with 68% probability over the time period in the case study.

Following Hull (1993), page 210, we take the distribution of the price of the underlying asset (here the PV of the cash flows of the follow-up project) to be log normal. The logarithm of the project's PV at time T, $\ln S_T$, is distributed as

$$\Phi\left[\ln S + \left(\mu - \frac{\sigma^2}{2}\right)(T - t), \sigma\sqrt{T - t}\right] \qquad \text{(Hull, 1993, equation 10-7)} \qquad (3.1)$$

Where $\Phi(m, s)$ denotes a normal distribution with mean m and standard deviation s, and where S is the price at time t, S_T is the price at time $T > t$, σ is the volatility of the asset, and $\mu - \frac{\sigma^2}{2}$ is the expected continuously compounded rate of return (where μ is the expected rate of return in an infinitesimally short interval of time).

For simplicity, we have assumed $\mu - \frac{\sigma^2}{2}$ is identical to the rate of discount used in the cases to discount upper and lower bounds to the present. (This variable does not appear in the Black-Scholes model, but is implicit in the case studies. It does not have to be specified in our application but could be estimated using the CAPM. Use of the CAPM of course implies that the discount rate is case study-specific, depending on the case study project's β value). In this way, the discounted values of the upper and lower bounds reduce to $S\,e^{\sqrt{3}\,\sigma}$ and $S\,\frac{1}{e^{\sqrt{3}\,\sigma}}$. This allows us to describe the values in Table 3.2 to the respondents as the "discounted present values" of the upper and lower bounds.

Our case narratives do not identify the "discount rate" (which does not appear in the Black-Scholes model); nor do they identify the risk free rate (which does). Hence respondents are forced into an "intuitive" valuation of the cases which we can compare with the theoretical value, by assuming plausible values for r, i.e. values close to the actual yields on treasury bonds for the maturities and follow-up project life cycles represented in the case studies.

As for ln S_T, upper and lower bounds are:

upper bound: $m + \sigma$
lower bound: $m - \sigma$,

for S_T upper and lower bounds are:

upper bound: $e^{(m+\sigma)} = e^m e^\sigma$
lower bound: $e^{(m-\sigma)} = e^m / e^\sigma$.

For the assumptions made above, m reduces from $\ln S = (\mu - \frac{\sigma^2}{2})(T\text{-}t)$ to ln(S), and using (3.6), we arrive at the following computational rule for upper and lower bounds of S_T at time T>t:

upper bound: $S; e^{\sigma\sqrt{T-t}}$
lower bound: $S; \frac{1}{e^{\sigma\sqrt{T-t}}}$.

For the purpose of the experiment, we selected a range of values of the parameters of (3.6). The presently expected mean S, the volatility σ, and the time until the follow-up project can be undertaken T-t are summarised in the table together with the resulting calculated upper and lower one standard deviation bounds for the future PV of the follow up project ($S_{T'}$).

Table 3.2

Upper and lower values of the confidence intervals within which the PV of the follow-up project's future cash flows will lie with about 70% probability at the expiry of the option

	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2
Volat	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.17	0.32	0.58	0.7	0.81	0.26	0.59
Time	3	3	3	3	3	3	3	3	3	3	3	3	1	5
Upper bound	5.5	11	22	33	44	55	66	13	17	27	34	41	13	37
Mean	2.5	5	10	15	20	25	30	10	10	10	10	10	10	10
Lower bound	1.1	2.3	4.5	7	9	11	14	7.5	6	4	3	2.5	7.7	2.7

3.3.3.3 The risk-free interest rate

One parameter of the real options models is the risk-free interest rate. The risk-free interest rate over the period of the data collection (February-June 1995) was 6.3% or roughly 6.%. This was derived from the monthly market yields for three-months UK Treasury bills, as published by the International Monetary Fund in its International Financial Statistics. In fact this is a discount rate for near-term (e.g. 3 months) cash flows, and strictly speaking not the right discount rate for the cash flows in the case studies, which in most case studies are 3 year cash flows (one and five year cash flows in the last two case studies). Another risk-free rate is the long-term Treasury bond yield which ranges above the Treasury bill rate (an average 8.3% over the period of data collection). Clearly, the maturity of Treasury bonds of 15 years is too long a horizon for the present discounting needs. However, there is a risk premium of Treasury bonds over bills. Both securities have no risk of default, but while the prices of Treasury bills are relatively stable due to their short maturity, the prices of Treasury bonds vary as interest rates vary (Bond prices fall when interest rates rise and vice versa). According to Brealey and Myers (1991), this risk premium (which for the US market averaged 1.1% between 1926 - 1988) would have to be subtracted from the T bond yield, often roughly offsetting the current yield difference between Treasury bonds and bills. However, it is unclear which part of the bond-bill differential should be considered risk premium and which liquidity premium. We therefore used the Treasury bill rate as a rough-and-ready estimate of the risk-free interest rate. At this point it is noteworthy that, in sensitivity analyses of the theoretical option values of our case studies for various plausible risk-free interest rates (given below) we found the option value almost completely unaffected anyway.

In order to allow the managers to focus their attention on their intuitive feel for the investment value, we described all numbers in the cases as discounted to the present. This caused a further discounting/compounding need for the case study parameter "the follow-up project's initial investment cost" (the exercise price X of the option). However the exercise price enters into the Black-Scholes model at its nominal value at maturity. Therefore the figure of £10m given in the case studies and described to the respondents as discounted to the present had to be compounded forward, in line with the life of the options, (three years for case studies A1 to B5, one year for case study C1, and five years for case study C2) in order to form the correct input into the Black-Scholes model.

The discount rate to compound the exercise price has to be the risk free interest rate. This is because the initial investment cost, in contrast to the asset price which is stochastic and must therefore yield a risk-adjusted return, is assumed to be certain in the B-S model. (It was described as being certain in the case study narratives). Following Smith and Nau, 1995, the initial investment cost consequently is treated as "growing" at the risk-free interest rate of 6%. This reflects the basic contention of the discounted cash flow approach that the value of a project is defined as *"the future expected cash flows discounted at a rate that reflects the riskiness of the case flow"* (Copeland et al., 1990, p.75). These discount rates are usually defined as *"the equilibrium expected rate of return on securities equivalent in risk to the project being valued"* (Myers, 1989, p. 126).

In our case studies, the investment cost X of the follow-up project is certain and therefore equivalent in risk to a risk-free security. Therefore the appropriate discount rate for the investment cost is the risk-free interest rate. If managers erroneously compounded X at some risk-adjusted rate, this would, if anything, cause smaller valuations. (As will be seen in Chapter 5, this was obviously not the case).

Additionally, we performed sensitivity analyses of the effect of variations in the risk-free interest rate (e.g. due to slight mis-specifications) on the compounded future values of the investment cost X and of the resulting theoretical option value c. The sensitivity analyses are summarised in Table 3.3. The first three rows give the option model parameters S, σ, and T-t.

Table 3.3

Sensitivity analysis for the risk-free interest rate

r		A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2
	S	2.5	5	10	15	20	25	30	10	10	10	10	10	10	10
	Vol	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.17	0.32	0.58	0.7	0.81	0.26	0.59
	T-t	3	3	3	3	3	3	3	3	3	3	3	3	1	5
0.04	X	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	10.4	12.2
	c	0.06	0.5	3	6.8	11.1	15.7	20.4	1.2	2.2	3.8	4.6	5.2	1	4.9
0.06	X	12	12	12	12	12	12	12	12	12	12	12	12	10.6	13.5
	c	0.06	0.5	3	6.8	11.1	15.7	20.4	1.2	2.2	3.8	4.6	5.2	1	4.9
0.08	X	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	10.8	15
	c	0.06	0.5	3	6.8	11.1	15.7	20.5	1.2	2.2	3.9	4.6	5.2	1.1	4.9
0.1	X	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	11.1	16.5
	c	0.06	0.5	3	6.8	11.1	15.7	20.5	1.2	2.2	3.9	4.6	5.2	1	4.9

Over the (double-)rows four to seven, the (continuous) risk-free rate is varied from 4% to 10%. The effects are an increase of the compounded future value of X, which lowers the option value, and the positive effect of a higher risk-free interest rate which raises the option value. As can be seen from the table, these effects are almost exactly offsetting, so that the option value hardly changes. This shows that slight misspecifications or changes in the risk-free interest rate in a realistic interval can be neglected for our theoretical option values.

The Black-Scholes model used to calculate the option values (c's) will be given in the next section. Note that in the case studies two discounting/compounding mechanisms took place. Firstly, the exercise price as given in the case studies was compounded to the maturity at 6% risk-free discount rate in order to allow us to enter the correct future exercise price X into the B-S option pricing model. The B-S model again discounts this exercise price back to the present at the risk-free interest rate of 6%. Secondly, as discussed in the previous section, the expected continuously compounded rate of return, $\mu - \frac{\sigma^2}{2}$, is the appropriate discount rate for the upper and lower bounds in the case studies. This allowed us to describe to the respondents the upper and lower bounds, as determined in the previous section, to be discounted to the present.

3.4 Relevant real option types and the appropriate option pricing model for growth option investment structures

In the literature review, we explained why, in the present study, we decided to focus on growth options. In this section, we firstly examine whether and when other real option types, as identified in the literature review, such as the option to wait, the option to expand, etc., arise together with growth options. Secondly, we attempt to identify the most suitable option pricing model type for the valuation of the growth options in our case studies, namely American vs. European option pricing models and dividend paying vs. non dividend-paying option pricing models. Thirdly, we choose between replication-derived vs. equilibrium-derived option pricing models.

3.4.1 Relevant real option types

3.4.1.1 The option to wait

In the literature review, we identified claims that management's intuition agrees with the theoretical values of growth option theory and a gap concerning the empirical testing of this claim.

An anonymous practitioner author (1994) argues on the lines of Dixit and Pindyck (1994) that observed corporate "hurdle" required rates of return of two or three times the cost of capital are partial responses to the option to wait for better economic conditions and/or more information to arrive and to avoid worse economic conditions. This option, which is according to Dixit and Pindyck (1994) immanent in most investment opportunities, and which represents value in addition to the regular NPV of the project, if executed immediately, will be foregone as soon as the investment is taken. It has therefore to be compensated for by the return from the investment opportunity.

In this section we discuss the reasons why we decided, in the present study, to focus on the gap concerning growth options rather than the option to wait. Moreover, we discuss the question whether our growth options as described could contain implicit options to wait, which should have been explicitly included in the theoretical valuation analysis.

The option to wait arises for example when management holds a lease on (or an option to buy) valuable land or resources. Management can delay the investment in order to avoid loss if the prices do not justify investment (when the option is out of the money) and can wait to see whether in the future output prices will justify investing in for example constructing a building or plant, or developing an oil or gas field (Trigeorgis, 1993a).

This option arises at a different stage of the investment process than growth options. Whereas growth options are a model of the creation of investment opportunities (the option to invest in a follow-up project is created by investing in a pioneer project), the option to wait models the optimal timing of the exploitation of an existing investment opportunity (the option to wait for more information/better conditions is "killed" (exercised) by taking the investment).

The theoretical values of these two kinds of options both differ from the traditionally computed NPV of an investment project, but they do so in different ways. The growth option rule accepts investments with lower NPVs than the traditional NPV rule. The reason for this is that in growth option theory, in addition to the NPV of the investment in itself, the value of potential follow-up projects is taken into account. In this sense, growth option theory offers a possible cure for the well-known problem that standard discounted cash flow (DCF) criteria often undervalue investment opportunities, leading to myopic decisions, underinvestment, and eventual loss of competitive position (e.g., Trigeorgis, 1993a).

In contrast, under the option to wait rule, the NPV of the project must be higher than under the traditional NPV rule. This is because killing the option to wait is considered as an opportunity cost which is incurred when the investment is made. According to this rule, the traditional NPV rule would lead to overinvestment. It appears that a recognition of the value of the option to wait even worsens the aforementioned problem of underinvestment (assuming that a higher level of real investment would indeed be rational for the economy at large).

Another property of the option to wait which is at first glance confusing stems from the fact that for a non dividend-paying stock, an American call option is normally worth more alive than dead, and should not be exercised early. Option pricing theory assumes first order stochastic dominance of later prices over earlier prices. In option pricing models this is expressed in the positive growth rate alpha of the geometric Brownian motion random walk

$$dX = \alpha X dt + \sigma X dW \quad (3.2)$$

First order stochastic dominance implies that an asset is stochastically dominant over another if an individual receives greater wealth from it in every state of nature (Copeland and Weston, 1988). Taken on its own, this property of real options models would mean that it is always optimal to wait.

This is not necessarily the case for two reasons. Firstly, the growth rate of the stochastic process underlying the basic option pricing models is distorted by an additional Wiener process (the dW in the above equation). Secondly, if a delay in the investment causes the investor to forego cash flows, early exercise of an option might be sensible if the expected return from investing early is higher than the growth rate (i.e. the return achieved by investing later). Cash flows from a real asset investment project correspond to dividend payments on a stock. In a case where a stock pays a dividend payment before an American call option matures, the ex-dividend price of the stock and the possible payoff of the call option at maturity are both reduced. Therefore, sufficiently large dividends will prompt call option holders to capture them by exercising the option just before the ex-dividend date (Brealey and Myers, 1991). Similarly, if a real asset project's future cash flows seem to be sufficiently large, managers can "capture" the cash flows by investing right away.

In many general management contexts, the idea that there is a value for the option to wait appears partly counterintuitive. Under perfect competition, a company that is in a position to undertake a certain investment will in most cases do so. As it will try to be ahead of competition whenever possible, waiting is rarely possible. Competitive pressures and economies of scale lead to "first mover advantage", which seems to be the opposite of a value for waiting. Administrative rules often dictate that budgets cannot be transferred to the next period, and this also eliminates the (value of) the option to wait.

Trigeorgis' (1988) classification framework for real options can offer some assistance as to whether the option to wait is realistic under given circumstances. Addressing the "urgency of the decision", Trigeorgis distinguishes between "expiring" investment opportunities, i.e.

projects that need an immediate accept/reject decision, and "deferrable" investment opportunities, i.e. projects that management can defer for future action.

Only deferrable projects require an extensive analysis of the optimal timing of investment, and only for those projects must management compare the net value of taking the project today with the net value of taking it at all possible future years. Deferrable projects are most often investments involving commodity-type goods, since for these the risk of technical or market volume pre-emption is usually small, due to the low level of product and demand innovation.

In contrast, most other goods are under threat of technical or scale pre-emption from competitors and therefore opportunities to produce these are expiring. Classical examples of goods facing the risk of pre-emption are high technology products, consumer durables, and fast-moving consumer goods. They enjoy experience curve effects and first mover advantage, both reasons for not waiting to invest. Furthermore, although for commodity-type goods the assumption of a random walk of the price, which many real option models make, can be considered quite realistic, in contrast in many oligopolistic markets many markets (for example high technology products, consumer durables, and fast-moving consumer goods), product prices do not change randomly but are determined by identifiable strategic games between the competitors.

To conclude, the option to wait is most readily applicable in contexts with more or less commodity-like goods, namely natural resource extraction industries, but it is of limited usefulness in industries with expiring options.

3.4.1.2 Compound options and multiple operating options

Compound options

A more complex investment situation is one in which a company has the opportunity to undertake a follow-up project some time before or after the corresponding pioneer project has been completed. An example is the introduction of a new car model range, where the manufacturer needs the experience from the existing model generation to develop a new model generation to replace the existing one, but then has some leeway as to the time of the replacement. The pioneer project in this situation could be interpreted as similar to an American option (a financial option exercisable throughout its life).

However, as this real option is exercisable only from a certain point in time after the start of the pioneer investment, this situation would be more correctly be valued as a combination of an European option (the growth option) plus a consequent American option (the option to wait). Note that the American option should also be considered as dividend-paying, since as soon as the follow-up project is ready for investment, its cash flows are foregone so long as this investment is not made.

This is the basic structure of an option on an option, or compound option, as first analysed by Geske (1979). Although compound options have very realistic features, they were deemed too complicated to be expressible simple investment case studies and were not used in the present study. Moreover, the industries described in our case study narratives (see section 4.4.1) suffer a high degree of competition and, according to the textual narratives, often little scope for technological leadership this suggests that the option to wait is not likely to exist for long after the follow-up investment is first able to be made. Consequently, the investment case studies in the present study are not thought to contain compound options of substantive importance.

(Multiple) operating options

In growth option type investments, (multiple, interacting) operating options, such as the options to abandon, contract, expand, or switch use, as described in Trigeorgis (1993), could arise both in the pioneer project and in the follow-up project. In the investment case study narratives, however, we attempted to focus the respondents' attention on the growth option in the case studies in order to avoid complications stemming from the well-known limitations of human information processing. To this end, the pioneer project is treated as a black box, only described by its resulting NPV. Operating options for the follow-up project are conceivable, but are not explicitly described in the case studies. It is an empirical question whether empirical case study valuations are observed above the theoretical value of the basic B-S European growth option. If so, such overvaluations could be due to the respondents' recognition of multiple operating options.

3.4.2. The choice of an option pricing model type for valuing the real growth options

There exist several candidates among financial option pricing models for the modelling of the type of real growth options that we focus on in the present study.

American option models allow for the possibility of exercise at any point in time during the period to the expiry of the option. This is a realistic way to represent those real options which create exploitable investment opportunities from the moment of the first investment. American options can accommodate numerous special requirements since these can be modelled using a binomial tree (Hull, 1993). However, as discussed in the previous section, because the pioneer project is a prerequisite for the follow-up project, growth options quintessentially resemble European options, i.e. options which are only exercisable after a fixed time delay (maturity). For example in a situation involving a research project leading to a marketable product, profitable production can normally only start after completion of the research, the time period for which has little or no flexibility (safety trucks, legal clearances etc.).

European option pricing models can be non dividend-paying or dividend-paying. A European financial option on a stock that does not pay dividends during the life of the option is the classic situation modelled by Black and Scholes (1973). This model is utilised by Brealey and Myers (1991) for the evaluation of a follow-up investment opportunity in the microcomputer industry, by Newton and Pearson (1993) for the evaluation of a R&D project leading to an investment opportunity in a new product, and by Merck & Co. for the evaluation of the acquisition of technologies from a small biotechnology company (Nichols, 1994). The Black Scholes financial option model has the advantage that of all the available option pricing models, it is the one that managers are most likely to be familiar with. However, it may not be realistic to assume that the annualised continuously compounded rate of return of a real project is always normally distributed. This can be handled by decision tree methods, which we discuss later.

The European option model of Merton (1973) basically models a similar situation as the Black-Scholes model with the one difference that Merton incorporates dividend payments.

According to Dixit and Pindyck (1994), the difference between the risk-adjusted return and the expected percentage growth rate of the asset (Merton's dividend rate) can be interpreted in two ways in a real growth option context. It can reflect the cash flows from the follow up project, foregone when deliberately waiting to invest, or it could reflect the process of entry and capacity expansion by competitors, during the period of waiting to invest.

Foregone cash flows tend to increase the opportunity cost of holding the option, and thus reduce the value of the option making it optimal to exercise it sooner. In a real option context, dividend-paying models are usually used to model the cash flows foregone while deliberately delaying an investment in order to wait for more information and/or better conditions. In the narratives describing the growth options used in the case studies, we present a delay of the follow up investment until the full maturity period as compulsory, and no option to delay investment further beyond the maturity period is explicitly permitted.

In a growth option context, the follow-up project can only be started after the pioneer project is sufficiently advanced, i.e. after a finite period of delay following the pioneer project investment. Of course it is impossible to forgo cash flows from the follow-up project before it is possible to start that project. At the time the follow-up project can first be undertaken, the growth option matures and the growth option model ends. Potential cash flows from the follow-up project can therefore arise only after the growth option maturity period. Such foregone cash flows are mainly important in the context of options to wait (i.e. production has not been started yet) or after production had been temporarily abandoned.

The threat of entry or capacity expansion by competitors may or may not be present in a real options context. In order to assess the relevance of this threat, Trigeorgis' (1988) classification of real options according to their "exclusiveness of ownership" seems helpful. In an attempt to describe the effect of competition on the firm's ability to fully appropriate for itself the value of its real options, Trigeorgis (1988) distinguishes between "proprietary" and "shared" options.

A "proprietary" option exists if the company's choice whether and when to invest is unaffected by the moves of its competitors. Real proprietary options are usually investment opportunities with high barriers of entry for competitors. Examples of real proprietary options include patents for products having no close substitutes and unique know-how in a technological process that competitors are unable to duplicate for some time. For proprietary options, the threat of entry or capacity expansion by competitors is not substantial and need therefore not be included in the real options model. Hence the option to wait can have significant value. As mentioned before, both the industries and competitive situations described in our investment case studies do not suggest the existence of proprietary real options.

"Shared" real options are those investment opportunities which are also open to a company's competitors, enabling them to take part or all of the project's value away from the company. Introduction of new products unprotected against imitation and penetration of new geographic markets with low entry barriers are opportunities that are open to most firms in a particular industry. This is the situation in most of our investment case studies.

For shared real options, the threat of entry or capacity expansion by competitors is substantial and it is therefore necessary to consider this effect in the real options model of the option to wait. One way to achieve this is to incorporate a dividend rate in the real options model (e.g., Merton, 1973). However, it can be argued that this method is only a very rough way of dealing with the threat of entry or capacity expansion by competitors. More complete models endogenise the process of entry and capacity expansion, partly by using game theoretic considerations (e.g., Dixit and Pindyck, 1994, Smit and Ankun, 1993). Consequently, it was decided to use a non-dividend paying option model (the Black-Scholes model) as the basis for our investment case studies.

3.4.3 Replication derivation vs. equilibrium derivation of the B-S model

In their seminal paper, Black and Scholes (1973) describe two derivations of the European call option pricing formula. The first, which can be referred to as the "replication derivation" depends on the fact that the return from the option can be replicated by a continuously revised "hedge" portfolio of the underlying asset and bonds. It follows that if an option was not priced according to the B-S model, there would be an arbitrage profit to be made by some combination of either short or long sales of the option and the underlying asset. This derivation is commonly regarded independent of considerations relating to capital market equilibrium (McDonald and Siegel, 1984).

The second derivation, which can be referred to as the "equilibrium derivation", is based on the requirement that the option earn an expected rate of return commensurate with the risk involved in holding the option as an asset. Appendix 3 exemplifies discrete versions of both option valuation approaches by valuing one of our investment case studies.

If the underlying asset is traded in the market, the asset and the option belong to the same risk class (Constantinides, 1978). This implies that the option pricing differential equation is valid, even if the assumptions that underlie an equilibrium model such as the capital asset pricing model (CAPM) do not hold. For this reason, if the underlying asset is traded in the market, the derivation of the B-S model through the arbitrage argument dominates the derivation through the CAPM.

However, most "real" risky projects (such as those in our case studies, cf. Table 4.2) can at best be partially hedged by trading securities (Smith and Nau, 1995, Paddock et al., 1988). In many investment situations involving real assets the decision maker has an option but it is not easy to construct a perfect replicating trading strategy. Without a hedge portfolio, the value of the option cannot be determined using arbitrage (Bierman and Schmidt, 1990).

We therefore, in the present study, follow the equilibrium derivation of the B-S model, which does not rely on the ability to trade, replicate or otherwise justify risk neutral valuation in pricing options (Kasanen and Trigeorgis, 1994). Precedents for equilibrium-derived valuation heuristics with applications to (financial and real) options are e.g. Constantinides (1978) and Cox et al, (1985). Examples for specific real option models based on an equilibrium-derivation are McDonald and Siegel (1985 and 1986).

In the equilibrium approach, the B-S differential equation is derived based on the condition that the option earn a rate of return commensurate with its risk. This approach requires specifying a particular model of capital market equilibrium. In what follows, we reproduce the derivation of Black and Scholes (1973), who use the CAPM.

The ("Sharpe-Linter-Black") CAPM (e.g. Sharpe, 1970) describes the relation between risk and expected return for a capital asset. The expected return of an asset represents the discount rate that must be applied in order to discount the end-of-period value of an asset to give its present value. Under the CAPM, the value of an option is discounted to the present, using a discount rate that depends on both time and the price of the stock (Black and Scholes, 1973).

The CAPM approach requires that the assumptions which lead to the CAPM are satisfied. The CAPM assumptions are (as summarised in Copeland and Weston, 1988):

1. Investors are risk-averse individuals who maximise the expected utility of their end-of-period wealth.

2. Investors are price takers and have homogenous expectations about asset returns that have a joint normal distribution.

3. There exists a risk-free asset such that investors may borrow or lend unlimited amounts at the risk-free rate.

4. The quantities of assets are fixed. Also, all assets are marketable and perfectly divisible.

5. Asset markets are frictionless and information is costless and simultaneously available to all investors.

6. There are no market imperfections such as taxes, regulations, or restrictions on short selling.

The CAPM was originally stated a single-period model. Extending it to a multiperiod model is generally difficult (Black and Scholes, 1973). Under the additional assumption that the short-term interest rate is constant through time, the CAPM must apply to each successive period in time (Fama, 1970, quoted in Black and Scholes, 1973). Although not all these assumptions conform to reality, they are simplifications that permit the development of the CAPM, which is extremely useful for financial decision making because it quantifies and prices risk (Copeland and Weston, 1988). Most of the restrictive assumptions of the original Sharpe-Linter-Black CAPM have been relaxed in later versions of the CAPM.

The CAPM states that the expected return of an asset is a linear function of its β, i.e. the convariance of the return on the asset with the return on the market, divided by the variance of the return on the market. We now follow Black and Scholes (1973) to apply the CAPM to an option and the underlying asset.

Writing f (S, t) for the value of the option as a function of the stock price S and time t, the change in the value of the option is

$$\Delta f = f(S + \Delta S, t + \Delta t) - f(S, t) \qquad (3.3)$$

We can use stochastic calculus to expand this expression as follows:

$$\Delta f = \frac{\partial f}{\partial S}\Delta S + \frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2 \Delta t + \frac{\partial f}{\partial t}\Delta t \qquad (3.4)$$

where σ^2 is the variance rate of the return of the stock..

Equation (B) shows that the convariance of the return on the option $\frac{\Delta f}{f}$ with the return on the market equals $S\frac{\partial f}{\partial S}\frac{1}{f}$ times the convariance of the return on the stock $\frac{\Delta S}{S}$ with the return on the market. Using the option's beta (β_f) and the stock's beta (β_S) expressing this relationship yields:

$$\beta_f = (S\frac{\partial f}{\partial S}\frac{1}{f})\ \beta_S \qquad (3.5)$$

The expression of S $\frac{\partial f}{\partial S}\frac{1}{f}$ can be interpreted as the elasticity of the option price with respect to the stock price (i.e. the ratio of the percentage change in the option price to the percentage change in the stock price).

Let a be the rate of expected return on the market portfolio minus the risk-free interest rate r. We can then write the expected return on the stock and on the option write as:

$E(\Delta S/S) = r\,\Delta t + a\beta_S\,\Delta t$ (3.6)

$E(\Delta f/f) = r\,\Delta t + a\beta_f\,\Delta t$ (3.7)

We now first transform the equation for the stock return (3.6) and then the equation for the option return (3.7) in order to combine them into a differential equation for the value of the option.

Taking the expected value of equation 3.4:

$E(\Delta f) = \frac{\partial f}{\partial S}E(\Delta S) + \frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2\Delta t + \frac{\partial f}{\partial t}\Delta t)$ (3.8) and substituting for $E(\Delta S)$ from equation 3.6:

$E(\Delta S) = rS\Delta t = aS\beta_S\Delta t$ we find:

$E(\Delta f) = rS\,\frac{\partial f}{\partial S}\Delta t + aS\frac{\partial f}{\partial S}\beta_S\Delta t + \frac{1}{2}\sigma^2 S^2\frac{\partial^2 f}{\partial S^2}\Delta t + \frac{\partial f}{\partial t}\Delta t$ (3.9)

Multiplying equation (3.7) by f:

$E(\Delta f) = rf\Delta t + af\beta_f\Delta t$ (3.10) and substituting for B_f from equation (3.5) we have:

$E(\Delta f) = rf\Delta t + aS\,\frac{\partial f}{\partial S}\beta_S\Delta t$ (3.11).

Combining (3.9) and (3.11), the terms involving a and β_S cancel, and we obtain the so-called B-S differential equation for the value of an option:

$rf = \frac{\partial f}{\partial t} + rS\frac{\partial f}{\partial S} + \frac{1}{2}\sigma^2 S^2\frac{\partial^2 f}{\partial S^2}$ (3.12)

Subject to the boundary condition for a call option:

$f(S,T) = S - X$ if $S \geq X$ (3.13)

$= 0$ if $S < X$

and using Fourier series, the analytical solution of (3.12) for a call option is given by Black and Scholes (1973) as:

$$c = SN(d_1) - Xe^{-r(T-t)}N(d_2) \qquad (3.14)$$

where

$$d_1 = \frac{\ln(S/X) + \left(r + \sigma^2/2\right)(T-t)}{\sigma\sqrt{T-t}} \qquad (3.15)$$

$$d_2 = \frac{\ln(S/X) + \left(r - \sigma^2/2\right)(T-t)}{\sigma\sqrt{T-t}} = d_1 - \sigma\sqrt{T-t} \qquad (3.16)$$

with:

S = Stock price

X = Exercise price

σ = Volatility

T-t = Time-to-Maturity

r = Risk-free interest rate

We can now introduce the concept of the intrinsic and time values, and of "moneyness" which will prove important in the interpretation of the findings in Chapter 5.

The intrinsic value of an option, max(S-X) is defined as the maximum of zero and the value the option would have if it were exercised immediately (i.e. current asset price minus the exercise price) (Hull, 1993). The option's time value is the difference between the full option value and its intrinsic value.

Options can be referred to as in-the-money, at-the-money, and out-of-the money. An in-the-money option would lead to a positive cash flow to the holder if exercised immediately. An at-the-money option would lead to zero cash flow if exercised immediately, and an out-of-the money option would lead to a negative cash flow if exercised immediately. If S is the stock price, and X is the exercise price, a call option is in the money when $S>X$, at the money when $S = X$, and out of the money when $S > X$ (Hull, 1993).

Table 3.4 contains, for the 14 case studies, the moneyness of the option, the expected PV of the follow-up project's cash flows (the "S" of the option), the follow-up project's initial investment cost (the X of the option), the intrinsic value and the time value, and finally the Black-Scholes call option value.

Table 3.4

Intrinsic value, time value, and option value for the case studies

	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2
Moneyness	Out-of-the money				In the money					Out-of-the money				
PV of cf's	2.5	5	10	15	20	25	30	10	10	10	10	10	10	10
In.Inv. cost	12	12	12	12	12	12	12	12	12	12	12	12	10.6	13.5
Intrinsic v	0	0	0	3	8	13	18	0	0	0	0	0	0	0
Time v.	0.06	0.5	3	3.8	3.1	2.7	2.4	1.2	2.2	3.8	4.6	5.2	1	4.9
Option v.	0.06	0.5	3	6.8	11.1	15.7	20.4	1.2	2.2	3.8	4.6	5.2	1	4.9

3.5 Critical issues in real option theory

3.5.1 The log-normality and the complete markets assumptions

Many option pricing models used in real options theory assume a log-normal distribution of future asset prices. For example Black and Scholes, in the derivation of their formula for the value of an option in terms of the price of the stock, assume "ideal conditions" in the market for the stock and for the option. One assumption is that the stock price follows a random walk in continuous time with a variance rate proportional to the square of the stock price. Therefore the distribution of possible stock prices at the end of any finite time interval is log-normal (Black and Scholes, 1973).

This assumption precludes asset prices from being negative. Non-negativity certainly is correct for stock prices, which can only be positive, or zero in the case that the firm fails (In the case of a failed firm, such as Airfix Industries, the brands, patents, and other option-like features of the firm may still have value, but this may not be accessible to the equity holders). It therefore makes sense to use a nonnegative distribution like the log-normal distribution to model stock prices.

The PV of non-financial assets, however, and particularly the expected PV of the cash flows of a future investment project, clearly can be negative. At first sight, the all-positive log-normal distribution might not seem appropriate under these circumstances.

It might, however, not be necessary to model the case of a negative NPV explicitly provided one is willing to make the restrictive assumption that the investor can and will suspend operating the project if operating profits unexpectedly become negative. Of course, an expected negative PV can be avoided simply by not investing. Dixit and Pindyck (1994) show however that the actual suspension/resumption decision is more complex than this.

Our pilot interviews suggested that the organisations concerned are strongly biased towards only considering real options for which the expected PV is strongly positive, and the expected chance of a negative PV is small. Therefore although the nonnegativity assumption made in the Black-Scholes and other option pricing models is strictly speaking incorrect for a general real investment context, this should not affect the realism of the application of the B-S model to the narrative cases and parameter values used here.

We now consider what would happen if we departed from the usual real options assumption of complete markets. The securities market is complete if all project risks can be perfectly hedged by trading securities. For example, if there are two states of the world, a market is completed by two linearly independent securities, because the pay offs of every risky cash flow can be represented as a linear combination of the payoffs of these two securities. More formally, the securities market is complete if for every project $c(t,\omega_t)$ there exists a replicating trading strategy β_r that generates cash flows which exactly match the project's future cash flows at all times t and in all time-t states of information ω_t i.e, a trading strategy β_r such that for all $t > 0$ and ω_t

$$[\beta_r (t-1, \omega_{t-1}) - \beta_r (t_1 \omega_t)] \mathbf{S} (t_1\omega_t) = c(t_1\omega_t) \quad (3.17)$$

(the product here is an inner product or dot product) with the vector of the prices of securities

$$\mathbf{S} (t_1\omega_t) = (S_0(t_1\omega_t)_1 \; S_1(t_1\omega_t) \; ....., S_N(t_1\omega_t)) \quad (3.18)$$

where $S_i(t_1\omega_t)$ denotes the price of the ith security at time t in state ω_t (Smith and Nau, 1995).

We now consider the case that the securities market is incomplete, implying that not all project risks can be hedged. Rubinstein (1976) shows that given constant proportional risk aversion (CPRA), the B-S pricing formula is robust within lognormality conditions, even if a perfect hedge can not be constructed. Given the "risk-shunning" behaviour of managers observed in many studies (e.g. Swalm, 1966), the requirement of CPRA does not seem problematic.

3.5.2 Reasons for the value of the real option

As explained above, the option value consists of the intrinsic value and the time value. The reasons for the intrinsic value are most easily understood for the case of an American option. At any point in time, the intrinsic value is the amount that can be earned by exercising the option immediately. As a rule, if the NPV of a growth option situation is sufficiently high (i.e. higher than the difference between the (nominal) value at maturity and the present value of the exercise price), the option will have a positive intrinsic value. In this section we focus on the reasons for the time value of the option.

The reasons why the real option has a time value are similar to the reasons why a financial option is valuable. Financial option pricing theory assumes that the price of the underlying asset on which the option exists is likely to change over the life of the option. Generally, there is value from owning an option since the option provides the flexibility to capture gains from a rise in the price in the underlying asset but to avoid losses from its fall (McDonald and Siegel, 1986). This corresponds to the managerial flexibility to invest in a follow-up project only if the conditions are favourable. Managerial flexibility thus limits the downside risk of acquiring an investment option to the price of the option itself, while offering the potential upside from favourable investment conditions.

A real option offers the firm the opportunity to wait for new information to arrive about prices, costs, and other market conditions before it commits resources (Dixit and Pindyck, 1994). As a result, the firm might be in a better position to estimate the value of the real asset. This aspect is not usually important in financial markets where this function is performed by the market which supplies the main decision parameter in the form of the observable market price of the underlying asset. According to the different forms of the efficient market hypothesis, the arrival of fresh information on prices, costs, political, social and other market conditions (and the expectations about future states of these conditions) are more or less instantly and fully reflected in asset prices. Note that, compared to real assets, financial assets are relatively standardised and the market has enormous experience in valuing them.

In investment situations involving nonfinancial assets (such as a new plant, a new product or a new market), market prices for project values do not normally exist and the individual firm itself has to derive project values from current prices, costs, and other market conditions, (and also from expectations about future prices, costs, and market conditions). Because real investment projects show little standardisation and the firm is not as experienced as the market in valuing assets, single firms might be faced with what Frank Knight in 1921 called "uncertainty" rather than "risk":

"The practical difference between the two categories, risk and uncertainty, is that in the former the distribution of the outcome in a group of instances is known (either from calculation a priori or from statistics of past experience), while in the case of uncertainty that is not true, the reason being in general that it is impossible to form a group of instances, because the situation dealt with is in a high degree unique." (pp.232-33)

By means of observing price-, cost-, and market conditions over time or by conducting specific market research, the firm can be hope to arrive at more accurate project values. More accurate project values, of course, offer a better chance to get the decision right. At this point it is noteworthy that although information arrives over time, the future value of the project is always uncertain (cf. Dixit and Pindyck, 1994).

However, in the real option models we know of, the price of the asset is assumed to be perfectly observable and the fact that the potentially inexperienced firm rather than the skilled market has to determine the value of a far less standardised asset is not formally expressed. The "objective" risk, i.e. the volatility of a (financial) asset with perfectly observable prices, would be blurred by a "subjective" uncertainty in the form of the uncertainty a particular company has about the objective volatility (due to unobservability of prices). (Note that even for perfectly observable asset prices, the volatility of the asset price is not directly observable and has to be estimated. In the next section, we will discuss alternative approaches to volatility estimation more closely). "Uncertainty instead of risk" is often referred to as "ambiguity", (cf. Thaler, 1991) and decreases with increasing valuation skills on the part of the company.

3.5.3 Volatility in real and financial option pricing

The volatility of an asset price is a measure of how uncertain future asset price movements are. Higher volatility implies a higher chance that the asset will itself do either very well or very poorly. In contrast, a call option on the asset benefits from a price increase but has a downside risk limited to the price of the option. Call option values therefore increase as volatility increases.

In order to estimate the volatility of a real asset's price or project value, two approaches are conceivable: the use of data from previous real asset projects and the use of volatility figures from financial assets with similar risk. We will discuss each approach in turn.

Newton and Pearson (1994) suggest a somewhat idealised method to derive volatility from previous investment projects. Data on the amounts and timings of cash inflows and outflows for a set of projects which were, at the outset, considered to have similar probability distributions of profit would be gathered. From the projects' post audits, the mean profit/return and the standard deviation (i.e. the volatility) of the returns could be computed for each set of projects. However, it is the standard deviation of returns from potential projects rather than of realised projects which is of interest in investment decision making. The difference between both lies in the fact that a company tries to avoid bad potential projects and selects them out. If it does so at least with some success, data from realised projects are biased in favour of successful projects and the assumption of volatility estimation of a (symmetrical) normal distribution does not apply.

Newton and Pearson (1994) argue that the observed distribution of returns from realised projects should peak at the same value as the distribution of returns from potential projects, in which case the right hand part of the observed distribution should be used to estimate volatility for potential projects. Newton and Pearson (1994) emphasise the desirability of the formation of different risk classes of projects by pointing out this is also a practical requirement of the Net Present Value (NPV) approach. Accordingly, given firms' well-known inertia to use project-specific discount rates, firms should at least use different discount rates for different risk classes of projects. The biggest obstacle to this approach of historical volatility estimation seems to be the low popularity of post-audits of investment projects in companies (e.g. Brealey and Myers, 1991).

We now turn to estimating real assets' volatility from similar financial assets. We first discuss approaches to identifying financial assets with similar risk characteristics (following Jägle and Howell, 1996) to the real assets of interest. Secondly, we summarise approaches to the volatility estimation of financial assets.

The real assets that underlie non-commodity real options are of course not traded, except indirectly through trade in the companies that are creating them. One way of estimating their volatility is to identify (a portfolio of) traded securities that have similar risk characteristics (i.e. are highly correlated) with the nontraded real asset.

In many non-commodity investments, it is not easy to identify such securities. However, it is generally felt that, with enough ingenuity, it may be possible to do so (cf. e.g. Bierman and Schmidt, 1992). Three types of projects, with different types of highly correlated portfolios can be distinguished.

Firstly, for an "across the board expansion", i.e. an investment with the same risk characteristics as the existing business. The highly correlated portfolio might be the stock of the company itself, or, better, in order to prevent non-operations "shocks" to the company from distorting the correlation, a portfolio of stocks of several similar firms. Secondly, for an "investment in an area new to the company", the highly correlated portfolio might be a portfolio of stocks of firms in the respective industry-sector. This project type includes investments in new or rare products, in which case only one single quoted company, exclusively manufacturing the product in question, might form the highly correlated portfolio. Thirdly, for an "investment in a completely new product", a highly correlated portfolio can be found using asset betas. The project beta could be estimated, by examining the asset for characteristics that are associated with high or low betas, such as "cyclicality" or "operating leverage" (Brealey and Myers, 1991). A suitable portfolio of traded assets with the same beta could be created. The fact that two assets are correlated with the market portfolio in the same way, is a necessary (but not sufficient) condition that these assets are perfectly correlated with each other. However, a portfolio of several related assets (i.e. assets correlated with each other by more than the minimum imposed by their joint correlation with the market) can be correlated extremely highly with any one of these assets, to the extent that departures from perfect correlation are small enough to be numerically unimportant. Previous studies have shown that betas appear to be reasonably stable over time (cf. Brealey and Myers, 1991).

We exemplify the above argument by indicating the choice of industry sectors (as listed by London Business School's Risk Measurement Service) that could be a starting point for devising highly correlated portfolios for the respective real assets in our 14 case studies. For those projects involving foreign investments, the twin security is more likely to be the (sterling equivalent of) assets in the respective foreign capital market, as in this way potentially different economic conditions and currency fluctuations can be taken into account (for these foreign investments, UK-based "Group number"- and "Number of companies"-information appears in brackets).

Table 3.5

Starting points for the determination of portfolios highly correlated with the respective case study assets

CS	Nature of follow-up project	Country	Group number	No. of companies	Starting point for twin security-determination
A1	New rubber type	UK	234	17	Speciality chemicals
A2	Tramways system	E. Europe	(490)	(33)	Transport
A3	Market introd. of body care products	Russia	(360)	(42)	Health & personal care
A4	Dental care product	Switzerland	(360)	(42)	Health & personal care
A5	New pet food	UK	330	47	Food manufacturing
A6	Next-generation microchip	UK	253	51	Electronic equipment
A7	New tarpaulin material	UK	234	17	Speciality chemicals
B1	Market introduction of bakery product	France	(330)	(47)	Food manufacturers
B2	Windfarm	UK	620	17	Electricity
B3	Mobile telephone product	UK	660	5	Telecommunication
B4	Human remedy	UK	370	15	Pharmaceuticals
B5	Residential project	UK	210	85	Building & Constructio
C1	Market introduction of disposable nappy	Spain	(360)	(42)	Health & personal care
C2	Special-purpose adhesive	UK	360	42	Health & personal care

Note: CS = case study, E. Europe = Eastern Europe.

Note that in the case of less than perfect correlation between the real asset in question and the traded twin security, the real asset's volatility might be mis-specified. It can be hoped, however, that by using a more detailed industry sector classification than the one used above, the expected correlation can be improved. Given the generally high uncertainty in capital budgeting, the component of misvaluation due to imperfect correlation might be comparatively low.

We now first formally define the volatility of an asset price as a historical simple (moving) average (as given in Hull, 1993) and then discuss alternative historical and implied volatility estimation methods that have been researched in finance in recent years.

The volatility of an asset price σ can be estimated by the standard deviation of the returns from the asset in a specific interval of time divided by the square root of this time interval. The continuously compounded return ("compound return") μ in the ith interval follows from:

$$S_i = S_i e^{ui} \quad (3.19)$$

and is given as:

$$u_i = \ln\left(\frac{S_i}{S_{i-1}}\right) \text{ for } i = 1,2,\ldots., n \quad (3.20)$$

with:

S_i = Stock price at end of ith interval (i = 0,1,....n)

n+1 = Number of observations

The usual estimates of the standard deviation of the compound returns is given by: (3.21)

$$s = \sqrt{\frac{1}{n-1}\sum_{i-1}^{n}(u_i - \bar{u})^2} \quad (3.21)$$

where $\bar{u}$ is the mean of the u_i's.

If we assume the u_i's to result from Brownian motion, their standard deviation is given by (3.22):

$$u \sim \phi\left[\left(\mu - \frac{\sigma^2}{2}\right)(T-t), \sigma\sqrt{T-t}\,\right] \quad (3.22)$$

where t = current time

T = some future time

T-t = length of measurement interval in years.

This implies that our uncertainty about the continuously compounded return, as measured by its standard deviation, is proportional to the square root of how far ahead we are looking. Combining the last two equations show that s is an estimate of $\sigma\sqrt{T-t}$

Finally, it follows that the volatility of the asset price σ can be estimated as $\hat{\sigma}$ where:

$$\hat{\sigma} = \frac{s}{\sqrt{T-t}} \quad (3.23)$$

Concerning the choice of an appropriate value for n (i.e. a measurement "window"), there exists a trade-off between on the one hand, the more data leading to more accuracy (smaller standard error $\frac{\hat{\sigma}}{\sqrt{2n}}$) and on the other hand, since σ changes over time, the inclusion of excessively old data being irrelevant for predicting the future. Traditionally, most measurement samples used the rule that the longer the forecast horizon, the more historical data we should use (Guldimann, 1994). Hull (1993) generally suggests 90 to 180 trading days (not calendar days).

There are two main ways to use past data (equally weighted moving average and moving average). The simplest form of a moving average model is described as follows:

$$X_t = Z_t + bZ_{t-1} \quad (3.24)$$

where

X_t = Moving average at time t

Z_t = Observation at time t

b = Coefficient (weight)

Note that in the simple moving average approach to volatility estimation, all observations have identical or "fixed" weights. This works well for stationary return processes. However, volatility estimates can decline abruptly once a large movement falls out of the measurement sample.

In contrast, in the exponentially weighted moving average scheme, the latest observations carry the highest weight in estimating volatility (i.e. the weights decrease exponentially for periods farther in the past).

In this scheme, we can use the following expression to estimate volatility (c.f. Guldimann, 1994):

$$\sigma_{\tau}^{2} = \lambda\, \sigma^{2}_{\tau-1} + \lambda\,(1-\lambda)\,(X_t - \bar{x}_{t-1})^2 \quad (3.25)$$

where

σ^2 = volatility

λ = decay factor or discount coefficient

$\bar{x}_{t-1}$ = exponentially weighted average of observations

X = east observation

The advantages of the exponential scheme are that it can rapidly respond to market shocks (i.e. variance changes, introducing non-stationarity into the return process) and then declines gradually. It is optimal when the process to which it is applied is Arima (0,1,1).

Using historical data to make forecasts artificially assumes that volatility is stable in statistical terms, i.e. its changes are unpredictable, or uncorrelated with previous levels of volatility. However, empirical time series realisations of returns often show time dependent volatility, i.e. volatility changes are dependent on previous levels of volatility. ARCH (Autoregressive conditionally heteroscedastic) models and GARCH (Generalised ARCH) models try to formalise this finding. ARCH (1) defines a stochastic process (e.g. a return generating process) for which the volatility varies over time in a way that depends on past values of a stochastic error process. It is given as

$$h_t = a_0 + a_1\, \varepsilon^2_{t-1} \quad (3.26)$$

with

$$\varepsilon_t \mid X_{t-1}\, X_{t-2} \ldots\ldots \sim \mathrm{NID}\,(0,h_t) \quad (3.27)$$

where

h_t is the conditional variance function and ε_t are error returns.

GARCH (1,1) defines a process for which, in addition, the volatility depends on its own past values:

$$h_t = a_0 + a_1\, \varepsilon^2_{t-1} + \beta_1\, h_{t-1} \quad (3.28)$$

Advantages of ARCH/GARCH are that the implicit weighting of observations and the effective length of the moving window are chosen by the data (cf. Mills, 1993).

Most recently, so-called stochastic volatility (SV) models have been developed. SV models treat volatility as an unobservable variable and model its logarithm as a linear stochastic process, such as autoregression.

So far, we have discussed various approaches to compute the volatility of an asset price from past data (historical volatility). An alternative approach, implied volatility, measures the volatility implied by an option price observed in the market. The fundamental difference between the two is that the former is determined by the past while the latter reflects market participants' expectations regarding the future.

The implied volatility is the value of σ which, when substituted into an option pricing model for an option of which all other parameters are known gives the observed option price. For the B-S model, σ can be found through an iterative search procedure, such as the Newton-Raphson method. For cases where several options on the same stock exist, various weighting schemes have been suggested. An argument in favour of implied volatility is that it represents the market's prediction of future volatility. An argument against implied volatility is that it is priced by traders, who consider different windows of historical data and then decide which one is most appropriate for the horizon of the option theory they are pricing. In this way, implied volatility is heavily influenced by subjective situational circumstances. What is more, option prices are often influenced by factors such as demand and supply, transaction costs, and liquidity considerations. To conclude, implied volatility is commonly denied to have better predictive power than historical volatility (cf. e.g. Guldimann, 1994).

When ARCH, GARCH, and stochastic and implied volatility models are put into the perspective of the present study, their high level of statistical sophistication (e.g. relaxation of unrealistic assumptions) is notable. This is in contrast to the application of the B-S model to real (growth) options, which has been described as a *"short-cut practical procedure"* (Trigeorgis, 1996, p. 346). Moreover, the "twin security" argument which creates the link between the real options application of the B-S model and the above volatility estimation techniques can only be considered to be roughly correct.

However, as implied by Nichols (1994), among all the option pricing models with various degrees of sophistication, at least initially, the basic B-S model is the one most likely to be considered by corporate capital budgeting practitioners for the valuation of real options. Conversely volatility estimates of "twin securities" are likely to be requested by corporate practitioners from their investment bankers (who might in turn use the aforementioned relatively sophisticated volatility-estimation approaches to derive these).

3.6 Summary

In this chapter, we have discussed the critical theoretical questions and choices arising in the application of an option pricing model to growth option-type investments. We have noted that real options theory has in some situations advantages over traditional decision tree analysis. We discussed that a key feature of any option pricing model, the assumption of risk-neutral valuation, is not in conflict with the risk aversion which had been empirically observed in many empirical studies of investors. We argued that the assumption of a lognormal distribution of the price of the underlying asset, on which many option pricing models are based and is compatible with applications to real assets. For simplicity, we did not include the "option to wait" in the analysis of our investment case studies involving growth options. We concluded that for the type of growth options for which the pilot project effectively has a fixed maturity, with no possibility of early or late investment in the follow up project, the use of a non dividend-paying option price model is an adequate model. It is also the most likely candidate to be initially applied by corporate practitioners to the valuation of real (growth) options. Therefore we chose the European, non dividend-paying Black-Scholes model as the source of theoretical valuations to be compared with the empirical valuations of the case studies given by the respondents in the present study.

4. THE RESEARCH METHODOLOGY

4.1 Introduction

The previous chapter considered the necessary theoretical issues in the design and valuation of our real growth option investment case studies. The present methodology chapter, will lay out and discuss critical points in the research methodology used in the present study. In the following section 4.2, we introduce the three main research questions of the present study, namely do a sample of decision makers value, hypothetical investment projects in accordance with normative theory ("Correspondence"), how far is the normative (European, non-dividend-paying) real option model relevant to the "real world" investment situations it tries to model ("Relevance"), and can we discern any differences in valuation behaviour and attitudes towards real options for subgroups of respondents ("Acceptability"),

In section 4.3, we introduce the two strands of research methodology which we use, namely laboratory experiment and opinion survey. For each strand of methodology, we explain its concrete application in the present research context and discuss its validity and reliability. In section 4.4, the research instrument, i.e. the document that was presented to the respondents, containing the hypothetical case studies of the laboratory experiment and the questionnaire of the opinion survey, is described in detail, and the questions which arose in the design of the research instrument are discussed. In section 4.5, firstly, the population of interest to the present study is defined. After that, we describe the stages in the sampling process and data collection procedure, namely the pilot study, the gaining of access phase, and the main study phase. In section 4.6 the sample actually obtained is described and some limitations inherent in the present research methodology are summarised. Finally, in section 4.7 our broad research questions are refined into detailed research issues, hypotheses on which will be tested in chapters 5 and 6.

4.2 Research questions

The present research applies a behavioural methodology to study managerial decisions on real growth options (involving "general", i.e. non-commodity investments). We compare the two theoretical frameworks of DCF analysis and real option theory (plus potential additional factors). The real option framework suggests the use of financial option pricing theory to evaluate investment projects in certain non-financial, i.e. real, assets. The research raises three broad, interrelated questions.

Firstly, it will be investigated whether, and to what degree, decision makers decide on hypothetical investment projects in accordance with the NPV rule as opposed to the real options framework (and/or any additional factors) ("Correspondence"). This is to examine claims in the non-commodity strand of the real options literature that there is a correspondence between the real options theoretical framework and managers' intuition. (e.g. Dixit and Pindyck, 1994, Kemna, 1991, Barwise et al, 1987, Kester, 1984, Myers, 1984). By comparing a (normative) model with subjects' (intuitive) decision making behaviour, this research question also contributes to both the "Bayesian" and "lens model" strands of HIP research.

Secondly, it is of interest how far the normative (European non-dividend-paying) real option model is relevant to the "real world" investment situations it tries to model ("Relevance"). This research strand aims to gather empirical evidence on claims concerning how relevant and important the real options framework is perceived to be by managers for general (i.e. non-commodity) capital budgeting (e.g. Hodder and Riggs, 1982, Bierman and Schmidt, 1990, Copeland et al., 1990, Aggarwal, 1991, Brealey and Myers, 1991, and Trigeorgis, 1996).

Thirdly, we examine whether, and in what way, there are differences in valuation behaviour and in the attitudes relevant to real options between different subgroups of the respondents in the sample ("Acceptability"). By doing so, we hope to shed some light on various issues in the implementation of the real options framework. Precedents to this part of the present research are mainly in the systems implementation literature (as discussed in section 2.4), e.g. Zmud, 1979, Hirschheim and Newman, 1988, Aydin and Rice, 1991). We are aiming to learn from the case study valuations how likely cognitive dissonance (Simon, 1960) is to arise if the managers are formally confronted with the real options framework (e.g. if it is introduced in their company). Cognitive dissonance in turn increases the likelihood of low initial acceptance of the real options framework. It might also imply an increased risk of ongoing reluctance to use the real options framework. From these considerations, it may be possible to identify training needs.

4.3 Description and justification of the research method

The research methodology we will use in the present study has two main strands which are determined by the first and the third of our research questions.

In general terms, the first research question, namely whether decision makers decide in accordance with real options theory, is asking whether a certain human population behaves (in simulation) in conformity with a normative model. This kind of research question calls for a deductive research approach, in which a conceptual and theoretical structure is developed prior to its being tested through empirical observation (cf. Gill and Johnson, 1991). The deductive method which we will use is an experimental research design.

This deductive strand of the research is methodologically related to the research tradition on probabilistic judgement, or the Bayesian research area of the human information processing literature, which was discussed in the literature review. Precedents are Swalm (1966) on cardinal utility, Snowball and Brown (1979) on a normative model of bank trust officers' use of disaggregated probabilities, and Brown (1980) on a Bayesian model of investigation strategies. All these studies set human decision makers hypothetical business tasks the answers to which are capable of distinguishing between the participants' attitudes. The results show various degrees of consistency between the participants' decisions and the respective normative model.

The third research question is how far a specific model, drawn from option pricing theory, matches the perceived structure and conventions of real world investment decision making in companies. This research question asks how far a given normative model is relevant to the "real world" situations that our respondents face. In order to evaluate this, it is necessary to gain a picture of the respondents' perceptions of the "real world", which can be compared with the internal structure and assumptions of the theoretical model. This kind of research question requires an inductive research approach, in that it looks for explanations of what has been observed. The inductive research technique used here will be a descriptive survey.

The inductive strand of the present research design has precedents in the lens model research tradition, e.g. Barona (1985) produced a descriptive model of the lending behaviour of British bank managers. Other precedents exist in empirical studies on capital budgeting, such as Pike (1983) or Marsh, Barwise and Wensley (1988), both of whom used questionnaire surveys to measure capital budgeting practices.

The second research question, whether there are any consistent differences in valuation behaviour in our sample, uses information from both the experiment and the survey.

The strategy of combining deductive laboratory research with inductive field research which we follow has been strongly urged by Griffin and by Wayne and Ferris in Griffin and Kacmar (1991).

4.3.1 Laboratory study/experiment

A laboratory experiment is a research method in which the variance of all or almost all of the known extraneous variables, i.e. the possibly influential independent variables not pertinent to the immediate goal of the investigation, is kept to a minimum (Kerlinger, 1986, quoted in Griffin and Kacmar, 1991). An experimental research design lies towards the deductive end of the continuum between deductive and inductive research methods.

According to Ilgen (1986), the use of laboratory experiments is most justified when: (1) high fidelity between the laboratory and the field can be established, (2) laboratory conditions are to be recreated in the field, (3) field conditions limit the feasibility of field research and (4) the hypothesis of interest is simply the demonstration that an effect exists rather than the prediction of a particular effect in a particular setting. The first three conditions seemed to hold in the present research situation. In order to deal with, and possibly overcome, the fourth condition, the questionnaire survey was undertaken.

4.3.1.1 The experimental design

The chosen experimental research design involves varying the parameter settings (the independent, or causal, or explanatory variables) of a Black-Scholes option pricing model, then embedding these parameters in imaginary textual case studies, designed to realistically reproduce "real world" investment situations, and then having managers decide on them. By comparing managers' hypothetical valuation decisions (the dependent variable(s)) with the values predicted by real options theory, the researcher can conclude how well normative real options theory is followed by human decision behaviour, i.e. how rationally, in terms of real options theory, do decision makers decide on (laboratory) investments.

The laboratory research method of the present study has features of both a true experiment and of a quasi-experiment. The main difference between the two types of experiments is that in the true experiment, the so-called experimental treatment, i.e. the change in the independent variable(s), is administered to the participants, while in the quasi-experiment, the researcher tries to identify ex post the groups of participants who have and have not experienced the experimental treatment by some selection process outside the experimenter's control (Gill and Johnson, 1991) The dependent variable in this experiment is the value reported by a participant for a hypothetical investment opportunity.

Interpreting the present laboratory research method in terms of a real experiment, the independent variables are the parameters of the real growth options model (the option pricing model), namely the follow-up project's initial investment cost (exercise price), the currently expected present value (PV) of the follow-up project's cash flows (asset price), the risk-free interest rate, the time until the follow-on project can be undertaken (maturity), and the volatility of the evolution over time of the expected PV of the follow-up project's cash flows. All of these will be discussed in detail below. In the present experimental treatment, the expected PV of the follow-up project's cash flows, the volatility of the PV, and the time until the follow-on project can be undertaken are varied over the set of case studies set to each participant.

Extraneous variables are phenomena that might cause some of the variation observed in the dependent variable and can therefore represent alternative explanations of the observed variability in the dependent variable (Gill and Johnson, 1991). In the present design the extraneous variables include variations in the personal characteristics of the respondents. By examining answers by the entire sample of all respondents, the variation of those personal characteristics inside the sample can be excluded. However, respondents were not selected randomly but companywise and the sample size is not large enough to guarantee that the "population" mean personal characteristics occur in the sample. Consequently, the extraneous variable "personal characteristics" can only be partly "controlled" by looking at the sample in its entirety. Potential sample bias cannot be controlled.

Alternatively, interpreting the present laboratory research design in terms of a quasi-experiment, the varying personal characteristics of the participants can be regarded as independent variables. In this respect, the quasi-experimental treatment, i.e. the change in the independent variables, is the observed variation of these personal characteristics between subjects. "Control groups", i.e. groups who do not receive the experimental treatment and experimental groups, i.e. groups who have experienced the treatment which is to be considered experimental, are identified in the field from observations of the different levels of the various personal characteristics possessed by the various respondents.

Since we are able to interpret the parameters of the option pricing model as independent variables (in the spirit of a true experiment) and since we can treat participants' personal characteristics as independent variables (in the spirit of a quasi-experiment) we have what might be termed a "two-dimensional" experimental structure.

The chosen experimental design has various advantages. Firstly, being at the deductive end of the continuum of research methods, the experiment could be designed to use directly the real options literature. Secondly, the manipulation of one independent variable at a time enables the researcher to gain a comprehensive picture of how sensitive managers are to specific changes in the option situation. Finally, disturbing influences on investment decisions such as "company politics", that are often important in reality, can be controlled in the experimental setting.

The experimental research instrument consists of 14 case studies describing investment opportunities. Over the first seven case studies, only the real option model parameter asset price ("expected PV of the follow-up project's cash flows") is varied. Over the next five case studies, only the volatility of the random walk evolution of this PV is varied. Finally, over the last two case studies, the maturity, or the time until the follow-up project can be taken, is varied. In addition to the above quantitative variation, the 14 case studies differ qualitatively in their textual narratives, i.e. they describe different scenarios of investment opportunities.

4.3.1.2 Validity and reliability of the experimental research instrument

Questions of validity and reliability arise for any measuring instrument.

We can distinguish between internal and external validity. Internal validity refers to the accuracy of the measurement process. The internal validity of a measuring instrument indicates the extent to which differences in scores on the measuring instrument reflect true differences among individuals on the characteristic that is sought to be measured, rather than constant values or randomly varying values (Sellitz et al, 1976). It is clear, that the concept of internal validity has two aspects: internal validity requires (1) that the measuring instrument is actually measuring the concept in question and not some other concept, and (2) that the measured concept is being measured with a low level of random noise or error.

In experiments, in order to achieve internal validity, it is necessary to exclude the influence of extraneous variables. If the influence of extraneous variables is not excluded they might confound the interpretation of observed relationships between the dependent and independent variables (Gill and Johnson, 1991). In our case, the different textual narratives underlying the various case studies might constitute such an extraneous variable. It was sought to deal with this danger by using the same logical structure in all case studies, and making the textual narrative of the case studies only different to the degree that each separate case study would be perceived as a separate problem in its own right rather than a purely numerical restatement of the previous case study with a different parameter value.

Furthermore, in an experimental research design, the question arises whether or not various individual subjects (and the researcher) attach the same meanings to the stimuli. This could pose a significant threat to the internal validity of the research findings. In the present study, an effort was made to minimise this problem of differences in interpretation by conducting a pilot study with five fellow doctoral students at the Manchester Business School, and by discussing the potential meanings of the terms, and rewording to minimise ambiguity. In the early stages of the main study, some further, minor improvements were made to the research instrument.

Finally, experimenter effects, i.e. the social interaction that occurs between the experimenter and individual subjects, can endanger internal validity. Generally, the personal qualities that a subject attributes to the experimenter might influence the way in which subjects conduct themselves in the experimental setting (Gill and Johnson, 1991). Sometimes, the experimenter can influence responses by unintentionally giving cues about how subjects should behave. For example, by using sophisticated finance jargon, an experimenter might stipulate a subject to represent corporate practice as being more sophisticated than it is in reality. In the present research the researcher tried to develop a feel for the different degrees of financial and managerial sophistication of the various interviewees in order to act as an equal partner in the interview discussions.

External validity of the measurement instrument of a research approach refers to the generalisability of the measurements. The external validity of a measuring instrument relates to how far other populations, occasions, or stimuli might generate usefully related results.

In social research. problems of external validity of experiments stem from the fact that, in a true experiment, behaviour is not observed in its natural setting. The situation in which a true experiment takes place is generally markedly different from, and outside of, the normal, everyday situation in which subjects perform the acts that are the focus of the research (Gill and Johnson, 1991). The decisive question is how far any behaviour elicited during the course of a laboratory experiment can be understood in isolation from the laboratory context which has been contrived to produce it, and hence whether or not the behaviour observed in an experimental situation will be repeated in a subject's natural or everyday setting. The concept of indexicality predicts that people vary their behaviour according to the situation in which they find themselves. This problem seems to be less serious for the present study on investment decision making than for some other study areas. This is because in practice, just as in the experimental setting, there are, at least for more senior managers, many investment proposals on medium-sized projects to decide about, so that the investment decisions have often to be taken with only a small, standardised information set. Of course such managers may also be using social and other cues (such as the track record of the proposer) which are not formally researched in the standardised data set.

The reliability of a measuring instrument refers to its consistency, i.e. the extent to which the instrument will produce the same results when applied more than once to the same person under similar conditions (Gill and Johnson, 1991). In general, the ways of testing reliability include replication, either by asking the same people the same questions at different times, or by asking similar questions at different times during an interview. The latter strategy was applied in the questionnaire as will be discussed below, but in the case studies, replication was not practicable because of time constraints. Adequate reliability was hoped to be ensured by the widely accepted fact that if a measure is valid, it will also be reliable (but not the other way around, see e.g. Gill and Johnson, 1991).

4.3.2 Opinion survey (Appendix 4)

4.3.2.1 Opinion survey design

Surveys can be classified as either analytical surveys or descriptive surveys (Gill and Johnson, 1991). Analytical surveys usually have a theoretical question as their starting point, but descriptive surveys primarily try to identify the characteristics of a specific population. On the continuum of research methods between deductive methods and inductive methods, the analytical survey has an intermediate position and the descriptive survey is closer to the inductive end.

The opinion survey conducted in the present research can be classified as an analytical survey insofar as its purpose is to learn more about peoples' conscious opinions about the realism (for them) of the different aspects of the real options model used in the case studies. It is typical of an analytical questionnaire that it does not contain many open-ended questions. In fact, many of the answers to the questionnaire used in the present research are coded on a five point Likert scale. It is partly the purpose of the questionnaire to evaluate the perceived realism of some of the underlying assumption of real options theory by measuring the companies' perceived values for the Black-Scholes parameters (such as volatility and maturity) and comparing them with the values as suggested in the case studies.

On the other hand, insofar as it tries to measure "real world" parameters and investment decision making procedures, the questionnaire tries to gain a descriptive picture of the project parameters and the decision structures that decision makers are used to in their real world projects. In this respect, the present questionnaire has an inductive quality to it and is used to capture the investment decision making background against which real options theory may or may not be seen as relevant.

4.3.2.2 Validity and reliability of the survey research instrument

For the validity and reliability of the questionnaire, the same basic considerations apply as for the case studies. The measures collected in the questionnaire are believed to be more internally and externally valid than those collected in the case studies, as the questionnaire simply requests actual perceptions of company data, rather than asking managers to evaluate a (potentially unrealistic) problem. Misunderstandings might also be fewer, as the questionnaire asks only for single pieces of information, whereas the case studies introduce a complex decision situation.

In contrast to the case study responses, in the questionnaire responses it was possible to incorporate some checks for reliability by asking similar questions at different points in the questionnaire. This was possible because, unlike for the case studies, where due to time constraints each respondent was only asked to answer a subset of the case studies, all the respondents answered all the questions in the questionnaire, because these could be answered very quickly.

4.4 Research instrument

The research instrument used in the field work consists of a set of 14 case studies and a questionnaire. Additionally, an introduction to the research project and a prime example for the case studies was given (see Appendix 4.1).

4.4.1 The case studies' textual narratives

The dependent variable in the case study experiment was the value reported by the participant for each case study investment. This can be interpreted as an option value. The independent variables of the experiment included the various variables and parameters that, in the relevant standard option pricing model, determine the value of the option to undertake the follow-up project, namely the follow-up project's initial investment cost, the expected PV of the follow-up project's cash flows, the volatility of the expected PV of the follow-up project's cash flows, the time period until the follow-up project can be undertaken, and the risk-free interest rate.

The present research focuses on varying only three of these parameters, namely the expected PV of the follow-up project's cash flows, the volatility of these cash flows, and the time period until the follow-up project can be undertaken. As explained in the theory chapter, we neglected to vary the follow-up project's initial investment cost and the risk-free interest rate for two reasons. Firstly, in order to vary "moneyness" of an option, it is sufficient to vary either the expected PV of the follow-up project's cash flows, or the follow-up project's initial investment cost. Our choice was the expected PV of the follow-up project's cash flows. Secondly, the risk-free interest rate is outside a company's control (and relatively stable, at least in real terms).

In order to examine how the perceived value of the option was affected by changes in these three independent variables, three sequences of case studies were designed. Over the first sequence of seven case studies (labelled A1 to A7), the expected PV of the follow-up project's cash flows was varied. Over the next sequence of 5 case studies (labelled B1 to B5), the volatility of the expected PV of the follow-up project's cash flows was varied, and over the last sequence of two case studies (labelled C1 to C2), the time period until the follow-up project could be undertaken was varied.

Over all 14 investment case studies, we hold constant two option parameters namely the follow-up project's initial investment cost and the risk-free interest rate. For the random evolution of the expected PV of the follow-up project's cash flows over time, we assumed as in most option pricing models a geometric Brownian motion, leading to a lognormal distribution of the expected PV of the follow-up project's cash flows.

One objective when designing the variations around this basic case study was to create case studies offering enough variety for the participants to take a fresh approach to each new case study. In addition, it was intended that the case studies should describe business situations that were interesting to read and that the managers could realistically relate to.

Various descriptions of real growth option situations in the real options literature (e.g. Brealey and Myers, 1991, Kester, 1984, Kemna, 1991) all use this same structure of a pioneer project being a prerequisite for a potential follow-on project.

However, the narrative of the investment situation can vary qualitatively in two ways: the kind of investment situation and the business setting.

Five kinds of investment situations for growth options were used in the case studies:

- an initial product with a follow-up product
- a R&D project leading to a marketable product
- a market development leading to a follow-up market development
- a two-stage acquisition
- a two-stage joint venture.

To make the valuation task as realistic as possible for practising manager subjects it was decided to elicit valuations in the form of a decision on a business transaction. The kinds of transactions which seemed suitable were:

- selling a project
- buying a project
- forgoing a project
- paying someone for taking a project off oneself
- obtaining a government subsidy.

In table 4.1, the 14 case studies are classified by columns in terms of the kind of investment situation, and by rows in terms of the kind of business transaction each describes.

Table 4.1

Kinds of investments and underlying transactions of the case studies

	Kind of investment				
Underlying transaction	Product + follow-up product	R&D project + marketable product	Market developm. + follow-up mkt development	Two-stage acquisition	Two-stage join venture
Selling project	A7	A5, C2			B3
Buying project	A6			B4	
Foregoing another project	B5	B2	A3, B1, C1	A4	
Someone taking project off you					A2
Obtaining government subsidy		A1			

In table 4.2, the business settings that each case study describes are summarised.

Table 4.2

Business settings of investment opportunities

Case study	Type of pioneer investment	Type of resulting follow-up opportunity
A1	Improve a chemical process in a rubber plant.	Produce a new rubber type.
A2	Supply rail network in joint venture to set up a tramway.	Buy out the JV partner.
A3	Market test a line of body care products in Poland.	Follow up the Russian market.
A4	Acquire a stake in a Swiss toothbrush producing company.	Acquire the majority of the Swiss company.
A5	Run an R&D lab researching on pet food.	Produce a new pet food.
A6	Produce first-generation microchip.	Produce second-generation microchip.
A7	Produce tarpaulin as a raw material.	Produce ready-to-use pieces of the material.
B1	Test-market muffins in Belgium.	Tackle French market.
B2	Build prototype windmill.	Build full-production wind farm.
B3	Supply hardware in a mobile telephone joint venture.	Buy out the software supplier.
B4	Testing a veterinary remedy for human use.	Produce human remedy.
B5	Buy rural land.	Construct residential area.
C1	Introduce new disposable nappy in Portugal.	Tackle Spanish Market.
C2	Develop new adhesive and sell it as general purpose glue.	Use adhesive in assembly of dentures.

When designing case studies to express varying levels of volatility (case studies B1 to B5), an attempt was made to devise narratives in which the industry setting plausibly reflected the level of uncertainty implied by the volatility numbers used. The selection of industries according to their relative riskiness was performed intuitively. Additionally, as a more formal, though crude measure to assess the uncertainty inherent in an industry "variability" (i.e. the average standard deviation of shares in the industry traded on the London Stock Exchange as provided by the risk measurement service of London Business School) was considered. The table below shows that the industries intuitively chosen as narrative settings for a sequence of scenarios of increasing risk do actually have consistently increasing variability based on LBS Risk Measurement Service industry tables October - December 1994 (except for B4). The specific scenario of special project descriptions is probably intuitively plausible to the respondents, as it was to the researcher.

Table 4.3

Comparison of case study volatility and industry variability

Case study	B1	B2	A3	B3	B4	B5
Industry	Food retailing	Electricity utilities	Health & personal Care	Telecommu-nications	Pharma-ceuticals	Building & Construct.
Volatility	0.17	0.32	0.45	0.58	0.7	0.81
"Variability"	23	27	29	32	26	43

4.4.2 Questionnaire

The questionnaire on general (i.e. non-commodity) capital budgeting is organised in four main sections:

(1) questions on the occurrence of growth options in the respondents' company

(2) questions on the realism of the assumptions underlying real options theory

(3) questions on the determinants of the real option value (i.e. the variables used in the real options model)

(4) questions on the process of investment decision making in the respondents' company

Additionally, nine personal professional characteristics of the respondent were gathered.

The main part of the questionnaire consists of 21 questions collecting 30 items of information (which we called questionnaire variables or questionnaire items). The questionnaire variables relate to the respondents' attitude towards the information given in the case studies and to his or her industry environment. Additionally, the questionnaire gathers nine items of information on an individual's professional characteristics or role (which we called grouping variables).

In order for the answers to the questionnaire to be statistically analysable, most of the questions requested responses on 5-point Likert scales. Some questions ask for quantified absolute values or percentages, and some open ended questions were also set.

For easier handling, in the following, each questionnaire variable is assigned an abbreviation., Table 4.4 contains a summary of the questionnaire variables, their abbreviations, how they are measured, and the range of answers obtained. The full questionnaire is given in Appendix 4.1.

Table 4.4

Summary of the "questionnaire-variables"

Abbrev.	Description	Q. no	Measurement	Range
(1) Occurrence of growth options in the respondent's industry				
Perc fu	Percentage of projects that have follow-up projects	3	prop.	0,1
Fu r&d	Frequency of projects with follow-up projects in R&D	4	L5	1-5
Fu mark	F. of projects with follow-ups in marketing	4	"	"
Fu IT	F. of projects with follow-ups in IT	4	"	"
Fu proc	F. of projects with follow-ups in process improvements	4	"	"
Fu contr	F. of projects with follow-ups as built-in in contracts	4	"	"
Fu other	Frequency of other projects with follow-ups	4	"	"
Treat fu	Quantitative treatment of follow-ups?	5	"	"
Fu quan	Quantitative treatment desirable?	6	"	"
(2) Perceived realism of the assumptions underlying real options theory in general and the Black-Scholes model in particular				
Sure pp	Profit prospects sure?	7	"	"
Avg life	Average life of a product	7	years	3-125
Difficult	PV difficult to estimate?	8	L5	1-5
Fore mc	Time horizon forecasting market conditions	9a	L6	0-5
Fore co	Time horizon of forecasting competition	9b	"	"
Fore pc	Time horizon of forec production costs	9c	"	"
Red unc	Test marketing reduces uncertainty faster?	10	L5	1-5
Test tim	Avg. duration of test marketing	10	years	.17-2.5
(3) Perceived realism of the option parameter settings assumed in the case studies				
Sd 30	Standard deviation smaller than 30%?	11	L5	1-5
Sd	Actual standard deviation	11	sd.	.1 - .7
X uncert	Initial cost of follow-up uncertain?	12	L5.	1-5
Pl hor8	Planning horizon smaller than 8 years?	13	"	"
Pl hor	Actual planning horizon	13	years	4-25
Dev t3	Development time of 3 years unrealistic?	14a	L5	1-5
Dev t	Actual development time	14a	years	.75 - 8.5
Fu5	Life-cycle of follow-up of 5 years unrealistic?	14b	L5	1-5
Fu	Actual life-cycle of follow-up	14b	years	3-30
(4) General investment decision making practices in the respondents' company				
Single p	Pioneer + follow-up treated as single project?	15	L5	1-5
Don't or	Don't organise dec. making this way.	16	"	"
Add dat	Need additional data.	17	"	"
Stra pol	Take strategy and politics into account.	18	"	"

Note: L5 = 5-point Likert scale, L6: 6-point Likert scale, Q. no: number of questionnaire question (Appendix 4.1)

4.5 Procedure of data collection

4.5.1 Description of population of the study

It is the intention of the present study to examine decision making relevant to a class of business investments (in non-financial assets with a strategic focus) which are analysable by real options theory. This restricts the present study to the private sector, and excludes households from the analysis.

The first consideration was whether to restrict the study further to exclude the financial/banking sector. The investments of banks, e.g. loans, have a somewhat different structure from the investments that arise in industry. An example of a growth option situation for a bank might be a student account. Banks, by offering students free accounts, take an investment with a negative NPV against the hope of generating some profitable business after graduation of the student. (Note that this would imply that banks can drop the student if unprofitable later.) However, to our knowledge, such considerations have not yet found attention in growth options theory. Moreover, formal capital budgeting procedures in banks are much less developed than in industry. This is partly because it is relatively cheap for banks to enter, and if necessary, leave again, new businesses (as the main asset is people and appropriated tangible assets are often negligible). For simplicity, the study was therefore restricted to the non-financial sector. However, it was suspected that attitudes might differ between different industries within the non-financial sector. We will speculate about these differences as part of the second research question.

The next question was whether to investigate not-for-profit organisations. Although investment situations might arise similar to those in industry, not-for-profit organisations by definition take many considerations other than profit into account. Growth options theory, however, strives to quantify a given investment situation in profit terms. Therefore, no not-for-profit organisations were approached.

Additionally, it was sought to focus on very large companies. Due to the large portfolio of businesses investment projects in these companies, managers might be expected to be more used to considering investment proposals per se and not primarily in a given political/business situation-specific context. Since large companies are known to employ more sophisticated capital budgeting techniques than small and medium-sized enterprises they were also expected to be more likely to be interested in, and to offer assistance in investigating, a new capital budgeting tool. One of these companies had in fact been the location of several pieces of real options research reported in the literature (Kemna, 1991).

Next, the organisational level of the investigation was defined. Although members of a company's general workforce might in some cases be involved in investment decision making, the decision power over investments and particularly strategic investments lies mainly in the hands of management. This limits the population of the study to the managerial ranks of an organisation.

Among the many categories of managers in industry, it was hypothesised that almost all would be formally or informally be involved in investment decision making. Nonetheless, as we will discuss in detail below, it might be expected that attitudes might systematically differ between managers in different functions, (consider e.g. the widely cited prudence and conservatism of accountants), and between managers of different roles. We will speculate about these differences below as part of the second research question.

The population relevant to the study is therefore managers in the non-banking segment of the for-profit sector of the UK industry. In order to achieve an interesting spread of participants, it was sought, in each company, to involve on the one hand financial managers, who would be directly involved in the formal analysis of investment decisions, and on the other hand non-financial managers, who might typically be less involved in formal aspects of investment decision making.

4.5.2 The design and pilot study of the instrument

The set of 14 case study narratives was initially piloted on 5 doctoral students at Manchester Business School in September and October 1994. Participants were encouraged not only to indicate their solutions to the case studies but also to comment on perceived weaknesses or ambiguities in the case narratives and their explanations, and to make suggestions for improvements. This method led to numerous improvements in the case studies. Perhaps in consequence at the beginning of the main study only minor additional changes to the case study narratives were required.

4.5.3 Gaining access

Two avenues were pursued in gaining access to the target companies. One approach was a "shotgun" approach by a letter to board members of all the largest British Plcs in various industries. The other approach was via alumni (in all cases MBAs) of Manchester Business School. Both groups were asked to act as gatekeepers and to facilitate the researcher to conduct interviews with a number of managers in their companies (see letter in Appendix 4.1).

In the first approach, senior managers in 55 large UK Plcs were approached in two stages. A mailing in January 1995 was addressed to the managing directors of 38 large British Plcs in various, mainly consumer-related, industries. A mailing at the beginning of February 1995 contacted 17 large British Plcs in some other, mainly manufacturing-related industries, approaching both the finance director and a "commercial" i.e. marketing or strategy director. These letters were, where necessary, followed up several weeks later with a reminder. As a result, 5 out of the 55 companies approached by the "shotgun" approach participated in the project (9% response).

In the second approach, 12 Manchester Business School alumni employed in major British PLCs were contacted and in consequence 4 companies participated in the research (33% response).

The gatekeepers either sent a list of suitable potential participants in their company for the researcher to contact, or themselves arranged a sequence of meetings with participating managers, or offered to pass research instruments on to suitable participants.

The process of gaining access is summarised in table 4.5.

Table 4.5

Summary of the process of gaining access

	Companies		
Contacted gatekeeper	Approached	Participated	Percentage
Managing, or Finance and Commercial Directors	55	5	9%
MBS Alumni	12	4	33%
Overall	67	9	13%

4.5.4 The main study

The main study was conducted in the 9 participating companies in the 5 months between February and June 1995. (The bases for the main sample were arrangements by the gatekeepers for a sequence of meetings with participating managers, on the day of a researcher's visit to the company, and/or offers by gatekeepers to pass on a number of research instruments to suitable participants, and/or lists produced by the gatekeepers of suitable potential participants in the company for the researcher to contact.)

For the first 21 interviews, it was sought to visit the participants personally. This was partly a second stage pilot study, in order to identify any potential shortcomings in the case studies and to help the participants in cases of misunderstanding. It also ensured that the open ended questions at the end of the questionnaire were dealt with in detail. Also, in many instances, it was found that participants were willing to spend considerably more time face to face on answering the research instrument than the "half to three quarters of an hour" that was officially asked for. In this way, valuable background information on the nature of the investments and investment decisions in the industries concerned could be obtained.

In order to allow participants to prepare for the meetings, research instruments were sent to either the gatekeeper or directly to his nominees in good time before the day of the visit. In some cases, the subject managers suggested further colleagues who might be prepared to participate, and some offered to look for further participants. In these cases, on the day of the visit, additional copies of the research instrument were left with the participating managers or additional copies were posted to the participating managers or their nominees afterwards.

The managers to whom the research instrument was posted were offered assistance by telephone in the covering letter. This resulted in a further 8 "semi-personal" interviews involving telephone discussions of the research instrument.

Finally, in the non-personal part of the field work, research instruments were either sent to gatekeepers who had offered to pass them on to suitable participants, or lists, produced by the gatekeepers, of suitable potential participants in the company were used for posting the research instrument.

In cases not involving a personal visit, numerous telephone follow-ups were made to the gatekeepers to remind them to forward the questionnaires to their nominees, or to collect them, and the participants were directly and personally encouraged to answer the research instruments.

4.6 Description of the sample, introduction of the grouping variables and of the concepts of "Importance" and "Direction" of a variable's influence

Description of the Sample

90 answers to the research instrument were obtained. Of these, 4 were judged invalid, because the personal information requested was missing, and another 4 came from bank managers, which group, as discussed before, was excluded from the target population. Therefore, the sample obtained by the present study contains 82 valid responses from 9 non-financial companies in 5 different industries.

21 out of 82 responses, or 26%, were gained in personal meetings. (Where a meeting was planned, the managers were sent the research instruments beforehand and were asked to

have a look at the instrument.) 8 out of 82 responses (or 10%) were conducted in a semi-personal way providing support via telephone. 53 out of 82, or 65%, of responses were achieved without substantial personal interaction with the researcher.

In addition to the research instruments used in the 21 personal visits, 120 research instruments were postally distributed or left in the participating companies on the day of a personal visit. This implies an overall response rate of about 58%. The cells in table 4.6 contain the number of participants by company and by industry.

Table 4.6

Number of participants by company and by industry

	Industries				
	Oil	Aerospace	Telecom	Pharmaceuticals	Brewing
Company 1	5	29	8	10	15
Company 2	2		1[1)]	5	
Company 3				7	
Sum = 82	7	29	9	22	15

[1)] Respondent answered full set of 14 case studies and gave valuable information of investment decision making in the industry.

Introduction to the grouping variables

As our third research question, we will examine whether there are differences in valuation behaviour and attitudes towards real options between subgroups of the respondents in our sample. The question arose as to which individual differences between the respondents should be used in order to group respondents into meaningful subgroups.

In what follows we discuss the classes of individual differences commonly used in the literatures in systems implementation and on information processing and problem solving behaviour (as surveyed in Zmud, 1979). We discuss the three potential classes of individual differences (cognitive style, personality and demographic/situational variables) we considered and explain the reasons why, in the present study, we focused on the class of demographic/situational variables.

Cognitive styles are distinctive modes of functioning shown by individuals in their perceptual and thinking activity. The cognitive style construct is acknowledged to be multidimensional. The three dimensions most commonly used are the simple/complex discussion (e.g. the number and completeness of rules used in cognition), the field-dependent/field-independent dimension (low analytic/high analytic, i.e. the use of internal/external referents), and the systematic-unsystematic dimension (i.e. "thinking types", use of abstract models and systematic processes, versus "feeling types", use of common sense and experience). Due to time-constraints on the part of our respondents, in the present research design, it was not practicable to actually measure the multi-dimensional construct of cognitive style. However, awareness of the concept of cognitive style helped us to speculate on the likely behaviour of different subgroups.

Personality represents an individual's cognitive and affective structures in adjusting to events, people, and situations. Important personality variables are locus of control, dogmatism, ambiguity tolerance, extroversion/introversion, need for achievement, risk taking propensity, evaluative defensiveness, and anxiety level (Zmud, 1979). Most of these personality variables are multidimensional and measurement might require experiments in their own right. Again, from the information that it was possible for us to gather in the given interview time with each respondent, we can only speculate on most of the personality variables.

The demographic/situational variables refer to a broad spectrum of personal characteristics. Variables commonly used in the implementation/HIP-literatures are sex, age, communication, experience, task-knowledge, professional orientation, length of tenure in an organisation, organisational status/management level, and degree of organisational success.

Most of the variables in this class of individual differences are one-dimensional and directly measurable. Given the time-constraints on the part of our respondents we focused on demographic/situational variables to group our respondents into subgroups.

Nine professional characteristics of the respondents were collected. These professional characteristics are used in many of the following analyses to group the respondents into subgroups of respondents according to the professional characteristic considered. Therefore, in the following, these professional characteristics are often referred to as grouping variables. The grouping variables fall into three types. In the following definition of the grouping variables, we will, for each grouping variable, define the meaning of the "high" level of the grouping variable first, and secondly the meaning of the "low" level of the grouping variable.

The first few grouping variables classify the business environment in which a respondent is working, but at a very general level (namely "Industry" defines a respondent as being employed either in the oil, aerospace, telecommunications, pharmaceuticals, or brewing industry, and "Sector" defines a respondent as being currently employed either in one of the last two industries, which are consumer goods-related, or in one of the first three industries, which are capital goods).

The second set of grouping variables classify the business experience of a respondent in more detail (namely "Experience", i.e. above or below the approximate sample median number of years in business; "Position", i.e. employed at director or at manager levels, "Function", i.e. employed in the financial function of a company or in non-financial or "commercial" functions; "Level", i.e. employed at corporate headquarters or in a business unit; and "Involvement", i.e. a high or a low level of formal and informal involvement in investment decision making.

Note that the "commercial" functions encountered in our sample were R&D, manufacturing and sales/marketing. On the one hand, it is obvious that in most industries investment projects in e.g. manufacturing are quite different from investment projects in e.g. marketing. On the other hand, (in any one industry) characteristics of projects in different functions could be assumed to be positively related (e.g. relatively quickly changing markets (marketing) require relatively short development times (R&D) etc. We therefore did not analyse the subgroup of "commercial" managers any further. The third set of grouping variables captures details of the respondents' educational background, which are potentially independent of the respondent's age or length of business experience, namely "Business Education", i.e. whether a respondent had a degree in a business-related subject or not, and "Qualification", i.e. postgraduate degree/professional qualification or not.

All nine grouping variables can be interpreted as influencing the quality of a respondent's "gut feeling" concerning investment decision making.

The grouping variables Business Education (in many tables abbreviated as Educbus), Experience, Function, Involvement, Level, Position, Qualification and Sector each have a "high level" and a "low level". We call these grouping variables the "dichotomous" grouping variables. They each can be used to split the sample into two subgroups. For each of the dichotomous grouping variables, we will refer to the subgroup with the low level in the grouping variable (mostly coded as "0" in the tables) as the "low level" subgroup and to the subgroup with the high level in the grouping variable (mostly coded as "1" in the tables) as the "high-level" subgroup. The grouping variable Industry has five levels. This can, with caution, be interpreted as an ordinal scale in terms of location between the extremes of primary production and final consumption goods. Points along this scale can in turn be grouped into two quasi sectors. Industries 1, 2, and 3 form a quasi sector, and industries 4 and 5 form a second quasi sector. Therefore, the grouping variables "Industry" and "Sector" overlap. The grouping variables are summarised in Table 4.7.

Table 4.7 The grouping variables

The grouping variables	Definition and levels	Size of subgroups	Source of information in section 5 of the questionnaire
Business Education (Educbus)	Degree in business-related subject		business-related subjects:
	no = 0	37	- Economics
	yes = 1	41	- Business Studies/
	n/a	4	Management Science
Experience	Years of business experience		Direct question
	low level = 0	39	
	high level = 1	41	
	n/a	2	
Function	Non-finance, or "commercial"		Conclude from "job title"
	function = 0	43	
	Finance function = 1	37	
	n/a	2	
Industry	Industries in order of distance from primary production		Direct question
	1 = Oil	7	
	2 = Aerospace	29	
	3 = Telecommunications	9	
	4 = Pharmaceuticals	22	
	5 = Brewing	15	
Involvement	Involvement in investment decision-making:		60%: "formal involvement" plus
	low level = 0	35	40%: "informal
	high level = 1	42	involvement" (see Appendix
	n/a	5	4)
Level	Business unit = 0	43	Conclude from "company"
	Corporate headquarters = 1	37	
	n/a	2	
Position	Manager = 0	58	Conclude from "job title"
	Director = 1	22	
	n/a	2	
Qualification	Postgraduate/professional qualification		1 if: postgraduate course(s) or
	no = 0	11	professional qualifications
	yes =1	63	
	n/a	8	
Sector	Capital goods Sector (industries 1,2,3) = 1	45	Conclude from "Industry"
	Consumer-goods Sector (industries 3 and 4) = 2	37	

Introduction of the concepts of "Importance and "Direction" of the influence of a variable

Throughout the statistical analyses of chapters 5 and 6, subgroups of respondents, as defined by the grouping variables, are compared to see whether their mean case study-valuations differ. In many of the following statistical tests, we use the number of significant differences between the pairs of subgroups (as defined by a certain grouping variable) in their mean valuations of the 14 case studies as a measure of the strength of that grouping variable's effect or influence on the case study valuations (the degree to which a grouping variable is influential on the empirical case study valuations). Analysing all (eight dichotomous) grouping variables in this way allows us to determine a grouping variable's relative ability, or power, to generate differences in the empirical case study valuations. We will consequently refer to this ability as a grouping variable's importance (for splitting the sample into subgroups with contrasting valuation tendencies). We will also examine the direction of a grouping variable's influence on the empirical case study valuations (positive or negative influence of a high level of the grouping variable. Of course "influence" measures correlation, which need not imply causality).

4.7 Research issues and hypotheses

In this section we discuss how the various conceivable outcomes of the empirical data analysis could be interpreted and we express our expectations in the form of a set of research hypotheses on the twelve research issues (in this way operationalising our three research questions).

Before we examine the role that respondents' risk tolerances might play in their valuations we discuss the theoretical valuation approaches which respondents might consciously follow or by which they might unconsciously be influenced.

4.7.1 NPV rule and risk tolerances

The most popular valuation approach in capital budgeting, which is currently being used in most companies, is the Net Present Value (NPV) rule. This discounts all project-related cash flows to the present at a risk-adjusted interest rate and then adds them up, giving the NPV of the project. However, the NPV rule does not properly capture real options. The latter is allegedly achieved by the valuation approach which is our main focus in the present study, real options theory.

At this point, it should be recalled from the discussion in section 3.5 that real options theory can be considered a special case of decision tree analysis which often, and particularly for the continuous distribution of outcomes in our case-studies, *"provide(s) a simpler and more direct way to compute the project's value and determine the optimal management strategy"* (Smith and Nau, 1995, p. 802).

In section 3.5.1 we noted that managers' case study valuations, if they follow the B-S option pricing formula, should not be affected by their risk tolerances (i.e. whether managers are risk-averse, risk-neutral, or risk-seeking). If managers follow (an)other valuation approach(es), or if assumptions of the B-S model are violated, risk tolerances might yet matter.

The first case we consider is where managers fail to perceive the option aspects of the case study investments and follow the traditional NPV rule in their valuations. Under the NPV paradigm, managers would consider the mean of the PV of the cash flows from the follow-up project. By doing so, they implicitly (consciously or unconsciously) assume that both the upside and the downside of volatility is relevant to the decision, with risk-averse managers being more concerned about the downside and risk-seeking managers being more focused on the upside. In the NPV approach, cash flows are discounted to the present using a risk-adjusted discount rate. In theory, the risk-adjustment is determined by the expected rate of return from the investment, which, in turn, reflects the riskiness of the cash flows. This is where ambiguity arises as in practice both the market expected rate of return (e.g. as determined by the CAPM) and a company or manager-specific expected rate of return are known to be used.

The manager-specific rate of return would depend on the manager's risk tolerance and would be lower the more risk-seeking the manager is. It follows that the NPV would be higher the more risk-seeking a manager is. We should point out that the importance of individual risk-tolerances on the valuations might be reduced by giving all values as discounted to the present. Due to limited information and time-constraints, it was unlikely that respondents would be willing or able to try to compute their own discounted values. It is conceivable, however, that respondents considerably more risk-seeking than the average added a subjective lump-sum to the NPV as implied by the discounted cash flows in the case studies. (Conversely, managers considerably more risk-averse than the average might have subtracted a subjective amount from the NPV suggested by the figures in the case studies).

The second case we consider is that managers might generally perceive the optionality in the case studies but use (additional) quantitative valuation heuristics instead of only their gut feeling as they are asked to. This might lead to a situation similar to the previous scenario. Risk-tolerances would enter the valuation as part of the valuation heuristic (e.g. misspecification depending on risk-tolerances of the probabilities in the distribution-based valuation heuristic described in Appendix 3)

Note that the asymmetry of the option situation implies that extra volatility means greater potential gains without changing the downside loss (which is limited to the price of the option). Consequently, if they perceive the optionality properly, both risk-averse, risk-tolerant and risk-seeking managers should welcome extra volatility. If optionality is perceived properly, individually specified valuation heuristics as pointed out above are the entry point for risk-tolerances, not volatility.

Thirdly, one might think that risk-tolerances become important if less than perfectly diversified investors are considered. It is a usual assumption in real options theory that options to invest are owned by many well-diversified investors (e.g. McDonald and Siegel, 1986). An example is stockholders in publicly owned corporations, who need only be compensated for the systematic (i.e. market-related) component of the risk of projects and options to invest. In contrast, if a project is owned by a single less than perfectly diversified investor (a manager or a company) this investor would have to consider the overall risk of projects and of options to invest (i.e. both the systematic and the unsystematic (or firm/project-specific) risks.

We note that this distinction at best concerns the expected return from an option, while the option value always depends on the overall risk of the underlying asset. This is because it is the overall risk which drives the asset price (and volatility) which in turn determine the option price. Consequently, the question of whether an investor is well-diversified or not does not affect the (ir)relevance of risk-tolerances in option valuation.

To sum up, risk-tolerances can matter both under the NPV and the real options paradigms. However, we should note that the "risk-shunning" behaviour of managers observed in many studies (e.g. Swalm, 1966) encourages us to, where applicable, interpret potential findings in the light of risk-aversion, but casts an immediate doubt on the appropriateness of explanations of any potential findings based on risk-fondness.

4.7.2 Introduction of research issues and hypotheses

The three research questions of the present study, as stated in section 4.2, are (1) the alleged correspondence between managers' intuitive valuations and theory, (2) a "reality-check" for real options and assumptions and (3) valuation differences for subgroups. To investigate the first research question, we will mainly focus on the sample as a whole, trying to use findings from the subgroups as additional checks. For the second research question we will consider both the entire sample and subgroups. For the third research question we will examine subgroups of respondents.

Table 4.8 contains the twelve research issues on which we will set up research hypotheses. It also indicates how the research issues are related to each other and which common features they share. For most of the twelve research issues we will consequently define a null-hypothesis H_0 following an NPV- perspective and an alternative hypothesis H_1 following a real options-perspective.

Generally, we follow a standard procedure for each research issue of : hypothesis (Chapter 4) - hypothesis test (Chapter 5 and 6) - interpretation (Chapter 7).

Table 4.8 The research issues

Research Issue	1st Research Question: "Correspond"	2nd Research Question: "Relevance"	3rd Research Question: "Acceptab."	Data Source	Unit of Analysis	Concepts examined	Param. of judgemental correctness	Continuous number of hypotheses
1 Comparison of level of empirical case study valuations with prescriptions by theory				Case studies	Entire sample	Valuation	Bias	1, 2
2 "Unanimity" in empirical case study valuation				"	"	Unanimity	Spread	3
3 Grouping variables' importance for splitting sample into subgroups with contrasting case study valuation-levels				"	Subgroups of respondents		Bias	4, 5
4 Direction of grouping variables' influence on level of empirical case study valuations				"	"	Valuation level	"	6, 7
5 Grouping variables' importance for "unanimity"				"	"		Spread	8, 9
6 Direction of grouping variables' influence on unanimity				"	"	Unanimity	"	10, 11
7 "Consistency" - differencs for subgroups				"	"	Consistency	"	12,13
8 "Real-world" occurrence of real options and perceived realism of real option assumptions				Question-naire	Entire sample subgroups	Realism	"	14
9 Grouping variables' importance for "openness towards real options"				"	"		"	15
10 Direction of grouping variables' influence on openness				"	"	Openness	"	16
11 Direction of "openness's" influence on empirical case-study valuations				"	"	Influence of attitudes on valuation behaviour	Bias	17
12 Direction of influence of important questionnaire variables on empirical case study valuations				"	Entire sample		"	18

Under the "unanimity" of the respondents we understand the spread in the case study valuations around the mean empirical valuation. Under "importance" of a grouping variable we understand the degree to which a certain grouping variable is potentially influential on the phenomenon under consideration. Possible directions of a grouping variables' influence on the valuation behaviour are a positive influence or a negative influence. By the "consistency" of a respondent's valuation behaviour we mean, given the three case studies normally answered, the degree to which an individual manager tends to overvalue or undervalue all three at once. The construct "openness" of respondents to the real options approach consists of various items of information, such as the manager's agreement with the assumptions of real options theory, the existence of real growth options in his or her company, etc., as collected in our questionnaire survey. ("Questionnaire variables" are the items of information collected in the questionnaire).

The valuations of our case study investments by both NPV and real options (B-S) valuation approaches were given in table 3.5 (which also contains the annual returns, that the NPV corresponds to.) As explained in section 3.3.2, our case studies vary the quantitative B-S parameters in the following ways. Cases A1 to A7 vary only the expected PV of the cash flows of the follow up project (this varies the current stock price S and hence the "moneyness" of the option, in B-S terms). Cases B1 to B5 vary the volatility (σ)

In the naive NPV approach, in proportion as the uncertainty (volatility) associated with the cash flows from an investment increases, these cash flows will be discounted more heavily. If the uncertainty "proceeds too far", i.e. if it falls beyond the range with which managers feel intuitively comfortable, no investment may be made. In the real options framework, uncertainty has the opposite effect: it increases the value of the option. This is because higher volatility raises the chance that the asset price may exceed the exercise price before the (call) option expires (Hamilton and Mitchell, 1990).

Cases C1 and C2 (jointly as departures from A3) vary several factors. The main variation is in the maturity (T-t) of the option. In the naive NPV approach, lengthening the maturity of a single payoff reduces its present value, as a result of the time value of money. Again, within the real options framework, lengthened maturity has the opposite effect. Extending the time during which the option may be exercised increases the probability that the asset price may exceed the exercise price during that time period (Hamilton and Mitchell, 1990).

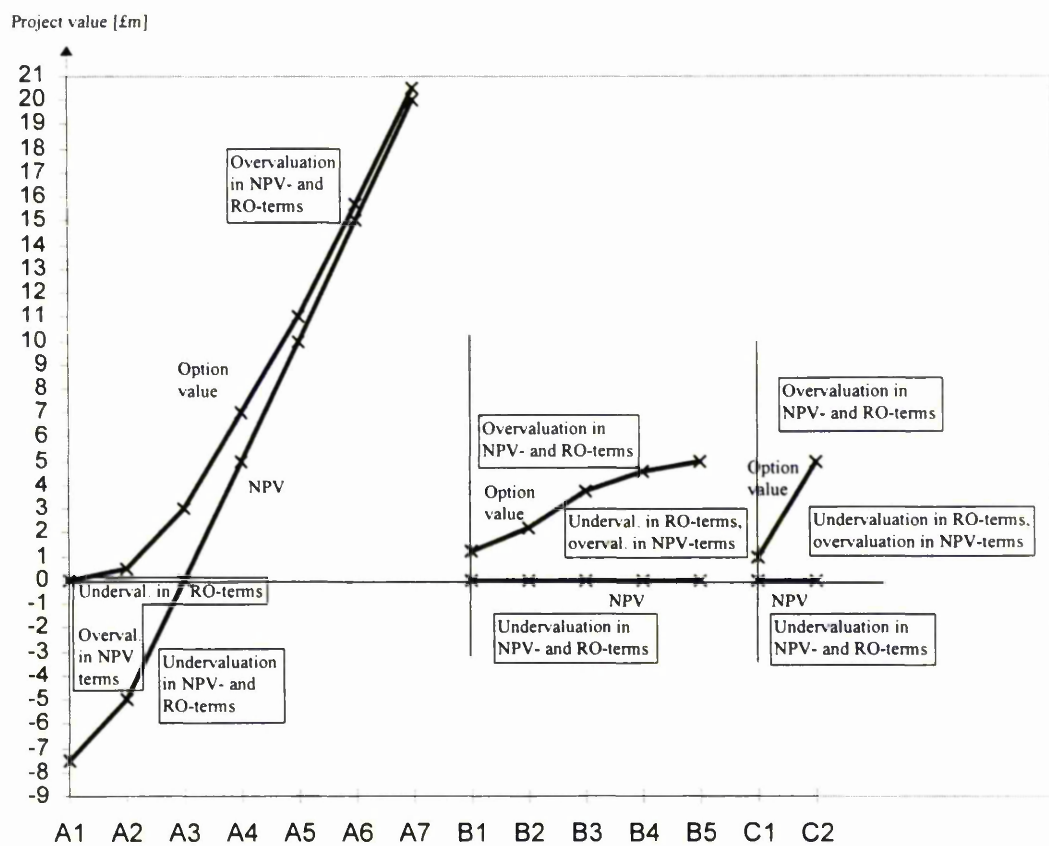
If managers correctly perceive the optionality in the case studies, their valuations should hypothetically be close to the theoretical option values (given in the row "OV/T") in table 3.5. Three outcomes seem possible for the mean valuation: the respondents value the case studies "correctly" (in real option theory terms), they over-value the case studies, or they undervalue the case studies.

If managers do not perceive the optionality in the case studies, their valuations should be lower than if they do, and possibly close to the NPV values (given in the row "NPV" in table 3.5). Again, three outcomes are possible: respondents value the case studies "correctly" (in NPV terms) or they over- or undervalue the case studies.

Apart from these two "black" and "white" alternatives, there are, of course, several possible scenarios in between, e.g. respondents "sense" the optionality without fully recognising it, or respondents perceive the optionality for some, but not for all of their case studies etc.

Figure 4.1 shows how correct, over- and under-valuation in real options terms on the one hand and in NPV-terms on the other hand, relate to each other in our 14 case studies.

Figure 4.1 Correct, over-, and undervaluations in NPV- and real option (RO)-terms



Undervaluation in NPV-terms implies that the NPV-rule describes the valuation behaviour better (because in this case the empirical valuation is closer to the NPV). Overvaluation in NPV terms and undervaluation in real option-terms is ambiguous and would depend on the amount of misvaluation. Overvaluation in real option-terms implies that real options theory describes the valuation behaviour better than NPV.

As reasons for undervaluation in NPV-terms, we refer to the commonly stated reasons for underinvestment, as summarised in Hayes and Garwin (1982) in section 2.2 of the literature review.

Potential for overvaluation in NPV-terms and undervaluation in real option-terms (resulting in undervaluation in real option terms) could be the failure to fully perceive the optionality of the investment case and/or strong undervaluation of the NPV-component of the investment (out of the reasons stated above) thus eliminating (part of) the additional value stemming from the properly perceived optionality. Finally, in the next section we list factors facilitating overvaluation in either NPV-terms or real option-terms

At this point, we can define the null hypothesis H_0 and the alternative hypothesis H_1 for the first research issue, namely the comparison between the empirical case study valuations and the values prescribed by theory.

. Measurement for H_0 : The mean empirical case study valuations are close, or below, the NPV-values of the case studies (in row "NPV" in table 3.5)

Measurement for H_1: The mean empirical case study valuations are close, or above the theoretical option values of the case studies (in row "OV(T)" in table 3.5)

As noted before, in the real option paradigm an option is assumed to be equally valuable to any investor (since subjective preferences or beliefs are not part of the B-S equation). Consequently, no differences in valuation between the subgroups in the sample should occur.

It is conceivable, however, that in the real world factors which are not part of the model, such as behavioural factors, can influence the results. We scanned the implementation research and HIP/problem solving literatures (as summarised in sections 2.3 and 2.4) to identify factors that might affect valuations but which are not part of either the NPV or real option models respectively. We will use these factors to set up our hypotheses on the differences in the valuation behaviour of the different subgroups in the sample (research issues 3-7, 9 and 10).

Although most of the studies in sections 2.3 and 2.4 do not relate directly to investment decision making, many touch upon issues related to this field. From this body of empirical findings, seven phenomena, for whom individual differences had been measured, seemed to be relevant to investment decision making. These are summarised in table 4.9.

Table 4.9

Findings from implementation/HIP/problem solving research relevant to investment decision making

Finding from implementation/HIP/problem solving research	Implications for investment decision making: "behavioural factors"
E.g. Experienced decision-makers show a high level of decision confidence (Taylor, 1975)	"Overgenerosity" on the part of the e.g. more senior managers
Probabilistic analysis appears extremely uncomfortable for most individuals. Humans tend to be reluctant to work with probabilistic data (Conrath, 1973)	Misinterpretation of the lognormality of the asset price (e.g. by using the arithmetic mean of the upper and lower bounds as the current asset price
Empirical studies usually suggest risk-aversion (cf. Swalm, 1966)	Risk-fondness
E.g. Experience of decision makers were shown to be more flexible (Taylor and Dunnette, 1974)	Perception of additional real options not allowed for in B-S model
Possession of a high level of task knowledge (Benbasat and Schroeder, 1977)	Perception of the information gain during the pioneer project
Utility-maximising subjects use simplifying heuristics for problems which are not associated with a high expected utility (Thiessen, 1993)	A tendency towards using imprecise valuation heuristics can cause over-or under-valuation
Investors in financial markets "overreact" to new information (cf. De Bondt and Thaler, 1985 and 1987)	Respondents who actually perceive the optionality in the case studies overvalue them due to a "novelty factor"

Note that the first three "behavioural factors" can influence the perception of the NPV of an investment, whereas the last four factors can influence the perception of the time value of an option-investment.

Using the articles quoted in table 4.9 and additionally Eysenck (1977), Hunt et al., (1973), and Hunt et al. (1975).

In table 4.10, in the part entitled "behavioural factors", we report whether a certain behavioural factor has been shown to occur in a certain high-level subgroup as defined by a grouping variable, (which we mark with a plus sign in the corresponding cell) - or not (minus sign).

For illustration we quote here three such findings on (1) cognitive style, (2) prior (computer) experience, and (3) age, as stated in Aydin and Rice (1991):

(1) "Individuals who rely on logical structures to clarify a situation (*thinking types*) should have less difficulty adapting to computer-based tasks and consequently a more positive attitude towards a new medical information system than those who rely primarily on affective processes in problem solving (*feeling types*)." (2) "The lack of standardisation may make it difficult for experienced computer users to adapt to a new system, resulting in "too much" experience being negatively related to acceptance". (3) "People who are younger, and who have spent fewer years at an organisation may be less resistant to innovations").

(Note that in the case of our grouping variable Industry the implementation research/and HIP/problem solving literatures do not contain empirical findings. We therefore rank industries according to our expectation about the relative likelihood of a certain behavioural factor is occurring in a certain industry (from ++ = most likely to -- = least likely). (Our expectations for grouping variable Sector are derived from this industry ranking).

The columns "Net no. of signs (RO)" contains the (net) number of plus or minus signs across the seven behavioural factors which potentially affect the real options valuations. Numbers in this column can be interpreted (for the example of the grouping variable "Function") to mean that the subgroup of Finance managers are relatively little affected by the behavioural factors (in comparison with the "commercial" managers). The column "Net no. of signs (NPV)" contains the (net) number of plus or minus signs across the first three behavioural factors, which can influence the NPV component of the valuations.

These two columns determine the hypotheses on research issues 3 and 4 ("Valuation-level"), research issues 5 and 6 ("Unanimity"), research issue 7 ("Consistency"), and research issues 8 and 9 ("Openness") as indicated in the "Research issues" part of table 4.10.

The column "Net no of signs (NPV)" is used to set up the null hypothesis H_0, reflecting our expectation for NPV-rule - following respondents. The column "Net no of signs (RO)" is used to set up the alternative hypothesis H_1, which represents our valuation-related expectation if respondents follow real options theory.

"High valuation" (column "RI 4") is assumed to be positively related to the behavioural factors, "Unanimity" (column "RI 6") and "Consistency" (column "RI 7") are assumed to be negatively related to the behavioural factors (because the presence of behavioural factors represent "opportunities" for the respondents to disagree/be inconsistent), and "Openness" (column "RI 10") is assumed to be positively related to the behavioural factors

"Perception of asymmetry", "Perception of additional options", and "Perception of information gain".

In columns "RI 3" and "RI 5" which contain information on how likely the different grouping variables are to influence the phenomenon in question, ranks are given to the grouping variables according to their respective number of signs in columns "Net no. of signs (RO)" and "Net no. of signs (NPV)" (from the highest number of positive signs to the highest number of negative signs). This follows the rationale that those grouping variables that define the subgroups that are potentially affected by the highest (net) number of behavioural factors are most likely to be influential on the phenomenon in question. (In column "RI 9", ranks are given to the grouping variables according to their respective number of signs from columns "Perception of asymmetry, Perception of additional options", and "Perception of information gain").

For example, the last cells in columns "H_1" and "H_0" of column "RI 4" imply that the subgroup of managers with an additional qualification are conjectured to value the case studies higher than managers without an additional qualification if both use a real options approach, while they should not value them higher if both use an NPV approach. We will compare these hypotheses with the empirical valuations in the next two chapters.

Table 4.10 Speculation on valuations and attitudes by subgroups

Grouping Variables			Behavioural factors – Influencing OV – Influencing NPV: Over generosity	Misinterpretation of boundaries	Risk-fondness	Perc. of asym.	Perc. of add. options	Perc. of info gain	Imprecise valuation heuristics	Overreaction due to novelty factor	Net no. of signs (NPV)	Net no. of signs (RO)	Research Issues – High Valuation – RI 3 Importance H4 H_0	RI 3 Importance H5 H_1	RI 4 Direction H6 H_0	RI 4 Direction H7 H_1	Unanimity – RI 5 Importance H8 H_0	RI 5 Importance H9 H_1	RI 6 Direction H10 H_0	RI 6 Direction H11 H_1	Consistency – RI 7 (Direction) H12 H_0	RI 7 (Direction) H13 H_1	Openness – RI 9 Importance H15 H_1	RI 10 Direction H16 H_1
Bus Env		Sect	+	+	+	+	+	+	+	-	3+	5+	1	2	+	+	1	2	-	-	-	-	1	+
Bus Env	Industry – Cap Goods	Oil	--	--	+	++	++	--	--	--	3-	7-	n/a	n/a		4							n/a	+
Bus Env	Industry – Cap Goods	Aero	-	-	--	--	--	-	-	+	4-	7-				4								-
Bus Env	Industry – Cap Goods	Telec	+	+	0	-	-	+	0	++	2+	4+				2								-
Bus Env	Industry – Cons. Goods	Pha	++	0	++	+	+	++	+	-	4+	7+				1								+
Bus Env	Industry – Cons. Goods	Brew	0	++	-	0	0	0	++	0	+	3+				3								0
Prof Exp	Seniority	Exp	+	+	+	+	+	+	+	+	3+	7+	1	1	+	+	1	1	-	-	-	-	1	+
Prof Exp	Seniority	Pos	+	+	+	+	+	+	+	+	3+	7+	1	1	+	+	1	1	-	-	-	-	1	+
Prof Exp		Fun	-	-	-	-	-	-	-	+	3-	6-	3	5	-	-	3	5	+	+	+	+	1	-
Prof Exp		Lev	-	-	+	+	+	+	-	+	-	+	2	3	-	+	2	3	+	-	+	-	2	+
Prof Exp		Invo	-	-	-	-	-	+	-	+	3-	3-	3	4	-	-	3	4	+	+	+	+	2	-
Educational Background		EdBs	-	+	-	-	+	+	-	+	-	+	2	3	-	+	2	3	+	-	+	-	2	+
Educational Background		Qua	+	-	-	+	+	+	-	+	-	+	2	3	-	+	2	3	+	-	+	-	1	+

4.7.3 Relating hypotheses back to research questions

The first research question ("correspondence") is covered by the first research issue, the comparison of the level of the empirical case study valuations with the prescriptions by the NPV-rule and by real options theory respectively, and by the tests in research issues 3 to 7 of the hypotheses formed according to a NPV and real options view respectively using the "behavioural factors".

In passing, in research issue 2 (as pointed out in table 4.8), we will consider the spread in the case study valuations by the entire sample. Our hypothesis on research issue 2 follows a common observation in judgmental research: the standard deviation of a judgement behaves in line with its mean: for higher means a higher standard deviation is observed and is expected.

The second research question ("Realism") is covered by research issue 8. Our hypothesis is that real options occur in the real world and that the real option theory assumptions are acceptable. We also checked for unusual effects among subgroups of respondents and regarding the influence of attitudes on valuation behaviour in research issues 9-12. Our hypotheses for research issues 9 and 10 are in Table 4.10. From the case study valuations, we could draw conclusions on whether the output of real option analysis (i.e. the option values, "the whole") was perceived to be realistic. From the questionnaire, we could infer whether the logic behind real option analysis (as expressed in its assumptions and inner workings, "the parts") was perceived to be realistic. Note that realism of the "parts" is not necessarily a prerequisite for realism of the "whole". However, if the parts of real option analysis were perceived as realistic, the resulting output (the option values) should be considered normative. This is the basic contention of our research issues 11 and 12. Our hypothesis for research issue 11 is therefore that openness towards real options tends to produce more correct empirical valuations (in real option terms).

Our hypothesis for research issue 12 concerns the direction of the influence of important questionnaire variables on the empirical case study valuations. As will be shown in section 6.3.1, these are (1) respondents' high familiarity with the time horizon of eight years (used in many of the case studies), (2) respondents' tendency to look at the pioneer and follow-up projects as a single project, and (3) respondents' wish for additional data.

Our hypothesis concerning the first of the mentioned questionnaire variables was that respondents will feel more at ease with case studies which have similar parameter settings to those in their own industry and as a consequence will value such case studies most rationally (the general contention of lens-type research).

As mentioned above, the second questionnaire variable influential over the empirical case study valuations is whether the respondent was able and willing to accept an assumption of the (Black-Scholes) real options model, namely the respondents' willingness to look at the two-stage investment as offering two decision opportunities instead of one. A lack of experience in working with real option-type projects, and a failure to identify the case studies as offering two projects or decision opportunities, generally might lead to smaller valuations. We would then expect the empirical valuations to resemble the NPV.

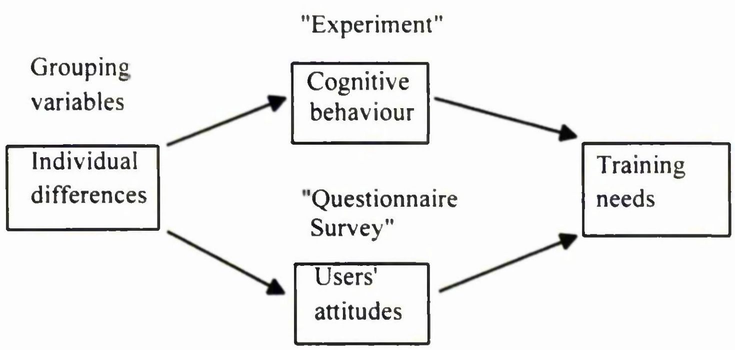
The third of the above mentioned overall significant questionnaire variables was the wish for additional data. This might be interpreted in terms of a respondents' confidence, or lack of confidence about his decisions. If it is true that a lack of confidence leads to smaller valuations, it might have been expected that a wish for additional data correlated with smaller valuations. The variable "Wish for additional data" resembles in interpretation the effect of (the opposite of) the grouping variables Experience and Position (interpreted as indicative of a respondents' self-confidence, leading to higher valuations).

Concerning the third research question ("Acceptability") we analyse subgroups of respondents to find where differences in training needs (as defined below) in the real option framework might arise. The discussion (in Chapter 7) will be organised around (an adapted version of) a model that is believed to portray the manner in which individual differences influence MIS success (Zmud, 1979).

We chose the classical model from the area of MIS implementation because we think that it fits well (management information systems and capital budgeting systems share many common points) and because, as far as we know, there are no formal models on the expected success of the implementation of capital budgeting techniques. This might simply be due to the fact that *"the application of option pricing to the problem of modelling flexibility for strategic investment decisions ... is the first major advance in capital budgeting for decades"* (Copeland and Weston (1988), p. 430). Moreover, the implementation of capital budgeting techniques might be considered less costly and less irreversible than MIS implementation, which implies buying tangible assets (hardware) and often involves major reorganisations.

Two distinct paths are conceptualised in the MIS success model (see Figure 4.2). An upper path shows individual differences influencing human decision behaviour. A lower path reflects the impact of individual differences upon the attitudes of potential users. Both cognitive and attitudinal factors influence potential training needs.

Figure 4.2 Model of individual differences' influence on potential training requirements in real option analysis



As far as "individual differences" are concerned, as explained in section 4.6, we do not use "cognitive style" and "personality" but focus on "demographic situational variables" (our grouping variables). Concerning "cognitive behaviour", we focus on its intuitive valuation aspect and use our experiment to measure it. Aspects of "users' attitudes", i.e. their beliefs, values and expectations regarding the role of the system within the organisation, are tried to be captured in the questionnaire survey.

The concept of "training needs" of the real options framework is measured using our research issues. The following constellation (both for the entire sample and for subgroups of respondents) would be most promising for little training needs of the real options framework: correct valuation (research issues 1, 3 and 4), high unanimity (research issues 2, 5, and 6), high consistency (research issue 7), high openness (research issues 8, 9, and 10), (and openness leading to more rational empirical case study valuations (research issues 11 and 12).

In case studies which are misvalued, low unanimity and low consistency would be preferable, as this might indicate that respondents are confused. This might make them more receptive to training in real options. High openness would still be desirable.

4.8 Summary

In this chapter, we defined the three main research questions of the present study, namely whether decision makers value investment projects in accordance with theory (Correspondence), how far the normative non dividend-paying European real options model is perceived by managers as relevant to the structure of "real world" investment decisions ("Relevance") and whether we can discern any valuation or attitude differences for subgroups of respondents in our sample ("Implementation"). We identify the two separate strands of research methodology we use to tackle these questions. Being at the deductive end of the research continuum, our experiment is the classical approach of normative, or Bayesian, research and is ideal to evaluate the first question. Our research also contains an element of the inductive descriptive lens model research tradition, in that the more inductive technique of a survey is used to explore the third question. Findings from both methodologies were used to examine the second research question. Precedents for this particular combination of research methods are discussed. The relevance of the experimental method, often questioned in the research methodology literature, seems to be reasonably high in the present problem. This is because in practice many senior decision makers face similar conditions to the ones in the experiment, namely time constraints and limited, highly abstract information on the investment opportunities. We limit the population of the present research to managers in large, non-financial companies. From our three broad research questions we developed twelve detailed research issues (Table 4.8), for which we set up hypotheses. For six research issues, we derived separate hypotheses for the NPV-rule and for the real options approach (resulting in 18 hypotheses overall (Table 4.10)). In the following chapters 5 and 6 we will use our empirical data set to test these hypotheses.

5. FINDINGS FROM THE EXPERIMENT

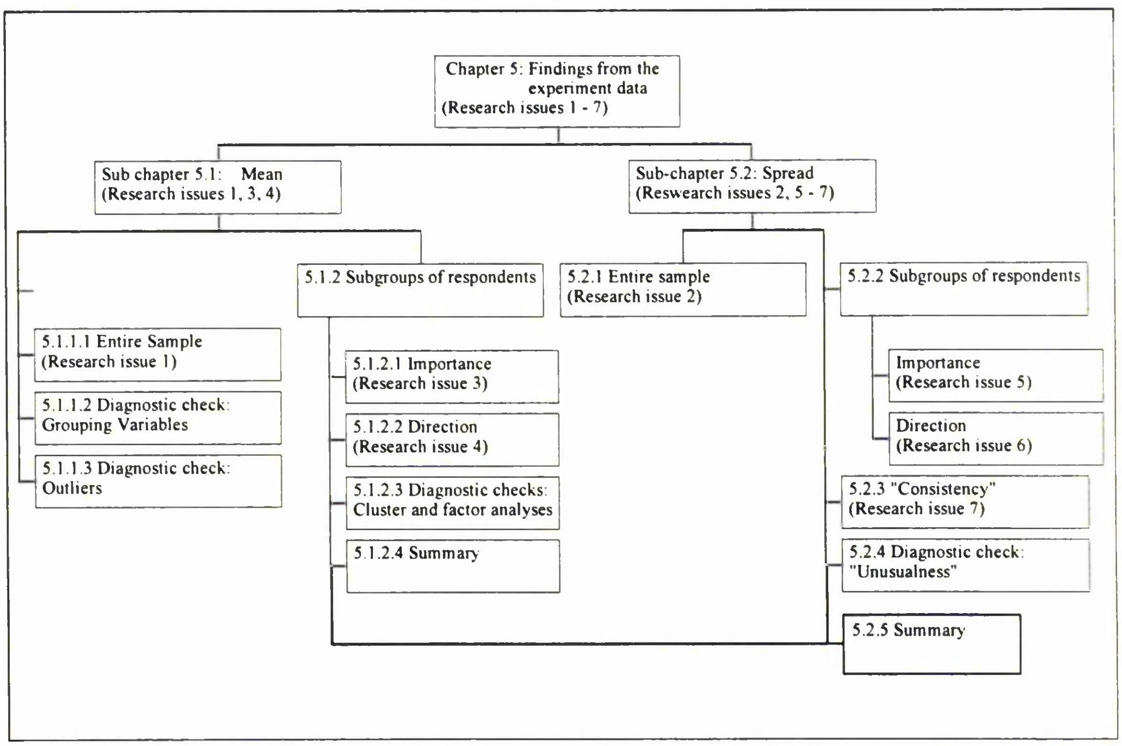
Introduction

Having defined the three broad research questions and more detailed research issues and hypotheses in the previous Chapter 4, we will now use the findings from the empirical fieldwork to test our hypotheses. The most important statistical analyses performed in this and the next chapters are hypothesis tests. In this sense, the twelve research issues and the corresponding 18 hypotheses represent the central thread of this and the next chapters. First reading can focus on these hypotheses tests (clearly marked in the section headings and starting with section 5.1.1.1, summarised in section 6.5). The remaining statistical analyses are somewhat less central to the present study and are mainly what we call "diagnostic checks" i.e. they check for potential conceptual or clerical errors, or they explore the data for potential unexpected patterns. In this chapter (and in Chapter 6) we will compare the empirical findings from the various tests with each other in order to detect any unsuspected effects (at the end of section 5.1.1.1b, in section 5.1.2.4, in section 5.2.5, at the end of section 6.2.2.1, and in section 6.4). We will discuss the statistical findings and implications of the hypotheses tests on a more interpretative level in Chapter 7.

In this chapter, we focus on the research issues concerning the empirical case study valuation (research issues 1-7). The chapter describes the findings from the analysis of the experiment data collected in nine companies in five different industries.

The simplest statistical model of judgmental correctness has two parameters, bias (mean or level) and dispersion (spread or variance). Accordingly, the present chapter is divided into the two sub-chapters "Means of the empirical case study valuations" (Sub-chapter 5.1 research issues 1, 3 , and 4) and "Spread of the empirical case study valuations" (Sub-chapter 5.2, research issues 2, and 5-7). The chapter follows the structure laid out in figure 5.1.1.

Figure 5.1.1: Overview over Chapter 5



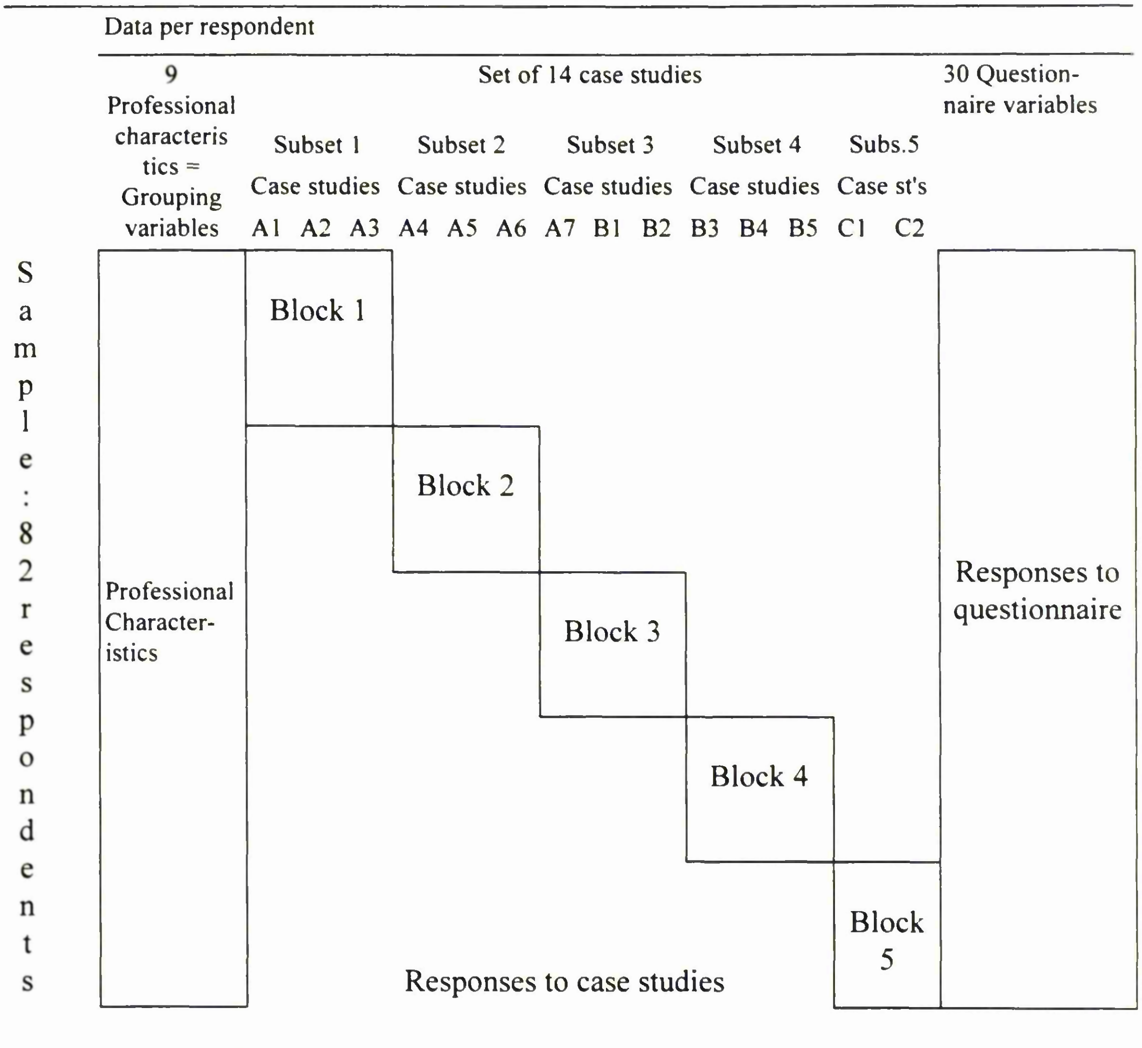
Before we start the statistical analysis, we give a short description of the data set, defining the terminology we will use. The entire sample consists of 82 respondents. The data per respondent include the respondents" nine professional characteristics, followed by the respondent's valuation responses to a subset of the 14 case studies, followed by the respondent's answers to the 21 questions of a questionnaire on investment opportunities and investment decision making in his or her organisation.

For almost all respondents, all nine categories of personal characteristics are available. Each respondent could take decisions on only a subset of the 14 case studies, due to time constraints on the part of the respondents. For this purpose, the case studies are grouped into five standard subsets. Subsets 1 to 4 of the case studies contain three case studies each. Subset 5 of the case studies contains only two case studies. Each respondent only answered one of these five subsets. The sample of all the responses to any one of the five subsets of the case studies is referred to as a "block" of responses to that subset of case studies.

For all the respondents, a more or less complete response was obtained to the 30 questions in the questionnaire on investment opportunities and behaviour in this organisation (which will be analysed in Chapter 6). The total structure of the data set is summarised in figure 5.1.2.

Figure 5.1.2

Overview over the data



5.1 Means of the empirical case study valuations

5.1.1 Means of the empirical case study valuations for the entire sample, examination of grouping variables, and discussion of outliers

In this section, firstly, the means of the empirical case study valuations across all respondents are discussed and compared with the values recommended by theory (research issue 1). Secondly, the data on respondents' professional characteristics (the grouping variables) are introduced and discussed. We also examine whether there is sampling bias in the professional characteristics between the subgroups of respondents who responded to different sets of case studies. Finally, the case study valuation responses are examined for outliers.

5.1.1.1 Comparison between the means of the empirical case study valuations and theory (Research issue 1)

Our first research issue, as defined in section 4.7 (Table.4.8), is the comparison of the mean case study valuations by the entire sample of respondents with the prescriptions of the traditional NPV-rule on the one hand, and of our chosen real options theory model on the other hand. We first restate the relevant null and alternative hypotheses (from section 4.7):

H_0: The NPV-rule has superior descriptive power for the mean empirical valuations.

Measurement: The mean empirical case study valuations are close to, or below, the

NPV values of the case studies.

H1: Real options theory has superior descriptive power for the mean empirical valuations.

Measurement: The mean empirical case study valuations are close to, or above, the theoretical option values of the case studies.

The successive means of the empirical valuations of the 14 case studies will show the effects of varying the following main parameters of the real options model (the option pricing model): the expected PV of the follow-up project's cash flows (the asset price) (in the "A-sequence" of case studies), the volatility of this PV (the asset's volatility) (in the "B-sequence" of case studies) and the time until the follow-up investment can be made (the time-to-maturity) (in the "C-sequence" of case studies) (plus potentially the effects of any sampling bias).

Before we examine the mean empirical valuations for each of the three case sequences, we introduce a quantitative measure of the deviation of the decisions taken on the case studies by the respondents from the decisions recommended by real options theory, the variable "Discrepancy", which will be used in all three sequences (and in some consequent tests) and check for the applicability of a t-test of discrepancy.

D = EV - OV(T)

with:

D = Discrepancy,

EV = "Empirical case study valuation" = Decision on, i.e. valuation of, the investment opportunity described in a case study, by one or more respondents

OV(T) = "Theoretical option value" = B-S value of the investment opportunity.

The variable "Discrepancy" captures the size and direction of any differences between the empirical case study valuations and the values recommended by real options theory.

To test for the statistical significance of potential discrepancies for each of the 14 case studies, a t-test at a 5% confidence level is carried out. The t-test assumes normality, which means in our case that the distributions of the empirical case study valuation for the entire sample would have to be normal in order for the t-test to be applicable. We test for normality using a Kolmogorov-Smirnov test with Lilliefors significance levels. At 5% and even at 10% significance level, only the responses to case studies B2 and B3 are non-normal. However, across all 14 case studies, two (5%) significant case studies might have been expected to occur out of sheer coincidence without implying an overall significant departure from normality. We apply the binomial test (see e.g. Siegel and Castellan, 1988) to demonstrate this claim with $P(X= 2 \mid n = 14, p = 0.05)$ and find the result not significant at 5%. We therefore conclude that the assumption of the t-test (i.e. the assumption of normality) is met by the present sample.

A-sequence of case studies

We first review the effects of varying the expected PV of the follow-up project's cash flows (the asset price) on the respondents' valuations. This factor is varied across the sequence of case studies A1 to A7 (the "A-sequence case studies"). As the follow-up project's initial investment cost is held constant, in effect we vary the "moneyness" of the real option. The options in case studies A1 to A3 are out of the money, and the options in case studies A4 to A7 are, to varying degrees, in the money.

Table 5.1.1 contains for each A-sequence case study the moneyness of the option, the sample size, the expected PV of the follow-up project's cash flows, the NPV the theoretical option value, the mean empirical valuation, the discrepancy between mean empirical valuation and NPV, the discrepancy between mean empirical valuation and theoretical option value, the "relative misvaluation" (i.e. the discrepancy in per cent of the theoretical option value), and the results of the t-test for the significance of the mean discrepancy.

Table 5.1.1

Valuations for A-sequence case studies (Mean empirical valuations are for the complete subsample of the respondents who answered these case studies)

	A1	A2	A3	A4	A5	A6	A7
Moneyness	Out-of-the-money					In-the-money	
Sample size	17	18	20	19	18	15	17
PV of cf's	2.5	5	10	15	20	25	30
NPV	-7.5	-5	0	5	10	15	20
Theoretical option value	0.06	0.5	3	6.8	11.1	15.7	20.4
Empirical valuation	-0.02	1.7	4	6.3	15.4	11.4	13.8
EV-NPV	7.5	6.7	4	1.3	5.4	-3.6	-6.2
Discrepancy	0	1.4	1.7	0.7	5.8	-2.5	-4.8
D/OV(T) [%]	-133	240	33	-7	39	-21	-32
Significance	ns	s	s	ns	s	s	s
H_0: EV≤ NPV						X	X
H_1: EV ≥ OV		X	X		X		
NPV≤ EV≤ OV	X			X			

Note: ns = not significant at 5% level of significance, s = significant at 5% level of significance.

The respondents significantly overvalue, or value optimistically, three A sequence case studies A2, A3, and A5, (i.e. the value chosen by the respondents is larger than the value indicated by real option theory so that respondents value the case study projects as if they were overly optimistic regarding the project's future profit prospects). However they significantly undervalue case studies A6 and A7, giving values even below the NPV. For two of the seven A series case studies, A1 and A4, the empirical valuation lies between the NPV and the option value, but is closer to the option value. (The discrepancies are insignificant). We conclude that the respondents are approximately rational in terms of real options theory, or are "option-rational" for case studies A1 and A4. As the last three rows of the table show, for the A-sequence of 7 case studies, the real options approach describes the empirical valuation behaviour better (better 3 times) than the NPV-rule (better only 2 times). Based on the A-sequence of cases, we therefore accept the alternative hypothesis that the real options approach describes the empirical valuation behaviour better.

Over the A- sequence- case studies, the expected PV of the follow-up project's cash flows is increased, and this causes the theoretical NPV and real option values to increase. However the sign of the significant mean discrepancy, and of the mean EV-NPV, changes over the A-sequence: A2, A3, and A5 have a positive mean discrepancy/EV-NPV-value and A6 and A7 have a negative mean discrepancy/EV-NPV value. Therefore the empirical valuations do not correlate with the theoretical option values.

It seems important to look for potential explanations of this strongly marked pattern. Given that real options theory is the less inaccurate descriptor for the A-sequence of empirical valuations, one possible way to analyse these empirical valuations further is to look at the discrepancies in the components of the theoretical option values, namely the intrinsic value and the time value in the A-sequence- case studies. The intrinsic value of an option, max(0, S-X), is the value of the option if exercised immediately. The time value of an option is the difference between the theoretical option value and its intrinsic value (Hull, 1993). Table 5.1.2 summarises the discrepancy, the intrinsic value, and the time value for the A-sequence- case studies.

Table 5.1.2

Discrepancy, intrinsic value, and time value for the A-sequence- case studies

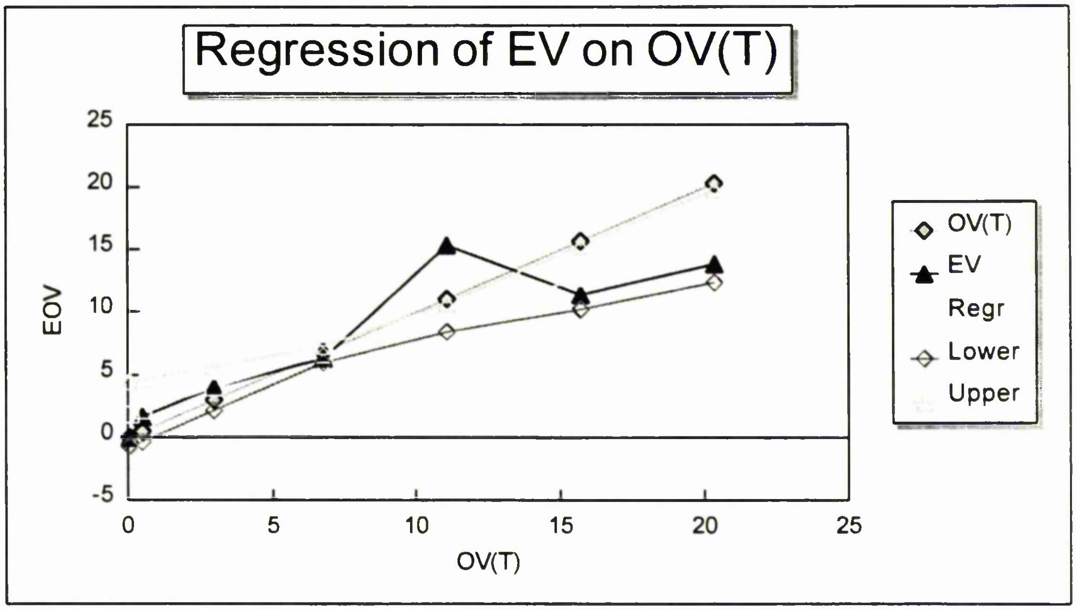
	A1	A2	A3	A4	A5	A6	A7
		Out-of-the-money				In-the-money	
Discrep.	-0.1	1.2	1	-0.5	4.3	-3.3	-6.6
Intrinsic v	0	0	0	3	8	13	18
Time v.	0.06	0.5	3	3.8	3.1	2.7	2.4

Respondents seemingly overvalue the low value option and undervalue the high value option. One possible interpretation of this behaviour is that respondents put too much weight on the time value and too little weight on the intrinsic value.

Having compared the empirical valuations with the theoretical NPV- and option values for each individual A-sequence case study in the previous paragraph, and having found that real options theory is a superior descriptor to the NPV-rule, we now turn to review the relationship between empirical valuations and theoretical option values for the entire sequence. This is to check whether there are any patterns in the overall relationship between empirical valuations and theoretical option values that escaped the analysis per case study. Figure 5.1.3 shows a scatterplot of mean empirical valuations versus theoretical option values (line EV), a line representing theoretically correct valuations (the "45 degree" line OV(T)), the regression line of the empirical valuations regressed on the theoretical option values, and the upper and lower bounds of a 95% confidence interval around the regression line.

Figure 5.1.3

Scatterplot of empirical valuations versus theoretical option values for the A-sequence-case studies



Lines EV and OV(T) in the figure show the over- and undervaluations already discussed (cases A2, A3, and A5 are overvalued, and A6 and A7 are undervalued). Moreover, the figure indicates that most of the trend in the A-sequence valuations is fairly close to the theoretical line.

In order to verify this more formally, we conducted a regression analysis to predict the empirical valuations from the theoretical option values. The regression equation is:

y = 1.8 + 0.7x

where y is empirical valuation and x is theoretical option value.

Regression analysis produces a good fit ($R^2 = 0.80$, F = 0.007). In order to test whether the regression line, y = 1.8 + 0.7x, is significantly different from the theoretical line, y = 0 + 1 x, we calculate the 95% upper and lower confidence bounds for the mean of y given x applying the usual formula (see e.g. Gujarati, 1992):

$$y = b_0 + b_1 x \pm t(\tfrac{\alpha}{2}{}_1, d.f.)\sigma \sqrt{\frac{1}{n} + \frac{(x-\bar{x})^2}{\Sigma x_i^2}} \quad (5.1)$$

and arrive at the parameterised formula:

$$y = 1.8 + 0.7x \pm t(0.95, n\text{-}2)\ 2.53 \sqrt{\frac{1}{n} + \frac{(x-8.2)^2}{368}} \quad (5.2)$$

The theoretical option value line lies inside the 95% confidence interval around the empirical valuations for the first four case studies, and only slightly above the upper 95% confidence band for the last three case studies.

Since the regression showed such a good fit to the mean empirical valuations, this can be interpreted such that the empirical regression line is not significantly different from the theoretical regression line.

Summarising the results from the regression analysis, we can conclude that while the empirical valuations of the A-sequence- case studies were individually different from the theoretical option values, as a whole, the trend of the empirical valuations differed only insignificantly from the theoretical option values.

B-sequence of case studies

We next consider the effect of varying the volatility of the expected PV of the follow-up project's cash flows (the asset's volatility). This factor is varied in the sequence of case studies B1 to B5 ("the B-sequence- case studies") while the expected PV of the follow-up project's cash flows is held constant at £10m, i.e. at the level of the "base case", out-of-the money option of case study A3. Since case study A3's volatility lies between the volatilities of B2 and B3, A3 can be included in the "B-sequence of case studies".

Table 5.1.3, for the B-sequence case studies, contains the sample size, the volatility of the PV, the NPV, the theoretical option value, the mean empirical valuation, the mean discrepancy between empirical valuation and theoretical option value, the relative misvaluation, and the results of the t-test for the significance of the mean discrepancy.

Table 5.1.3

Valuations for B-sequence-case studies (Mean empirical valuations by the complete sample of the respondents to these case studies)

	B1	B2	A3	B3	B4	B5
Sample size	17	12	20	16	17	17
Volatility	0.17	0.32	0.45	0.58	0.7	0.81
NPV	0	0	0	0	0	0
Theoretical option value	1.2	2.2	3	3.8	4.6	5.2
Empirical valuation	3.2	6.5	4	4.8	8	4.1
Discrepancy	2	4.3	1	1	3.4	-1.1
D/OV(T) [%]	167	195	33	26	74	-21
Significance	s	s	s	s	s	s
H_0: EV≤ NPV						
H_1: EV ≥ OV	X	X	(X)	X	X	
NPV≤ EV≤ OV						X

Note: ns = not significant at 5% level of significance, s = significant at 5% level of significance

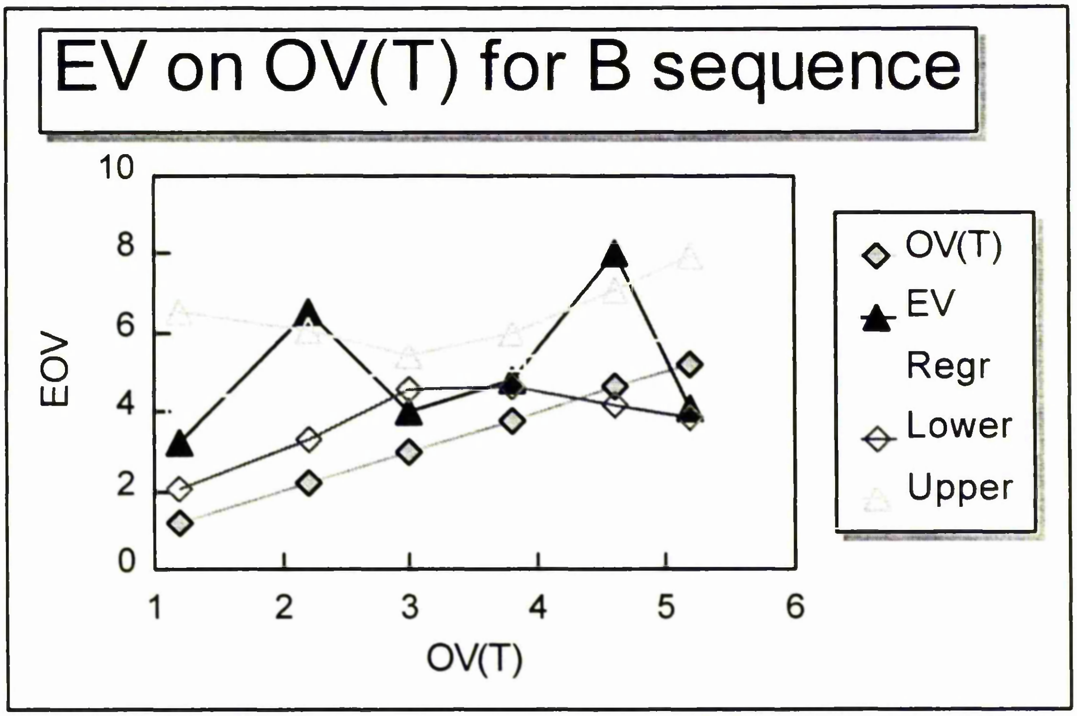
All options in the B-sequence are significantly overvalued (in real option-terms), except for that in case study B5, which is significantly undervalued in real option terms but overvalued in NPV-terms. As apparent from the last three rows, the alternative hypothesis is 4 times supported by the B-case study empirical valuations, and in one case the outcome of the hypothesis test is ambiguous. Based on the B-sequence, we therefore reject H_0 and accept H_1.

The pattern for the size of the overvaluation seems to be that while the mean level of the empirical valuation is "too high" for cases B1 to B4, the relative effect of the increase of the volatility over the B-sequence case studies only very approximately drives the change in respondents' valuations. Over cases B1 to B4, in contrast to the intuition behind the NPV rule, which recommends lower valuations for cases with higher volatility, progressively higher volatility does not lead the respondents to estimate progressively lower empirical values. However, their confidence in responding to volatility is erratic and seems to falter at the highest volatility used here, in case study B5, which is the only case study in the B-sequence that is undervalued.

Having accepted the alternative hypothesis that empirical valuations of the B series of cases are better described by real options theory, than by NPV theory, we now turn to check whether there are any patterns in the overall relationship between empirical valuations and theoretical option values of the B-sequence-case studies that escaped the analysis per case study so far conducted. Figure 5.1.4 shows a scatterplot of mean empirical valuations versus theoretical option values (line EV), a line representing theoretically correct valuations (by "45 degree" line OV(T)), the regression line of the empirical valuations versus the theoretical option values, and the upper and lower bounds of a 95% confidence interval around the regression line.

Figure 5.1.4

Scatterplot of empirical option valuations versus theoretical option values for the B-sequence-case studies



The falter of valuation is neither consistent not intuitively obvious. We therefore conducted a regression analysis of the empirical valuations on the theoretical option values. The regression equation is:

$$y = 3.8 + 0.4x \quad (5.3)$$

where y is empirical valuation and x is theoretical option value.

In order to test whether the regression line, y = 3.8 + 0.4 x, is significantly different from the theoretical line, y = 0 + 1 x, we calculate the 95% upper and lower confidence bands for the mean of y given x:

$$y = 3.8 + 0.4 \pm t\,(0.95, n\text{-}2)\; 1.55 \sqrt{\frac{1}{n} + \frac{(x-3.3)^2}{11.3}} \qquad (5.4)$$

For the B sequence- case studies, the data were very noisy. There is little correlation between theory and empirical valuation (linear regression produced an R^2 of just 11%). The theoretical option value line lies below the 95% confidence interval around the empirical valuations for the first four case studies, while for the last two case studies the theoretical line lies inside the 95% confidence interval (see Figure 5.1.4). Because the regression was not found significant (F = 0.52), strictly speaking no conclusions can be drawn from its slope. The data are compatible with a slope of zero and also with the slope of 1 required by real option theory.

Summarising the regression analysis of the B-sequence case studies, we can conclude that, as a whole, the empirical valuations were significantly higher than the theoretical option values for four out of six case studies. However, the empirical slope is not significantly different either from zero or from that required by theory. This hints that the managers in our sample may be able to respond to volatility, as described in the case studies using upper and lower bounds of the future PV. Moreover, it implies that respondents may vary their (biased) valuations very roughly in line with the prescriptions by real option theory.

C-sequence of case studies

Finally, we examine the effect of varying the time until the follow-up project can be undertaken (i.e., the time-to-maturity, or maturity of the option) in the C-sequence of case studies (C1 and C2 plus "base case" A3). Option parameter S is held constant at the level of the out-of-the money option in case study A3 (£10m). However, because we did not change the discounted values in which the case study information other than maturity was presented to the respondents the shorter/longer maturity implies slight decreases/increases in the undiscounted value of the exercise price and in the volatility. Because the C-sequence case studies were normally given to the respondents in a set of three case studies, containing one additional A- or B-sequence case study, up to four parameters were varied in a set containing C-sequence case studies. Option parameters T-t, X, and σ were varied between the C sequence case studies and option parameters T-t, X, σ and S were varied if the third case study was from the A sequence (compared to normally one parameter). Of course, the respondents might or might not notice all of these variations. Given the well-known limitations of the human information processing capability (cf. HIP literature in section 2.3.1), it appears that respondents might suffer from information overflow, resulting in e.g. confusion or overvaluation. This might hamper the meaningfulness of C-sequence results.

Note that a constant annual volatility leads to a higher spread in the possible expected PV's as the maturity is increased. For better interpretation of these case studies, in which the maturity differs from the standard maturity of 3 years (case studies C1 and C2), we re-express the variation in maturity as an equivalent variation in volatility, i.e. the volatility that would produce the same spread of values after 3 years as the original volatility does after 1 and 5 years.

Table 5.1.4 compares for the C-sequence case studies, the sample size, the time period until the follow-up investment can be taken (the maturity), the volatility, the corresponding 3-year volatility, the follow-up project's initial investment, the NPV, the theoretical option value, the mean empirical valuation, the discrepancy between mean empirical valuation and theoretical option value, the relative misvaluation, and the results of the t-test for the significance of the mean discrepancy.

Table 5.1.4

Valuations for C-sequence case studies (Mean empirical valuation by the complete sample of the respondents to these case studies)

	C1	A3	C2
Sample size	15	20	16
Maturity [years]	1	3	5
Volatility	0.26	0.45	0.59
Corr. 3-y. volatility	0.15	0.45	0.75
Initial investment	10.6	12	13.5
NPV	0	0	0
Theoretical option value	1	3	4.9
Empirical valuation	5.7	4	9.1
Discrepancy	4.7	1	4.2
D/OV(T)	470	33	86
Significance	s	s	s
H_0: EV≤ NPV			
H_1: EV ≥ OV	X	(X)	X
NPV≤ EV≤ OV			

Note: ns = not significant at 5% level of significance, s = significant at 5% level of significance.

Here, the respondents overvalue (in real options terms) all three case studies, particularly C1 and C2. Based on the C-sequence we therefore accept the alternative hypothesis. It did not seem useful to produce a scatterplot for the two case studies in the C-sequence. Because of the potentially limited meaningfulness of the C-sequence results, we will subsequently review the results both including and excluding the C-sequence results.

Overall, we reject the null hypothesis that the NPV-rule has superior descriptive power for the mean empirical valuations of the A B and C cases, and we accept the alternative hypothesis that real options theory has superior descriptive power for the mean empirical valuations. Furthermore, our results suggest that the respondents on average overvalue (in real options terms) individual case studies, but lose this bias in certain extreme situations (e.g.: very high (or low) PV, very high volatility, etc.). The average relative misvaluation (i.e. the average absolute amount of D/OV(T)) over all case studies is 107% (82% without the C-sequence), and the average relative overvaluation (i.e. the average D/OV(T) is 79% (47% without the C-sequence). It appears that those case studies with smaller theoretical option values (A1, A2, B1 and B2) are overvalued more, in each sequence, than case studies with larger theoretical option values. This is true to an extent that their relative misvaluations could be considered "outliers" (especially as the "relative misvaluation" measures of these case studies are extremely sensitive to misvaluations due to their small determinator). If we consider A- and B- sequences excluding the small option value case studies we arrive at what we could call "the most relevant case studies". For the most relevant case studies misvaluation is 32% and overvaluation is only 11%, which can be considered as an approximately correct valuation.

The patterns in the overall relationship between empirical valuations and theoretical option values for the A- and B- sequences indicate (taken together) three times significant undervaluation (A4-6) and three times significant overvaluation (B1-3). This suggests that overall, the case studies are approximately valued correctly (in real option terms), albeit with considerable noise. Note that the C-sequence results (twice overvaluation) might be less meaningful (as argued above) and need therefore not affect the validity of this conclusion. In chapter 7 we will provide an in-depth discussion of possible reasons for the patterns in the empirical valuations of the individual case studies.

The second research issue, concerning the spread in the valuation behaviour of the sample as a whole, will be analysed in section 5.2.1 of the next sub-chapter (5.2) on spread. In the next two sections, we will perform "diagnostic checks" on the grouping variables and on outliers respectively. The next research issue (Research issue 3, on the importance of the grouping variables for the level of the case study valuation responses) can then be examined in section 5.1.2.1.

5.1.1.2 Discussion and examination of the grouping variables

A condition for it to be valid to compare the mean empirical valuations across various case studies is that the responses to the different case studies should come from comparable subgroups of respondents. In this section we perform "diagnostic checks" of this prerequisite over which we had no control. Firstly, the professional characteristics which we will use to group the respondents (the grouping variables) are introduced. Secondly, we examine whether all the blocks of respondents have roughly the same average professional characteristics, at least as measured by this process.

The results of section 5.1.1.1 above could be due to differing response bias, since different subset's of respondents answered the various case studies within each set, for example case studies C1 and C2 were answered by a different subgroup of respondents from those who answered case study A3. Similarly, in the A-sequence, three separate subgroups of respondents are involved (the respondents to the set of case studies A1 - A3, the respondents to the set of case studies A4 - A6, and the respondents to the set of case studies containing A7 (A7 - B2)). Similarly, in the comparison across the responses to case studies B1 to B5, three separate subgroups of respondents are involved (the respondents to the set of case studies containing B1 and B2, and the respondents to the set of case studies containing B3 and B5, and the respondents to A3).

We first examine the split of the total sample into subgroups of respondents, our "grouping variables" which had been introduced in section 4.7. We distinguish between grouping variables that reflect a respondent's business environment (Sector and Industry), that reflect a respondent's professional experience ((Business), Experience, Position, Function, Level and Involvement), and that reflect a respondent's educational background (Qualification and Business Education).

Which grouping variables to collect was decided upon before the data collection began. (The division of respondents into subgroups using the grouping variables uses information categories defined prior to the respondents' actual responses). Therefore, we can say that the resulting subgroups are defined "ex ante" by the grouping variables.

It must be noted that in the present research design, the researcher had little or no control over how many respondents had a particular level of the grouping variable, for most of the grouping variables. However, for a few of the grouping variables it was possible to collect lower order ordinal or continuous data, and then select an appropriate cut off level of the variable. An attempt was made to define a cut-off level for each grouping variable such that the respondents fell into subgroups of approximately equal size on that variable (e.g. the median). This was in order to maximise the chance of statistically significant comparisons.

This was possible for the grouping variables Experience and Involvement. Raw data on the grouping variable Involvement were collected in the questionnaire using five-point Likert scales. In the case of Experience, the number of years y, a respondent had worked in a business environment, was captured in four intervals ($y<7$, $7<y<15$, $15<y<22.5$, and $y>22.5$).

From the received answers, a level that would split the respondents approximately into two equal halves was determined (the approximate median). Using this level as the cut off point, responses were then recoded into a subgroup with a low level and a subgroup with a high level of either Experience and similarly for Involvement.

Therefore, for the grouping variables Experience and Involvement, the two subgroups are defined as those respondents with a low level in the grouping variable, and those respondents with a high level in the grouping variable.

Limited control exists for creating alternative subgroups within the grouping variable "Industry". In the field work phase, after access had first been achieved to a certain company, efforts were made to obtain an appropriate sample size for the company's industry. This was achieved by, if necessary, by seeking access to more managers in the same company or by contacting more companies in the same industry. A division according to the grouping variable Sector (capital goods Sector vs.Consumer-goods Sector) happened to divide the sample into two almost equal halves.

No researcher control exists for creating subgroups for the variables Business Education (Educbus), Function, Level, Position, and Qualification, since these are already collected as binary variables.

There was of course no means of controlling the level of correlation in the sample between the various grouping variables. This is in some cases an empirical fact for the industry concerned (e.g. more senior staff may have had longer formal education). Another potential reason for correlation is the redundancy among some of the grouping variables, that are either empirically or theoretically interrelated in what they measure.

An important issue concerning the grouping variables is whether or not a near-random and homogeneous spread of the grouping variables has been achieved over the entire sample and over each block of respondents and case studies.

Factor analysis of grouping variables

The grouping variables themselves were therefore factor-analysed in order to check for redundancies among the variables, and to ensure that meaningful variation was achieved over all the variables. The results of the factor analysis are given in table 5.1.6. The column labelled "Pct of Var" indicates the percentage of variance each individual factor explains. The column "Cum Pct" contains accumulated figures of the previous column.

Table 5.1.5

Results of principal components analysis of the 9 grouping variables

Factor	Eigenvalue	Pct of Var	Cum Pct
1	2.2	24.5	24.5
2	1.89	21	45.5
3	1.17	13	58.5
4	1.04	11.5	70
5	0.8	8.9	78.8
6	0.68	7.6	86.4
7	0.66	7.4	93.8
8	0.47	5.2	99.1
9	0.08	0.9	100

In factor analysis, the factors with the highest eigenvalues explain the highest percentage of variance (column "Pct of var" in the table). Three factors have eigenvalues greater than one. Together, they account for only 58.5% of the variance (column "Cum Pct" in the table). To cover 90% of the variance, seven factors are needed and to cover 94% of the variance, eight factors are needed. This suggests that there are seven to eight genuinely independent factors underlying the nine personal characteristics or grouping variables. Given the fact that grouping variables Industry and Sector overlap because of their conceptual interrelatedness as explained above (i.e. the grouping variable Sector summarises the grouping variable Industry), we can conclude that virtually all of the other grouping variables are independent.

These findings indicate that there is little redundancy in the grouping variables i.e. the same levels of different variables do not systematically occur together. They also suggest that the sample shows a large variety of combinations of the levels of the grouping variables, covering most of the possible combinations, although perhaps at rather different frequencies.

Comparison of the personal characteristics of subgroups of respondents who decided on different case studies

As explained at the beginning of this section, similarity in professional characteristics between subgroups of respondents who responded to different sets of case studies is a prerequisite for comparing decisions across sets of case studies.

We can now compare the professional characteristics of the subgroups of respondents who responded to different sets of case studies. For each grouping variable $j = 1,...,9$, we compared the responses R in the five blocks $i = 1,...,5$:

R_{1j} with R_{2j} with R_{3j} with R_{4j} with R_{5j}.

This will be referred to as a "demographic" comparison of the subgroups of respondents. The key question is whether the various subgroups of respondents who answered various subsets of case studies had similar professional characteristics (in terms of the grouping variables used here).

Table 5.1.6 contains in its first row the average values of the grouping variables across the entire sample of respondents. Rows labelled 1 to 5 contain the average values of the grouping variables for a certain subgroup of respondents who responded to the same set of case studies (A1 - A3, A4 - A6, A7 - B2, B3 - B5, C1 - C2).

In the last two rows of the table, the results from a non-parametric Kruskal-Wallis One-Way-ANOVA are given. These indicate the statistical significance of the differences in the average values of the professional characteristics between the five subgroups.

Table 5.1.6

Demographic comparison of the subgroups of respondents who responded to different sets of case studies

Set	Educbu	Experi	Functio	Industr	Involve	Level	Positio	Qualifi	Sector
Overall/Avg.	0.53	0.51	0.46	3.11	0.55	0.46	0.28	0.85	1.45
1	0.81	0.4	0.44	3	0.64	0.44	0.25	0.81	1.44
2	0.21	0.57	0.36	2.93	0.31	0.36	0.31	0.77	1.43
3	0.5	0.5	0.56	2.88	0.5	0.5	0.25	0.93	1.37
4	0.5	0.5	0.33	3.06	0.57	0.43	0.27	0.92	1.44
5	0.5	0.57	0.43	3.2	0.73	0.47	0.13	0.8	1.47
Signif level	0.09	0.93	0.83	0.97	0.37	0.97	0.95	0.92	1
Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns

Note: sd = standard deviation, ns = not significant at 5% level of significance,
s = significant at 5% level of significance

As can be seen from the last row of the table, the average values of the professional characteristics of the five subgroups are not significantly different at 5%, though "Business Education" comes fairly close to significance. Therefore, it appears that differences in mean valuation responses between blocks of cases are not due to sampling bias in the professional characteristics of different subsamples of respondents, at least as measured by the present grouping variables.

5.1.1.3 Discussion of outliers

In this section we perform another "diagnostic check" concerning outliers. In statistical tests, in order to avoid misleading results, values that are very different from the majority of values deserve special attention. Although it is generally best to exclude cases containing outliers from the sample it should also be checked whether they show interesting patterns in their own right.

In the present study, outliers are defined as empirical case study valuations more than 1.5 box-lengths from the 25th/75th percentile of all empirical valuations of a particular case study, where the box-length is determined by the middle fifty percent of the sample.

Using this criterion, 17 outliers, which occur in the case study valuations made by 13 respondents, were found (outliers are listed in Appendix 5.2).

In this section, we perform a demographic analysis of those respondents whose decisions on one or more case studies generated outliers. This aims to detect whether this subgroup of respondents differs systematically from the subgroup of respondents whose responses did not include outliers. If so, it might be possible to identify certain characteristics that influence respondents towards generating outliers.

In table 5.17, we show the mean values and standard deviations of the professional characteristics both of the respondents who did not generate outliers and the respondents who did generate outliers. We also show the significance levels from a non-parametric Mann-Whitney test of the differences between the means. The mean values in the first column of the table, for example, mean that among the respondents whose case study valuations did not include outliers, 51% of the respondents have a degree in a business-related subject. In the subgroup of respondents whose case study valuations included outliers, 60% of the respondents have a degree in a business-related subject. The results of the significance test displayed in the last two rows of the table indicate, however, that this difference is not statistically significant.

Table 5.1.7

Demographic analysis of the subgroup of respondents whose decisions on one or more case studies represent outliers

		Educb	Experi	Functi	Indust	Involv	Level	Positi	Qualif	Sector
Responses free of	Mean	0.51	0.51	0.43	3.01	0.58	0.46	0.22	0.86	1.45
outliers	Sd	0.5	0.5	0.5	1.28	0.5	0.5	0.42	0.35	0.5
Responses containing	Mean	0.6	0.54	0.62	3.23	0.38	0.46	0.54	0.8	1.46
outliers	Sd	0.52	0.52	0.51	1.48	0.51	0.52	0.52	0.42	0.52
2-tailed P		0.62	0.84	0.23	0.7	0.2	0.99	0.02	0.63	0.94
Significance		ns	ns	ns	ns	ns	ns	s	ns	ns

Note: sd = standard deviation, ns = not significant at 5% level of significance,
s = significant at 5% level of significance

The significance test shows that for all the grouping variables except "Position", the set of respondents whose decisions on one or more case studies included outliers does not differ significantly in personal characteristics from the remainder of the sample .

The significant result for "Position" means that the respondents who create outliers include significantly more directors than the sample as a whole.

In general, outliers should be excluded from statistical tests whenever possible because they add noise. In the present study, the observed outliers arise mainly in the valuation responses to the research instruments that were administered by post. This hints that misunderstandings by the respondents when reading the case studies may have contributed to the outliers, but postal responses were in any case a majority of responses.

The high demographic similarity of the subgroups with or without outliers, and the possibility that the outliers are due to misunderstandings of the questionnaire, are reasons to exclude the outliers from the statistical analysis. Consequently, further statistical analysis will focus on the sample excluding outliers.

5.1.2 Comparison of the means of the empirical case study valuations by different subgroups of respondents

5.1.2.1 Identification of important grouping variables (Research issue 3)

In this section we will examine research issue 3 (as defined in Table 4.8), the grouping variables' importance for splitting the sample into subgroups with contrasting valuation-levels. Both parametric tests (sign test and non-parametric correlation analysis, in section 5.1.2.1a) and non parametric tests (multiple linear regression analysis and One-Way ANOVA, in section 5.1.2.1b) are first performed and then summarised in order to identify important grouping variables. At the end of section 5.1.2.1.b, the empirical ranking of the grouping variables obtained in this way is then compared with the null and alternative hypotheses on the ranking as set up in Chapter 4. Finally, in section 5.1.2.1c, we additionally test for potential interreactions between the grouping variables in their effect on the level of the empirical case study valuation.

5.1.2.1a Distribution-free scans for important grouping variables

The non-parametric tests performed in this section are the sign test and non-parametric correlation analysis.

The Sign Test

First of all, the sign test was used to check for differences between mean empirical valuations of each case study for the subgroups of respondents that we coded "high" or "low" on a particular grouping variable. This sign test is a broad non-parametric scan for important grouping variables. It must be noted that it was not possible to include the grouping variable "Industry" (5 levels) in the sign test, as the sign test is based on comparing dichotomous responses.

For each of the eight dichotomous grouping variables in turn, we compare mean empirical case study valuations between the subgroups of respondents who were coded either "high" or "low" respectively on that grouping variable. The null hypothesis is that the case study valuation responses of both groups have identical (unknown) distributions. The event "mean empirical valuation by the "high-level" subgroup is greater than mean empirical valuation by the of "low-level" subgroup is assumed to be binomially distributed, and is counted. In the first row of table 5.1.8, this score is compared with the total number of comparisons made. For example, the first cell entry "9" means that respondents who have a degree in a business-related subject give a higher mean valuation, to 9 out of the 14 case studies, than respondents who have no business-related degree. This comparison is selected to a binomial test of the hypothesis that the two subgroups have an equal probability of generating high valuations.

We assume the null hypothesis that the event "mean empirical valuation of the "high-level" subgroup is greater than the mean empirical valuation of the "low-level" subgroup" occurs exactly half of the time, i.e. that this grouping variable has no effect on empirical responses. A grouping variable is considered significant across the 14 case studies if the Bernoulli probability, $P(X \mid n, p)$, obtained from the binomial formula, is .05 or less. The observed scores are tested against this null hypothesis using binomial probabilities $P(X \mid n, p)$. The number of the described event occurring is taken as the number of successes X, the number of case studies (14) is taken as the number of observations n, and the overall significance level (5%) is taken as the probability of success p. The results are given in the row labelled "Significance". For example, the first cell of the first row means that although respondents who have a high level of Business Education give a high mean valuation to 9 out of the 14 case studies, this excess of high valuations is not significant (i.e. $P(9 \mid 14, 0.05) > 0.05$).

Table 5.1.8

Results of sign test of mean case study valuations by subgroups of respondents

	Educbu	Experie	Functio	Involve	Level	Position	Qualific	Sector
Mean(1) > Mean(0)	9	11	6	6	6	10	8	11
Signifi-cance	ns	s	ns	ns	ns	ns	ns	s

Note: (1) subgroup with high level in grouping variable, (0) subgroup with low level in grouping variable ns = not significant at 5% level of significance, s = significant at 5% level of significance

Table 5.1.8 suggests that grouping variables Sector and Experience produce significant effects on the mean empirical case study valuations. This implies that respondents working in the consumer-related Sector and respondents with a high level of Experience tend to value the case studies higher than respondents working in the capital goods Sector and respondents with a low level of Experience.

Non-parametric correlation analysis of grouping variable vs. empirical case study valuations

A different non-parametric approach to scanning for grouping variables that affect the case study valuation responses is to analyse the correlations between the case study valuation responses and the grouping variables.

For the present data, the responses to the case studies are measured at an interval level of measurement, and the grouping variables are measured at an ordinal level of measurement.

An appropriate non-parametric measure of the relationship between these variables is therefore Spearman's rank correlation coefficient.

We found that some of the grouping variables are correlated with decisions on more than one case study, but some of these correlations were positive and some negative. It seemed possible to interpret the observed correlations in two ways.

One possible assumption is that if grouping variables have an effect on empirical case study valuations, a given grouping variable should influence all case studies in the same direction (e.g. overvaluation). On this assumption, only the excess of positive over negative correlations would be useful for identifying a grouping variable's net mean influence over the empirical case study valuations. This assumption is supported by the fact that when the case studies were constructed, an attempt was made to create different "stories" around an identical underlying option theory structure.

On the other hand, potential interactions between the grouping variables could lead to the same grouping variable influencing empirical valuations in different ways depending on what other grouping variables (personal characteristics) also applied. Moreover, it is theoretically possible that a certain personal characteristic only has an effect in the presence of certain levels of the other parameters that underlie the case studies (e.g., a characteristic causes negative bias at high levels of volatility, and positive bias at low levels of volatility).

Therefore, the alternative assumption is that grouping variables may influence the empirical valuations of one case study in one direction and the valuation of another case study in another direction. We follow this second view, and count all the significant correlations between a grouping variable and empirical case study valuations, regardless of their sign.

In table 5.1.9, the row labelled "N" contains the number of correlations significant at 5% between the grouping variable named in the column and any of the empirical case study valuations. The row labelled "n" shows the number of correlations significant at 10%.

As before, the significance of a grouping variable across all 14 case studies is tested using a binomial test. A grouping variable is significant across the 14 case studies if the Bernoulli probability, $P(X \mid n, p)$, is .05 or less. The number of correlations individually significant is taken as the number of successes X, the number of case studies (14) is taken as the number of observations n, and the overall significance level (5%) is taken as the probability of success p to compute the binomial probabilities $P(X \mid n, p)$. The results from this significance test are given in the row labelled "Signif".

Table 5.1.9

Results of correlation analysis of empirical case study valuations vs. grouping variables

	Educbu	Experie	Functio	Industry	Involve	Level	Position	Qualific	Sector
N	1	2	-	4	-	1	1	1	3
n	2	2	2	4	-	4	1	2	4
Signif.	ns	ns	ns	S	ns	s	ns	ns	S

Note: ns = not significant at 10% level of significance, S = significant at 5% level of significance, s = significant at 10% level of significance.

To judge from these data, the following grouping variables are influential in the empirical case study valuations: Sector, Industry, and, more doubtfully, Level. As we have noted, Sector and Industry are correlated, and they measure similar constructs.

5.1.2.1b Parametric tests of differences between subgroups' mean valuations.

Assumptions needed in order to apply parametric tests.

The parametric tests we will perform in this section are multiple linear regression analysis and One-Way ANOVA. Parametric tests require that the samples are obtained from normally distributed populations having the same variance. Before applying parametric tests to the subgroups formed by the grouping variables, it is therefore necessary to check if the values such as "discrepancy" for the various subgroups are all normally distributed, and if various subgroups have the same variance.

Normality of the subgroups' case study valuations

First, Kolmogorov-Smirnov tests of normality with a Lillifors significance level were performed for all subgroups. The results of the Kolmogorov-Smirnov test of normality are summarised in table 5.1.10. In order to test for overall normality of the case study valuations by subgroups of respondents, as defined by the grouping variables, we count the number of case studies for which a certain subgroup's valuations are significantly non-normal. The column labelled "N" and "n" show the number of occurrences of non-normality that are significant at levels of significance of 5% and 10% respectively. If there were too few responses by a certain subgroup to a certain case study, the Lillifors significance level could not be calculated. Such cases are marked with a dash in the table. The column labelled "Siz" contains for each subgroup the number of case studies for which the Kolmogorov-Smirnov test produced Lillifors significance levels. The results of a binomial test computed as before (see the beginning of section 5.1.1.1 and section 5.1.2.1.a) are given in the column labelled "Sig".

Table 5.1.10

Test of normality of empirical case study valuations

		A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2	N	n	Siz	Sig
Ed	0	-	-	-							x					0	1	11	ns
	1		x				-									0	1	13	ns
Ex	0															0	0	14	ns
	1													x		0	1	14	ns
Fu	0							x								0	1	14	ns
	1		x							X						1	2	14	ns
Ind	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	ns
	2	-	X							-						1	1	12	ns
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	ns
	4		-			-		-	-	-	-	-		-	-	0	0	5	ns
	5	-					-	-	-	-	-	-	-	-	-	0	4	11	ns
Inv	0															0	0	14	ns
	1						-			x						0	1	13	ns
Le	0	X											X			2	2	14	ns
	1															0	0	14	ns
Pos	0		X							X	x		x			2	4	13	s
	1	X						-	-	-	-	-	-	-	-	1	1	6	ns
Qu	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	ns
	1									x					-	0	1	13	ns
Sec	1		X												-	1	1	14	ns
	2	X								x					-	1	2	14	ns

Note: X = significantly non-normal at 5% , x = significantly non-normal at 10% , N = number of significantly (5%) non-normal distributions , n = number of significantly (10%) non-normal distributions, ns = not significant at 5% level of significance, s = significant at 10%

The results from the rows imply that only the subgroup of respondents with a low level in grouping variable Position generated a significantly non-normal distribution of valuations.

Equality of Variance of Subgroups' Case Study Valuations

We also tested for equality of variance of the mean case study valuations between subgroups of respondents as defined by the dichotomous grouping variables. We used a Levene test of equality of variance. We observed both cases where the standard deviation of the mean case study valuation by the "high-level" subgroup is at 5% or 10% significantly smaller than the standard deviation of the mean case study valuation by the "high-level" subgroup, and cases where the standard deviation of the mean case study valuation by the "high-level" subgroup is at 5% or 10% significantly larger than the standard deviation of the mean response by the "low level" subgroup. At this point it is important to note that it is the overall number of significant positive or negative inequalities of variance, i.e. the sum of, significantly positive and negative inequalities of variance, that is relevant for the overall equality of variance. This is because the objective here is not to examine the direction of inequalities of variance but only to check how many inequalities of variance occur between the subgroups defined by each grouping variable.

In table 5.1.11 case study/grouping variable combinations with variances unequal at 5% significance level are marked with a large cross, those unequal at a 10% significance level are marked with a small cross. Blanks in the table indicate that for the particular case study/grouping variable combination, there are no significant differences between the variances.

In order to test for overall equality of variance for subgroups of respondents as defined by the dichotomous grouping variables, we apply the same binomial test as before.

First, we count the occurrences of significant inequality of variance in each row. The column labelled "N" shows the number inequalities of variance significant at 5% whereas the column labelled "n" shows the number of inequalities of variance significant at 10%. The column labelled "Size" contains for each grouping variable the number of case studies the Levene test produces results for. This number is used as the number of observations in the binomial formula. The results of the binomial test are given in the column labelled "Sign".

Table 5.1.11

Test of equality of variance of empirical case study valuations by subgroups

	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2	N	n	Size	Sign
Ed	x				X					x					1	3	11	ns
Ex	x	X						x							1	3	14	ns
Fu	x	x						x				x			0	4	14	s
Inv		x		X	X									X	3	4	14	S
Lev									x						0	1	14	ns
Pos			X												1	1	10	ns
Qu															0	0	6	ns
Sec			X					X							2	2	14	ns

Note: X: 5% significance, x: 10% significance, N = net number of 5%-significant unequal variances, n = net number of 10%-significant unequal variances, ns = not significant at 5% level of significance.

Table 5.1.11 suggests that the act of classifying the respondents into subgroups, as defined by the grouping variables, only leads to significant differences in variance between the subgroups as defined by grouping variables Function (10%) and Involvement (5%). Since the variances for only one out of eight grouping variables are significantly unequal at 5%

(and another at 10%), the assumption of equality of variance does not seem to be too strongly violated.

The failures to reject normality and equality of variances for the subsamples make it meaningful to apply parametric tests, such as the t-test and ANOVA, in order to examine whether the mean empirical valuations of particular case studies differ between subgroups of respondents.

Multiple Linear Regression Analysis

Before embarking on ANOVA, we carried out a multiple linear regression analysis (using stepwise selection) of empirical case study valuations versus grouping variables. This was a general parametric scan for important grouping variables. The empirical valuations of the each of the case studies (the dependent variables) were estimated using the grouping variables as the independent variables. Significant Betas for each grouping variable were counted across all 14 regressions.

Significant coefficients (Betas) are listed and counted in table 5.1.12. The row labelled "n" gives the number of coefficients significant at 10%.

Table 5.1.12

Results of multiple regression analysis of empirical case study valuation responses vs. grouping variables

	Educbu	Experie	Functio	Industry	Involve	Level	Position	Qualific	Sector
		A2: pos B1: pos						A1: neg	
n		2						1	

Note: pos/neg = positive/negative correlation, significant at 10% level of significance

The most important grouping variables, as identified by multiple linear regression analysis, are Experience (two significant correlations) and Qualification (one significant correlation).

One-Way ANOVA of empirical case study valuations by grouping variables

A parametric test more specific than multiple regression analysis is One-Way Analysis of variance (One-Way ANOVA). In order to scan for important grouping variables, a One-Way ANOVA of empirical case study valuations by grouping variables is performed.

The results of the One-Way ANOVA of empirical case study valuations by grouping variables are summarised in table 5.1.13.

A large cross in the table shows that for the row (grouping variable) and column (case study) combination, the mean valuations by the two subgroups created by the given grouping variable differ at 5% significance. For differences in the empirical valuations significant at 10%, a small cross is marked. In the column labelled "N", the number of occurrences of significant differences at 5% for each row is displayed. In the column labelled "n", the number of occurrences of significant differences at 10% for each row is displayed. The column labelled "Sign" gives the overall significance of the results for a grouping variable, as before derived using a binomial test.

Table 5.1.13

Results of One-Way ANOVA of empirical case study valuations by grouping variables

	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2	N	n	Sign
Edb					x									X	1	2	ns
Exp		X						X							2	2	ns
Fun				x											0	1	ns
Ind			X	x								X		X	3	4	S
Inv															0	0	ns
Lev				x	X						x				1	3	ns
Pos									X						1	1	ns
Qua	x									X					1	2	ns
Sec			X									X		X	3	3	S

Note: X = difference is significant at 5%, x = difference is significant at 10%, N = number of significant values at 5%, n = number of significant values at 10%, ns = not significant at 5% level of significance, S = significant at 5% level of significance.

The most important grouping variables as identified by One-Way ANOVA are the overlapping grouping variables Industry and Sector (both significant at 5%). In addition, the grouping variable "Level" is very nearly significant. A Bonferroni test of the multi-level variable Industry shows only 5%-significant differences between industries 2 and 4, 3 and 4, and 3 and 5 for case study B5.

Summary and hypotheses test

The following contains a summary of the most important grouping variables, as identified by the various tests performed in this section. (Sign test, non-parametric correlation analysis, multiple linear regression analysis and One-Way ANOVA). In order to form an overall empirical ranking of the importance of the grouping variables across all tests, the results (rankings of grouping variables) of all the above tests are combined. This overall empirical ranking must be interpreted with great caution, as the individual tests results are presumably not fully independent. However, this fact should serve simply to amplify any shared result of the individual tests. We do not in fact apply significance tests to the combined results (the overall empirical ranking) of individual tests.

For each test performed, weights are assigned to the grouping variables according to how important a particular grouping variable was in a particular test. The most important grouping variable according to a particular test is assigned the highest weight, the second most important grouping variable the second highest weight, and so on. As no more than four significant grouping variables had been identified by any one test, weights range from 4 = most important significant grouping variable to 1 = least important grouping variable. These figures are given in the rows two to five in table 5.1.14. In order to obtain a measure of a grouping variable's overall importance, these weights are summed up in the row labelled "Sum of weights", from which the (overall) "Empirical ranking" is concluded. This overall empirical ranking is used to test the null and alternative hypotheses on research issue 3 (as stated in the two columns entitled "RI 3" of Table 4.10), which are restated in columns H_0 and H_1. The last column indicates which of the hypothesised rankings, for each grouping variable, is closer to the empirical ranking.

Table 5.1.14

Summary of the most important grouping variables

	Educbu	Experi	Functio	Industr	Involve	Level	Positio	Qualifi	Sector
Sign test	2	4					3	1	4
Correlation				4		2			3
Regression		4						3	
1-W-ANOVA				4					3
Sum of weights	2	8		8,		2	3	4	10
Emp. ranking	5	2	6	2	6	5	4	3	1
H_0	2	1	3	n/a	3	2	1	2	1
H_1	3	1	5	n/a	4	3	1	3	2

As the last column of the table shows, the alternative hypothesis (which represent the real options perspective) comes closer to the empirical ranking more often (4 times vs. 2 times) than the null hypothesis (which was derived under an NPV-perspective). A comparison of the ranking of the alternative hypothesis with the empirical ranking shows that the grouping variables Sector, Experience and Qualification were correctly expected to be important and grouping variable Function was correctly expected to be unimportant, whereas our hypothesis and the ranking found empirically differ for Position which was wrongly assumed to be important. We will return to these findings on a more interpretative level in Chapter 7. The examination of research issue 4 (direction of grouping variables' influence on the level of the empirical case study valuations) will follow in section 5.1.2.2 after a short "diagnostic check" of interactions between the grouping variables in section 5.1.2.1c.

5.1.2.1.c Interactions between important grouping variables

Simple Factorial ANOVA of empirical case study valuations by grouping variables

In order to get a more precise picture of important grouping variables and particularly to examine interactions between them, Simple Factorial and Multivariate ANOVA were applied. We applied both tests for interaction effects only to those grouping variables that we had already found individually important in the previous parametric and non-parametric tests. We decided to focus on the dichotomous grouping variables, in order to limit the potential effects to second order interactions.

We selected the grouping variables Sector (which we had found significant at 5% in One-Way ANOVA, in the non-parametric sign test, and in correlation analysis), Experience (found significant at 5% in regression analysis and in the sign test) and Level (found significant at 5% in correlation analysis).

In Simple Factorial ANOVA, several independent (grouping) variables can be considered simultaneously. (One-Way ANOVA produces only a one-way analysis of variance for a list of dependent variables (responses to case studies A1 to C2) by a single factor (independent) variable (grouping variables)). In this way, interactions between the grouping variables can be detected.

The results of Simple Factorial ANOVA of empirical case study-valuations using the grouping variables Experience, Level and Sector are summarised in table 5.1.15.

In the first part of the table, under the heading "Effects of the individual grouping variables", it shows the effects on the empirical case study valuations of each of the three grouping variables individually which replicates the effect of one way ANOVA. The second part of the table, under the heading "First order interactions", contains all interactions between pairs of the two grouping variables, i.e. it shows the effects of pairs of grouping variables on the case study valuations. Finally, under the heading "Second order interactions", the table shows the interaction between all three grouping variables.

Where there is a difference significant at 5% between the empirical case study valuations (column) over the set of subgroups as defined in the left hand column, this is marked with a large cross in the table. Where differences significant at 10% occur, a small cross is indicated. Empty cells in the table mean that no statistically significant difference is found for this case (column) where respondents are split by this criterion (row). In the column "N", the number of occurrences of differences significant at 5% is summed for each grouping variable (row). In the column "n", the number of occurrences of differences significant at 10% is displayed for each grouping variable. At either level, significant interactions between grouping variables are added to the score for both variables involved in the interaction.

Table 5.1.15

Results of Simple Factorial ANOVA of empirical case study valuations by grouping variables Experience, Level and Sector

Summary			A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2
N	n	Effects of the individual grouping variables, per case study:														
1	4	Experien		X												
1	7	Level				x	X					x				x
3	3	Sector			X									X		X
		First order interactions between pairs of the grouping variables:														
		Exp/Lev				x						x	x			
		Exp/Sect														
		Lev/Sect														
		Second order interactions between all the grouping variables:														
		Exp/Lev/ Sect														

Note: X = difference is significant at 5%, x = difference is significant at 10%, N = number of significant differences at 5%, n = number of significant differences at 10%; higher order significant effects are taken into account by adding to the number of the involved variables.

The Simple Factorial ANOVA of empirical case study valuations by individual grouping variables suggest that Sector (3 times significant at 5%) is the most important grouping variable, followed by Level (once significant at 5% and 7 times significant at 10%), followed by Experience (once significant at 5% and 4 times significant at 10%). The only interaction effects are weak joint effects of Experience and Level, for cases A4, B3 and B4.

Multivariate ANOVA of empirical case study valuations by grouping variables

Multivariate analysis of variance (and covariance), abbreviated as MANOVA, is an extension of univariate analysis of variance to the case of multiple dependent variables. The difference is that sets of means (or vectors of means) replace the individual means specified in univariate ANOVA. Application of the multivariate analysis of variance procedure is warranted by the fact that there are some significant correlations between the dependent variables.

The results of MANOVA of case study valuations by grouping variables Experience, Level and Sector are summarised in table 5.1.16. The three sectors of the table contain first the effects of each of the three grouping variables individually (similar to those for the simpler techniques), then the "first order" interactions between pairs of these grouping variables, and finally the "second order" interaction between all three variables.

The columns labelled A1 to C2 contain the results of the univariate F-tests. F-values significant at 5% are marked with a large cross, F-values significant at 10% are marked with a small cross. The two columns labelled "MV" are included where the results of the multivariate test of significance (Hotellings significance of F) suggest multivariate significance.

Table 5.1.16

Results of MANOVA of empirical case study valuations by grouping variables Experience, Level and Sector

	MV	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	MV	C1	C2
Effects of the individual grouping variables, per case study:																
Experien			x													
Level												x				
Sector				X									X	x		X
First order interactions between pairs of the grouping variables:																
Exp/Lev				x							x	x				
Exp/Sect				x												
Lev/Sect			X					-	-	-						
Second order interactions between all the grouping variables:																
Ex/Lev/Sec	x		x		-	-	-	-	-	-	-	-	-	-	-	-

Note: X = significant at 5%, x = significant at 10%.

MANOVA confirms the interaction of Experience and Level (three significant interactions at 10%) already identified by Simple Factorial ANOVA and additionally finds significant interactions between Experience and Sector (once significant at 10%) and between Level and Sector (once significant at 5%). MANOVA also suggests that there is a both multivariately and univariately significant interaction between all three grouping variables in one of the case studies (A2). Overall the grouping variable Experience seems to be more important in interaction with the other grouping variables than on its own.

Counting both the univariate significant effects of the individual grouping variables on their own (first part of the table) and the univariate significant interactions between the grouping variables (second and third part of the table) suggest that Sector is the most important grouping variable (four times significant at 5% and three times significant at 10%), followed by Level (once significant at 5% and twice significant at 10%) and Experience (five times significant at 10%).

We now summarise the tests discussed in this section. These have scanned for the importance of, and for relationships among, only a subset of the grouping variables that are suspected to be individually important on the basis of previous tests. Simple Factorial ANOVA and MANOVA were only applied to the grouping variables Experience, Level and Sector, which had shown signs of importance in various "free-standing" or univariate tests.

We assign weights to the three chosen grouping variables according to how important each was found in a particular test. Since we analyse only three suspected important grouping variables, weights range from 3 = most important grouping variable to 1 = least important grouping variable. These figures are given in the first and second rows of table 5.1.18. In order to obtain an overall measure of importance for each suspected grouping variable (column), these weights are added up. The sums are given in the row labelled "Total importance".

Table 5.1.17

Summary of tests of suspected important grouping variables

	Experience	Level	Sector
Simple Factorial ANOVA	1	2	3
MANOVA	2	2	3
Total importance	3	4	6

It appears from the table that grouping variable Sector is most important, followed by grouping variable Level followed by grouping variable Experience. Compared with the results from section 5.1.2.1.b, these results suggest that taking interactions into account, Level overtakes Experience in importance.

5.1.2.2 Direction of a grouping variables' influence on the empirical case study valuations (Research issue 4)

In this section we will examine research issue 4 (as defined in Table 4.8), the direction of the grouping variables' influence on the empirical case study valuations. We calculated, and performed a significance test (t-test) for the differences between the mean empirical case study valuation by the pairs of subgroups as defined by the dichotomous grouping variables. For convenience, in table 5.1.19, we give the discrepancies between the empirical decisions taken on the case studies and the decisions recommended by real options theory (for the entire sample and for subgroups of respondents), as introduced in section 5.1.1.1. A positive discrepancy means overvaluation (in real options terms) and a negative discrepancy means undervaluation in real option terms of the case study. Note that although in this section we use an option value-based measure (discrepancy), because we only consider the *differences* between the discrepancies, the results are the same as if we used the absolute empirical valuations. Therefore, our option value-based measure is equally valid for testing the NPV-based null-hypothesis that subgroups do not differ in their valuations.

The mean discrepancies for the case studies for the entire sample (from section 5.1.1.1) and for subgroups of respondents are summarised in table 5.1.18. The column "L" indicates a subgroups' level in the grouping variables. The shaded areas in the table mean that the differences between the respective means are significant at 5% (dark shade) or 10% (light shade), as identified by an independent-samples separate-variance t-test. The column "D" indicates the "predominant direction" of each grouping variable's influence on the empirical case study valuations. We derive this "predominant direction" by subtracting for each pair of subgroups with significantly different discrepancies the discrepancy value of the "low-level" subgroup from the discrepancy value of the "high-level" subgroup and indicating the predominant sign of these differences for any one grouping variable. Blanks in this column indicate that there is no clear direction of the influence.

Table 5.1.18

Empirical direction of grouping variables' influence on empirical valuations and comparison with hypotheses.

	L.	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2	D
Average		-0.1	1.2	1	-0.5	4.3	-3.3	-6.6	2	4.3	1	34	-1.1	4.7	4.2	
Educ bus	0	0.1	0.3	0.8	-1.2	2.5	-4.4	-8.1	2.4	4	0.8	3	-0.6	5.1	6.4	+
	1	-0.1	1.3	1	-0.8	6.3	-4.3	-6.1	1.6	4.6	1.4	4.2	-1.6	4.9	1.7	
Experience	0	-0.2	0.2	0.9	-1	4.5	-4.9	-6.8	0.7	4	1.3	3.4	-1.4	4.7	2.5	+
	1	0.1	2.4	1.1	-0.2	4.1	-3.8	-6.3	3.8	4.6	0.8	3.5	-0.8	4.3	4.8	
Function	0	-0.2	1.2	1	-1.8	4	-4.5	-8.3	3.4	4.5	1.6	3.6	-1	5	6.2	-
	1	0	1.3	1	0.8	4.6	-4.1	-5.6	1.2	4.1	0.2	3.5	-1.1	4.3	2.3	
Industry	1	-0.3	-0.7	1.3	-4.3	1.9	-6.2	-4.1	0.3	4.1	2.7	7.9	-22	15	0.1	
	2	0.2	1.8	-0.1	-0.8	4.1	-4.3	-9.6	2.1	4.5	1.5	3.2	0.5	4.4	1.7	
	3	-0.6	0.3	0.8	-1.3	5.4	-5.4	-7.4	1	3.6	0.7	5.9	1.3	6	1.3	
	4	-0.2	1.9	1.5	-1.5	1	-4.3	-6.7	3.5	3.6	-0.9	0.8	-3.1	4.8	7.6	
	5	0.3	1.1	1.5	2.4	7.2	-2.4	-1.2	2.6	5.8	2	4.2	-1.7	4.7	7.9	
Involve-ment	0	-0.3	1.5	1	-0.1	3.9	-4	-8	1.5	4.6	1.3	2.9	-1.8	5.2	6.2	
	1	0.1	0.9	0.8	-1.1	5.4	-4.7	-5	2.4	4	1.1	3.4	-0.7	4.4	2.9	
Level	0	-0.1	1.2	1.1	-1.7	2.5	-5.1	-8.1	2.4	4.2	1.8	4.8	-1.5	5.8	4.7	+
	1	-0.1	1.3	0.9	0.8	6.1	-3.2	-5.2	1.6	4.3	-0.2	1.8	-0.8	3.7	3.6	
Position	0	-0.2	1.1	0.9	-0.9	3.8	-4.4	-6.7	1.9	4	1.3	4.2	-1.3	4.9	3.6	
	1	-1	1.5	1.1	-1	4.9	-4.6	-6.1	2.1	5.8	0.8	1.9	0.1	3.8	6.4	
Qualifica-tion	0	0.9	0.8	1	-2.6	1.2	-6.9	-10.9	2.8	4.8	6.7	7.9	-2.7	3.7	4.9	+
	1	-0.2	1.2	0.9	-0.8	4.2	-3.8	-6.8	1.9	4.3	0.6	3.2	-1	5.1	3.4	
Sector	1	-0.2	1	0.5	-1.6	4.1	-4.8	-8	1.5	4.1	1.5	4.3	0.4	4.6	1.4	+
	2	0	1.4	1.5	0.5	4.5	-3.8	-4	3.1	4.5	0.5	2.5	-2.5	4.8	7.7	

Note: [dark shading] difference significant at 5%

[light shading] difference significant at 10%

+ : mean (1) > mean (0)

- : mean (1) < mean (0)

If we consider the entire sample of respondents, most but not all case studies appear overvalued as shown in the row "Average". Consequently, if a grouping variable has a positive influence on the empirical case study valuations (a plus in column "D" (Direction)), this "tends" to mean that the "high-level" subgroup is less rational in real option terms than the "low-level" subgroups (i.e. its mean valuation is farther away from the valuation given by real options theory than that of the "low-level" subgroup). We check this by counting for the significant discrepancies, the number of cases where the "high-level" subgroup is more rational (closer to zero) than the "low-level" subgroup. Results of this check are given in the row "R" (Rationality) of the "T-test" section in table 5.1.19. In row "D" of the t-test section, we again give the directions identified in column "D" in the table 5.1.18. The results indicate that a "positive direction" normally means less rationality and a "negative direction" more rationality, except for the grouping variables Level (and Position as the sign test below shows) ("positive direction" and equal rationality) and Qualification ("positive direction" and more rationality).

We now compare, and in case of missing results, complement, the t-test results with the sign test results of section 5.1.2.1. In the "Sign test" section of the table in row "D", we summarise the results on the direction of grouping variables' influence from the sign test (in section 5.1.2.1a, table 5.1.8). Here, the rationality of the valuation responses (given in row "R") is checked by the same routine as for the t-test but for all discrepancies. In the "Combination" section of the table, we combine both tests by using the sign-test results for grouping variables Position and Educbus for which the t-test did not produce results.

In the rows labelled H_0 and H_1 , we restate the null and alternative hypotheses (from the two columns entitled "RI 4" of Table 4.10). The last row contains the correct hypothesis where H_0 and H_1 differ.

Table 5.1.19

The direction of the grouping variables' influence on the mean empirical case study valuations

		Educbus	Exp	Func	Inv	Level	Pos	Qualific	Sector
T-test	D	+	+	-		+		+	+
	R	x	x	*		o		*	x
Sign test	D	+	+	-	-	-	+	+	+
	R	x	o	*	*	*	o	*	x
Combin-ation	D	+	+	-	-	+	+	+	+
	R	x	x	*	*	o	o	*	x
H_0		-	+	-	-	-	+	-	+
H_1		+	+	-	-	+	+	+	+

Note: +: positive influence, - : negative influence, *: (1) more rational, x: (1) less rational, o: (0) and (1) equally rational

From the last row of the table, concerning the direction of the grouping variables' influence on the empirical case study valuations, we accept the alternative hypothesis (the real option perspective) and reject the null hypothesis (the NPV-perspective). We will return to this finding in Chapter 7. After comparing the real-options based hypothesis on grouping variable Industry with the empirical data in the next paragraph, in the remainder of this sub-chapter, we will perform several "diagnostic checks" and compare the empirical findings of this sub-chapter with each other to check for unhypothesised effects.

The next research issue concerns the spread in the valuations by the entire sample (Research issue 2), which will be examined in the first section of the chapter 5.2.

The pairwise comparisons of discrepancies performed for the 8 dichotomous grouping variables are impossible for the grouping variable Industry which has five levels. In order to obtain some measure of, and compare, the extent of misvaluation (in real option terms) by the different industries, we add the (positive and negative) discrepancies across all case studies (from table 5.1.19) for each industry (in column "Sum of discrepancies" in table 5.1.20). We then rank the 5 industries according to their "option-rationality", i.e. in the opposite order to their sum of discrepancies. (In column "empirical ranking" in table 5.1.20). Finally, we give the hypothesised ranking (derived using real options considerations as given in Table 4.8) (in the column "Hypothesised ranking").

Table 5.1.20

The extent of "option-rationality" of the different industries

Coding	Industry	Sum of discrepancies	Relative misvaluation	Empirical ranking	Hypothetical ranking
	Average	13.1			
1	Oil	1.9	-	1	1
2	Aerospace	9.2	-	3	1
3	Telecom	11.6	-	4	3
4	Pharma	8	-	2	4
5	Brewing	34.7	+	5	2

Note: +: above average misvaluation, -: below average misvaluation.

It appears from the scores in the table that, in real option terms, the oil industry is clearly the most rational and that the brewing industry is the least rational, while the differences between the aerospace, telecommunications, and pharmaceuticals industries are small. As can be seen from table 5.1.18, two factors account for the exceptionally high misvaluation by the brewing industry. Case studies A6 and A7 are comparatively little undervalued, and case studies A4, A5, B2, and C2 are comparatively very strongly overvalued by respondents from this industry. A comparison of the empirical ranking with the hypothesised ranking shows that the high rationality of the oil and aerospace industries was expected, while that of the pharmaceuticals industry was not and that the hypothesis was wrong for the brewing industry (which was erroneously expected to be comparatively option-rational).

5.1.2.3 Complementary tests based on observed differences in mean valuations

In the tests described so far in this section, the grouping variables used to group the respondents into subgroups were determined by the researcher ex ante to the experiments, using theoretical considerations. These tests could be summarised as "theory-driven" tests. The professional characteristics were expected to be, and indeed turned out to be, able to generate significant differences when used to split the sample.

A contrasting approach is to divide the respondents into subgroups ex post, i.e. according to their response behaviour within the experiment. In this way, the groupings of the sample are chosen by the data themselves. The first statistical method used here is cluster analysis. Another way of allowing the data to speak for themselves without any prior data manipulation by the researcher is to look for potentially interesting patterns. This can be achieved by using factor analysis. One might in general expect a strong overlap between the ex ante and ex post analysis i.e. splitting by professional characteristics and checking for significant differences in valuation ought to reveal some of the same information as splitting by valuation and checking for significant differences in professional characteristics.

We first, in section 5.3.5, cluster analyse the data and then, in section 5.3.6, we factor analyse the data.

5.1.2.3a Ex post analysis to locate subgroups of respondents with similar valuations

Cluster analysis can be used to identify clusters of respondents who have similar response patterns. Once a cluster of valuations is identified, it is interesting to examine if there are any shared features in the professional characteristics of the respondents in the cluster. The cluster analysis of the respondents can only be carried out within the block of respondents who answered a similar set of case studies. It proved possible to identify two clusters in each of the five blocks of respondents (cf. dendrograms in Appendix 5.3).

It is meaningful to ask if these clusters differ demographically. In order to produce a demographic analysis, mean values of the professional characteristics of the respondents in each cluster are computed. We will test for the significance of the differences in the mean professional characteristics of the pairs of clusters. Because of the non-parametric nature of the professional characteristics data, a two-tailed Mann-Whitney test is used.

The cell entries in the first two rows of table 5.1.21 show the means of the grouping variables for each cluster. In the third row, the two-tailed P-values from the Mann-Whitney test for the differences between the two clusters in the first block, are indicated. The row labelled "Signific" indicates whether the respondents' professional characteristics differ significantly at 10% for the two clusters of responses in the first block. Results for blocks two to five are summarised in the table in the same way.

In the column labelled "N", we indicate, for each block, the number of grouping variables which are significantly different between the clusters. This is in order to detect any overall significant differences in the grouping variables between two clusters.

Additionally, in the row labelled "N", we indicate the number of blocks in which a particular grouping variable is significantly different between the clusters. This is to see if cluster analysis identifies any important grouping variables different from the important grouping variables identified in the previous tests.

Table 5.1.21

Demographic analysis of clusters of respondents

Block	Cluster	Educb	Experi	Functi	Indust	Involv	Level	Positi	Qualif	Sector	N
1	1	0.83	0.14	0.71	3.86	0.67	0.57	0.29	0.83	1.71	
	2	1	0.67	0.25	2.75	0.75	0.5	0.5	1	1.25	
	2-tailed P	0.41	0.12	0.16	0.15	0.8	0.83	0.5	0.41	0.16	
	Signific.	ns	ns	ns	ns	ns	ns	ns	ns	ns	0
2	1	0.17	0.71	0.57	3.57	0.14	0.57	0.5	1	1.57	
	2	0.25	0.5	0.5	2.75	0.33	0	0.25	0.5	1.5	
	2-tailed P	0.76	0.5	0.83	0.33	0.51	0.08	0.45	0.09	0.83	
	Signific.	ns	ns	ns	ns	ns	s	ns	s	ns	2
3	1	0	0.33	0	3	0.33	0.33	0	0.67	1.33	
	2	0.6	0.8	0.8	3.4	0.6	0.8	0.2	1	1.6	
	2-tailed P	0.11	0.22	0.04	0.54	0.49	0.22	0.44	0.25	0.49	
	Signific.	ns	ns	s	ns	ns	ns	ns	ns	ns	1
4	1	0.33	0.75	0.67	3.75	0.5	0.5	0.67	1	1.44	
	2	0.38	0.38	0.38	3.13	0.5	0.67	0.13	1	1.75	
	2-tailed P	0.9	0.24	0.41	0.47	1	0.62	0.09	1	0.24	
	Signific.	ns	ns	ns	ns	ns	ns	s	ns	ns	1
5	1	0.63	0.56	0.63	2.67	0.78	0.67	0.11	0.78	1.22	
	2	0.33	0.67	0.25	4.5	0.5	0.5	0.5	0.67	2	
	2-tailed P	0.41	0.75	0.24	0.03	0.34	0.58	0.14	0.71	0.01	
	Signific.	ns	ns	ns	s	ns	ns	ns	ns	s	2
N		0	0	1	1	0	1	1	1	1	

Note: ns = not significant at 10% level of significance, s = significant at 10% level of significance

In the column "N", the table shows that in blocks 3 and 4, according to the Mann-Whitney test, only one grouping variable is significantly different for the two clusters and that in block 1, no grouping variable is significantly different. These results suggest that, according to a binomial test, no pairs of clusters in blocks 1, 3 and 4 are overall significantly different.

In blocks 2 and 5, however, according to the Mann-Whitney test, two grouping variables are significantly different between the two clusters. This means that overall the clusters in both block 2 (which contains the responses to case studies A4 to A6) and block 5 (which contains the responses to case studies C1 and C2) differ demographically at a significance level in the binomial test of 5%. We apply the binomial test once more to the number of significant blocks (2 out of 5) and find this result overall significant even at 5%. Consequently, the clusters defined by the data themselves differ significantly (at 10%) in their professional characteristics. This result is reassuring and supports the validity of the previous analyses.

In the row "N", the table shows that grouping variables Function, Industry, Level, Position, Qualification, and Sector are all significant for one block of cases only, while grouping variables Business Education, Experience and Involvement are significant in none of the blocks. This means that, according to a binomial test, none of the grouping variables is significant over all five blocks. Consequently, although cluster analysis showed that the clusters differ significantly in their professional characteristics, no information on which grouping variables are important overall emerges from the cluster analysis. The findings of the previous sections on the important grouping variables remain therefore unchallenged.

We now proceed to factor analysis, another way of analysing the data "ex ante", i.e. without prior manipulation by the researcher.

5.1.2.3b Examination of blocks of valuation responses for potential patterns

In this section, in order to examine the blocks of valuation responses for potentially interesting patterns, factor analysis is applied to the matrix of correlation between the case study valuation responses. The null hypothesis is that all individuals have unrelated patterns of decisions, and hence all factors explain the same amount of variance from one individual to another in the overall pattern of decisions

Table 5.1.22 shows for each block of case studies/respondents the factor analysis of the case study valuation responses. The main cell entries in the table are the percentage of variance explained by any one factor. The significance of the differences between the empirical percentage splits and the null-hypothesis-percentages (i.e. equal percentages) according to a Bartlett's test of sphericity are given in the row labelled "Significance".

Table 5.1.22

Results of factor analysis of empirical case study valuations

Null hypothesis for blocks 1-4	Observed percentage splits for blocks				Null hypothesis for block 5	Split for block 5
	1	2	3	4		
	Case studies A1-A3	Case studies A4-A6	Case studies A7-B2	Case studies B3-B5		Case studies C1-C2
33	45.5	67.5	42.7	61	50	56.4
33	32.7	31.2	36.1	30.3	50	43.6
33	21.8	1.3	21.2	8.6		
100	100	100	100	100	100	100
Significance	ns	s	ns	s		ns
	accept H_0	reject H_0	accept H_0	reject H_0		accept H_0

Note: ns = not significant at 5% level of significance, s = significant at 5% level of significance

The percentage splits in block 2 (case studies A4-A6) and in block 4 (case studies B3-B5) differ significantly from the equal percentage splits of the null hypothesis. In blocks 2 and 4, a single factor explains most of the variation between respondents in the answers to the three case studies. This means that, in these blocks, respondents' answers to the three respective case studies vary mainly in one dimension, rather than the potential three. This is what would be required by real options theory, since in theory, only one parameter or dimension is being changed between the cases within each set (except for set 3 in which both the PV of the expected cash flows from the follow-on investment and the volatility of the PV differ between case studies A7 and B1and 2). The finding that 2 out of 5 blocks of valuation responses are significantly different from the null hypothesis means that the result from a binomial test over all 5 blocks is significant at 5%.

This hints that respondents' valuations within a set of cases are actually mainly influenced by a simple variable - possibly the parameter of the real options model that is being changed, and not so much influenced by random case to case noise such as might be generated by spurious qualitative differences between the texts of the case studies.

It is noteworthy that in factor analysis, just as in the preceding cluster analysis, the responses of block 4 are found to be significant. It appears that block 4 contains a particularly strongly marked pattern of responses.

In order to understand the findings from the factor analysis better, it is useful to take a look at the data across all answers in one block. For each of the three case studies in a block, three independent sequences of valuation responses (across all the relevant respondents) can be imagined. If one dominant factor is identified by factor analysis, these three sequences are approximately multiples of an implicit "super answer", which might or might not be the correct answer. This might imply that within this block of case studies/respondents, each individual respondent is consistently over or undervaluing (or valuing correctly) all the case studies in a similar way. Conversely, if there is no dominant factor, differences between the valuation responses to the 3 case studies may be due to random noise, and there is no overall bias unique to an individual respondent or case study.

We find that in block 1 (case studies A1-A3), block 3 (case studies A7-B2), and block 5 (case studies C1-C2), there is no significantly dominant factor. This hints that the main difference between the answers to the case studies in blocks 1, 3, and 5 is random noise. One might conclude that block 2 and block 4 are being judged more "efficiently" than block 1, 3 and 5.

There are possible explanations for the more noisy judgements in blocks 1, 3, and 5. One concerning block 1 is that case studies A1 and A2 have very small option values. These might not be correctly perceived by the respondents. Block 3 is the only block that contains case studies from two different sequences of case studies (A7 on the one hand and B1 and B2 on the other hand). This might make their judgements more random. Conversely, if the textual (non-quantitative) aspects of the case study introduce a bias between the A7 and B1 and B2 cases, this bias might have been expected to produce a single dominant factor, summarising the difference between the two textual presentations. This seems not to have happened. Finally, block 5 contains the only case studies (C1 and C2) where three variables change: The time to maturity is varied and this causes the overall volatility of the asset as well as the exercise price to change in line with it. This might be the reason for a less efficient judgement on these case studies.

To conclude, factor analysis reveals some inefficiencies in the decisions on the case studies. This draws our attention to the particularities mentioned above in some of the case studies. Checks of mean valuations and their variance for these case studies show that the potential particularities identified do not influence the case study valuations' means and variances in any systematic fashion

5.1.2.4 Summary of the analysis of the means of the empirical case study valuations

In section 5.1.1.1 we compare the mean empirical decision taken on the case studies by the respondents and the decisions recommended by the NPV rule and by real options theory. We find that most of the 14 case studies were significantly over-valued in real option terms, (implying that they were even more overvalued in NPV-terms).

Over case studies A1 to A7, we varied the expected PV of the follow-up project's cash flows, over B1 to B5 the volatility of the PV and over C1 and C2 the time until the follow-up project can be undertaken. Except for A1 and A4, empirical valuations by the respondents for case studies A1 to A5 were too high in real option (and NPV) terms. Case studies A6 and A7 were undervalued in real option (and NPV) terms. Case studies B1 to B4 are overvalued in real option (and NPV) terms and case studies C1 and C2 are strongly overvalued in real option (and NPV) terms.

The overall average overvaluation in real option terms is about 79% of the theoretical option value. It appears that, in each sequence, the case studies with the lower theoretical option values are overvalued (in real option (and NPV) terms) relatively more than case studies with higher theoretical option values. Across the case studies in the A-sequence, the regression line of the empirical valuations on the theoretical option values shows a very good fit and does not significantly differ from the theoretical option values.

In sections 5.1.1.2 and 5.1.1.3 we introduce the grouping variables used to split the sample into subgroups.

In section 5.1.2.1 we perform non-parametric (sign test) and parametric tests (correlation analysis, multiple regression analysis, One-Way ANOVA), in order to identify grouping variables influential over the empirical case study valuations. In section 5.1.2.2 we perform a t-test and use the sign test of section 5.1.2.1 to examine the direction in which grouping variables influence mean empirical valuations and rationality.

In table 5.1.23 we summarise the results for importance of a grouping variable (in the row "I", from table 5.1.17) and for direction (in the row "D") and rationality (in real option terms, in the row "R" from table 5.1.20).

Table 5.1.23

Importance and direction of the grouping variables' influence on the mean empirical case study valuations

	Educ	Exp	Func	Ind	Involv	Lev	Pos	Qual	Sect
I	5	2	6	2	6	5	4	3	1
D	+	+	-	1)	-	+	+	+	+
R	x	x	*	1)	*	o	o	*	x

Note: +: mean (1) > mean (0), - : opposite, *: (1) more rational, x: (1) less rational, 0: (0) and (1) equally rational, 1) see table 5.1.21.

It appears from the table that (high levels in) two of the most influential grouping variables, Sector and Experience, make decision makers more optimistic but less rational (in real option terms). Conversely, the grouping variables Function and Involvement which make decision makers less optimistic and more rational in real options terms, are the least influential grouping variables. Finally, the examination of the grouping variable

Industry (cf. Table 5.1.20) showed that respondents in the brewing industry are excessively optimistic and of all industries least rational (in real option terms).

5.2 Spreads of the empirical case study valuations

As noted in the introduction to Chapter 5, the simplest statistical model of judgmental correctness has two parameters, bias (mean or level) and dispersion (spread or variance). In this subchapter 5.2, we move from considering mean to considering spread. The foregoing subchapter 5.1 has examined mean empirical valuations of the case studies, for the entire sample of respondents and for subgroups of respondents. Some light had been shed on ways in which the respondents' response behaviour might be biased. In this subchapter, we move to the spread in the empirical valuations of the case studies, first for the entire sample (Research issue 2) and then for subgroups of respondents (Research issues 5, 6 and 7).

The spread in the empirical valuations around the theoretical value can be interpreted as the "inaccuracy" with which the case studies have been dealt with. This term of course implies that there is a "true" value of the investment (e.g. the theoretical option value). Alternatively, the spread in the empirical valuations around the mean empirical valuation can be considered to be an indicator of the "unanimity" of the respondents. This term is more neutral in that it does not assume a correct value. Therefore, in what follows, we use this second definition, the spread around the mean empirical valuation. The statistical measure used in the statistical significance tests is the variance, which is based on the difference between each value in the data set and the mean of the group (Kazmir, 1988) However, whenever an illustration of the spread is required, we use the standard deviation, as it is measured in the same dimension as the mean.

5.2.1 Spread in the case study valuations by the entire sample (Research issue 2)

In this section, we will examine research issue 2 (as defined in section 4.7) which concerns the frequent observation in judgemental research that the standard deviation of a judgement behaves in line with its mean: for higher means a higher standard deviation is observed/thought to be acceptable. This is a hypothesis which we will now test.

We examine the patterns of variance for the A-sequence of case studies (across which the expected PV of the follow-up project's cash flows is varied), for the B-sequence (where the volatility of the PV is varied) and for the C-sequence (where the development time is varied).

In the first row (labelled "Sd") of table 5.2.1, the standard deviation of the empirical case study valuations is listed. For better orientation and interpretation, in rows two to six (rows labelled "EV", "OV(T)", "D", "IV" and "TV"), the mean empirical valuations, the theoretical option value, the mean discrepancy, the intrinsic value, and the time value for the 14 case studies (as examined in section 5.1.1.1) are listed again.

Table 5.2.1

Standard deviation of the case study valuations by the entire sample

	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2
Sd	0.57	1.74	0.98	3.05	3.65	3.07	4.84	2.94	1.1	2.35	3.14	1.9	2.89	4.42
EV	-0.02	1.7	4	6.3	15.4	11.4	13.8	3.2	6.5	4.8	8	4.1	5.7	9.1
OV(T)	0.06	0.5	3	6.8	11.1	15.7	20.4	1.2	2.2	3.8	4.6	5.2	1	4.9
D	-0.1	1.2	1	-0.5	4.3	-3.3	-6.6	2	4.3	1	3.4	-1.1	4.7	4.2
IV	0	0	0	3	8	13	18	0	0	0	0	0	0	0
TV	0.06	0.5	3	3.8	3.1	2.7	2.4	1.2	2.2	3.8	4.6	5.2	1	4.9

For the A-sequence of case studies, it is obvious that the standard deviation does not move in line with the intrinsic value, (which differs from the NPV of the follow-up project only in that it uses the undiscounted future value of X). The intrinsic value only starts to be greater than zero from case study A4 onwards but the standard deviation starts growing from case study A1 onwards. However, it seems that the standard deviation behaves more in line with the theoretical option value than with the empirical valuation. For example, the standard deviation rises from case study A6 to case study A7 above the level of case study A5 (in line with the theoretical option value) while the empirical option valuation falls from A5 to A6 and from A6 to A7. This is not in strict conformity with our hypothesis, which, however, seems to be *roughly* true.

Over the B- sequence of case studies, there is no apparent trend in the standard deviation, but the level of the standard deviation is markedly higher (average = 2.28) than that of the "base case" case study A3 (same PV of cash flows as in B-sequence) of 0.98. This is in contrast to our hypothesis. Case studies C1 and C2, which are both highly overvalued, both have a high standard deviation which increases from case study C1 (sd 4.42) to case study C2 (sd 2,89). This increase could be driven by both the theoretical option value (= time value) and the empirical valuation (but not by the intrinsic value which is constant over both case studies). The level of standard deviation in the C-sequence suggests, if compared to the level of the standard deviations in the A-sequence, that in the C-sequence, the empirical valuation might be the most likely driver of the standard deviation. This confirms our hypothesis that higher mean empirical case study valuations have a higher standard deviation. We will return to these findings on a more interpretative level in Chapter 7.

5.2.2 Differing spreads in the case study valuations by different subgroups of respondents (Research issues 5 and 6)

After having examined the spread for the entire sample, we next examine the spread for subgroups of respondents as defined by the grouping variables. Similarly to the analysis of the level of the empirical valuations in the previous sub-chapter, the question here is whether there are grouping variables that appear to influence the spread in the empirical valuations (the "Unanimity"). This corresponds to research issue 5, the grouping variables' importance for "Unanimity" and to research issue 6, the direction of grouping variables' influence on "Unanimity" (as defined in Table 4.8)

The procedure we follow is first to compute the standard deviation of the mean empirical case study valuations for each pair of subgroups as defined by the dichotomous grouping variables. We then determine the significance of potential differences between standard deviations by using both a sign test and a F-test. From the number of significant differences per grouping variable we can conclude a grouping variable's importance and from the signs of the significant differences we can conclude the direction of a grouping variable's influence on the spread in the empirical valuations. Finally, (in Table 5.2.4) we use the empirical findings to test our hypothesis on research issues 5 and 6.

Non-Parametric Sign test of variance

First, a simple sign test is used. As in section 5.1.2.1a, this test is used as a low power, non-parametric scan to detect influential grouping variables. We were aware of the fact it might not be possible to obtain significant results due to the low power of this test, but still performed the sign test in order to "get a feel" for the data before we proceeded to more powerful but less intuitive tests.

The results of the sign test are summarised in table 5.2.2. The table contains in the first row the number of occurrences of the event "the standard deviation of the case study valuations by the "high-level" subgroup is smaller than the standard deviation of the case study valuations by the "low-level" subgroup. For example, the "4" in the first cell means that for 4 out of the observed 14 case studies, the "high-level" subgroup has a lower standard deviation than the "low-level" subgroup. In the second row, the table indicates whether the differences between the standard deviations have been found overall statistically significant at 5% by a binomial test.

Table 5.2.2

Sign test of the standard deviation of the case study valuations by subgroups of respondents

	Educbu	Experie	Functio	Involve	Level	Position	Qualific	Sector
Sd (0) > Sd (1)	4	10	7	9	7	8	2/8	8
Signifi-cance	ns	ns	ns	ns	ns	ns	ns	ns

Note: Sd = standard deviation, ns = not significant at 5% level of significance.

From the table, the pattern of differences in the spread of the valuations between subgroups of respondents is not statistically significant using the low powered distribution-free sign test. The insignificant pattern is that, in the present sample, high levels of the grouping variables Involvement, Position, Sector, and Experience all seem to increase the unanimity of the subgroup (i.e. they imply smaller standard deviation of the case study valuations by a subgroup), whereas a high level in the grouping variable Business Education (Educbus) seems to decrease the unanimity of the subgroup.

Parametric F-test of variance

Therefore, secondly, the more powerful F test (which assumes normality) is applied to test the significance of the differences between the standard deviations of the case study valuations by the subgroups of respondents. The normality of the case study valuation responses by the subgroups as defined by the grouping variables had been confirmed in the Kolmogorov-Smirnov test of normality in section 5.3.2. The usual two subgroups for each of the 8 dichotomous grouping variables are formed. For each case study, the standard deviations of the two subgroups are compared using the F test.

Table 5.2.3 displays the results that are significant at 5%. In order to capture the direction of significant differences in the spread, a plus sign is displayed in the table in case the standard deviation of the case study valuations by the "low level" subgroup is significantly higher than the standard deviation of the case study valuations by the "high level " subgroup. In the opposite case, a minus sign is displayed in the table. Blanks in the table mean the result from the F test for this cell is not significant. An apostrophe in a cell means the F-test did not produce results for this cell. In the column "N", significant differences are added up regardless of its sign for each grouping variable. This number forms the basis for a binomial test of the overall significance of a particular grouping variable. The results from the binomial test of the null hypothesis (i.e., if the null is true, there is only a 5% probability of observing a violation of the null hypothesis that is significant at 5%) are given in the last column labelled "Sig.".

Table 5.2.3

Summary of F test of the spread in the empirical case study valuations for subgroups of respondents

	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2	N	Sig.
Edu	+				-					-	-				4	s
Exp	+	-						+		+					4	s
Fun	+			+				-		+		+			5	s
Inv		+		-	-					+				+	5	s
Lev							+						+		2	ns
Pos	+		+				-	-			+				5	s
Qua	'						'	'	'	'	'				0	ns
Sec			+					+		-		+		-	5	s

Note: + = Std dev. (0) > Std dev. (1) , - = Std dev. (0) < Std dev. (1), ' = no results from F-test. , blanks or ns = not significant at 5%, s = significant at 5%.

The grouping variables most influential over the spread in mean empirical case study valuations, as identified by the F test, are Function, Involvement, Position and Sector (5 times significant each). The next important grouping variables are Educbus and Experience (4 times significant each). Grouping variable Level (twice significant) is not overall significant and grouping variable Qualification does not seem to be influential over the spread in the empirical case study valuations.

In order to identify in what way a grouping variable influences the spread in the empirical case study valuations we next look at the signs of the differences in the standard deviations between the subgroups. Table 5.2.4 in its first row labelled "Importance", lists the ranking of the grouping variables according to their influence on the spread in the case study valuation responses (as obtained from the F-test). In rows two and three we restate the null and alternative hypotheses on the grouping variables importance for unanimity (Research issue 5, from the two columns entitled "RI 5" of Table 4.10). Row 4 indicates the superior hypotheses. The table then summarises the predominant signs (defined as before) from the sign test of Table 5.2.2 and from the F-test of the previous table. The results of both tests are combined in row "Direction". Row Direction indicates the direction of each grouping variable's influence on the "unanimity" of the subgroup, (high unanimity meaning little spread in the case study valuation responses). In the following columns "H_0" and "H_1", we restate the null and alternative hypotheses on the direction of the grouping variables' influence on unanimity (Research issue 6) from the two columns entitled "RI 6" of Table 4.10). The last row indicates which hypothesis appears superior in the face of the empirical evidence.

Table 5.2.4

Importance and direction of the grouping variables' influence on "unanimity"

	Edu	Exp	Fun	Inv	Lev	Pos	Qua	Sec
Importance	2	2	1	1	ns	1	ns	1
H_0	2	1	3	3	2	1	2	1
H_1	3	1	5	4	3	1	3	2
	H_0	-	H_0	H_0	H_1	-	H_1	-
Sign test	-	+		+		+	-	+
F-test	-	+	+	+	+	+		+
Direction	-	+	+	+	+	+	-	+
H_0	+	-	+	+	+	-	+	-
H_1	-	-	+	+	-	-	-	-
	H_1	-	-	-	ns	-	ns	-

Note: +: Std dev. (0) > Std dev. (1), -: Std dev. (0) < Std dev. (1)

From the first part of the table, it appears that, in the present sample, the null hypothesis is closer to the empirical ranking more often (3 times) than the alternative hypothesis is (2 times). We therefore accept the null hypothesis (NPV-view) on the grouping variables' importance for unanimity. Under the null hypothesis, the grouping variables Position and Sector had been expected to be influential over the spread of the case study valuation responses as is seen, but grouping variables Level and Qualification had been expected to be influential, which is not seen. From the second part of the table, focusing on the important grouping variables, it appears that the alternative hypothesis might be more acceptable than the null hypothesis. We therefore reject the null hypothesis and accept the alternative hypothesis (real options view) on the direction of the grouping variables' influence on unanimity. However, the alternative hypothesis appears acceptable for grouping variables Business Education, Function, Involvement and Qualification. We will return to these findings on a more interpretative level in Chapter 7.

5.2.3 Consistency of individual respondents' bias in their case study valuations (Research issue 7)

In addition to examining respondents' mean valuations and the spread in their valuations to any one case study, we can examine respondents' degree of consistency over all three of their valuations. This is the topic of research issue 7. In section 4.7 we described the consistency of a respondent's valuation behaviour, given the three case studies usually answered, as the degree to which an individual manager tends to overvalue or undervalue all cases similarly. A respondent's decisions are called consistent if he or she values all three case studies correctly or if he or she overvalues or undervalues all three case studies to a similar extent. In all other cases the respondent is more or less inconsistent. We measure consistency as the variance in (the discrepancy from theory of) a respondent's valuations of the (usually) three case studies he or she answered.

In what follows, first the consistency of the subgroups, as defined as by the grouping variables, are examined ("theory-driven" approach). This is in order to identify grouping variables that are influential on respondents' consistency and to identify the direction of their influence on increasing or decreasing consistency. The empirical directions of influence are used to test our hypotheses concerning the grouping variables' influence on consistency. Afterwards, we try to double-check these results by forming subgroups of respondents according to their consistency and by comparing the professional characteristics of these subgroups ("data-driven" approach).

"Theory-driven" approach

We measure a respondent's consistency as the standard deviation of the three discrepancies (difference between empirical valuations and theoretical option values) for each respondent, each minus the mean discrepancy by all respondents, each over the standard deviation of all valuation responses to the case study. This can be expressed by (for the example of the block comprising the case studies A1, A2 and A3):

$$\text{Consistency} = \text{sd}\ (Z_{A1}\ Z_{A2,}\ Z_{A3})$$

with: Z_{A1} = (respondent's discrepancy for A1 - mean discrepancy by all respondents for A1)/sd of all valuations responses to A1

Note that a small consistency measure means that respondents decide highly consistently on these three case studies.

Consistencies of the subgroups as defined by the dichotomous grouping variables are compared in table 5.2.5. The major cell entries in the table are the mean consistency for each subgroup, for each of the five sets of case studies. The consistency measures of the pairs of subgroups defined by the same grouping variable are compared for each set of case studies. Differences in the consistency measures between two subgroups are either positive or negative. The column labelled "N" contains for each grouping variable the number of times the "high-level" subgroup is more consistent (smaller consistency measure) than the "low-level" subgroup. As the null hypothesis, assuming there was no phenomenon, we assume one subgroup to be more consistent exactly half of the time. A binomial test, the results of which are given in the column "Significance", is used to determine whether the number of times the "high-level" subgroup is significantly more consistent than the "low-level" subgroup. Column "D" contains the direction of a grouping variable's influence on consistency. In the columns labelled H_0 and H_1, we restate the null and alternative hypotheses concerning the grouping variables' influence on consistency (from the two columns entitled "RI 7" of Table 4.10). The last column indicates which hypothesis appears superior in the face of the empirical evidence.

Table 5.2.5

Comparison of the consistency measures for subgroups of respondents

	Sub group	Means of consistency measures					N	Signifi-cance	D	H_0	H_1
		Block 1	Block 2	Block 3	Block 4	Block 5					
		A1-A3	A4-A6	A7-B2	B3-B5	C1-C2					
Average		0.86	0.57	0.76	0.66	0.55					
Educbus	0	0.83	0.5	0.94	0.73	0.23	2	ns			
	1	0.89	0.93	0.68	0.66	0.64					
Experien	0	0.85	0.69	0.7	0.66	0.6	2	ns			
	1	0.97	0.49	0.85	0.66	0.58					
Function	0	0.78	0.48	0.91	0.89	0.23	2	ns			
	1	0.91	0.65	0.68	0.36	0.82					
Involve	0	0.94	0.61	0.71	0.53	0.95	2	ns			
	1	0.83	0.58	0.81	0.78	0.35					
Level	0	0.79	0.64	0.79	0.87	0.71	4	s	+	+	-
	1	0.92	0.5	0.73	0.52	0.42					
Position	0	0.95	0.73	0.82	0.66	0.54	3	ns			
	1	0.71	0.41	0.53	0.81	0.59					
Qualific	0	0.87	0.33	0.75	1.52	0.37	1	s	-	+	-
	1	0.88	0.74	0.79	0.64	0.5					
Sector	1	0.9	0.64	0.81	0.84	0.62	4	s	+	-	-
	2	0.83	0.52	0.66	0.46	0.45					

Note: N: number of occurrences of mean (group 1) < mean (group 0), ns = not significant at 5% level of significance, s = significant at 5% level of significance.

As can be seen from the table, the only grouping variables for which significant differences in the empirical consistency measure exist are Sector, Level, and Qualification. The directions of the significant differences in consistency imply that: (i) respondents working in the consumer goods sector are more consistent than respondents working in the capital goods sector, (ii) respondents working in a company's headquarters are more consistent than respondents working in an operational business unit, and (iii) respondents having a postgraduate qualification are less consistent than respondents without a postgraduate qualification. Based on this information, no decision is possible on which hypothesis is superior.

In the remainder of this chapter, we perform a "data-driven" cross check of the results on consistency, a "diagnostic check" to find respondents with unusual scatters of responses, and we provide a summary of, and some comparisons between, the empirical findings of the chapter. The next research issue (8) on respondents' openness towards real options, will be examined in section 6.2.2.1 using the so called "questionnaire variables" after the introduction and preliminary "diagnostic checks" of the questionnaire variables.

"Data-driven approach"

As an alternative approach to examining consistency, we tried to test whether the subgroup of respondents whose decisions on the case studies show very high consistency differ from all other respondents in terms of their professional characteristics. Respondents with a consistency significantly higher than the average could be identified by using a chi square test on the consistency measure. In order to be able to apply a chi square test, the consistency measure was slightly modified. The rule for combining the individual Z's used here is (for the example of the first block):

$$\text{Consistency} = Z_{A1}^{2} + Z_{A2}^{2} + Z_{A3}^{2} \quad (5.5)$$

Respondents' consistency measures were then compared with values from a chi square table with these degrees of freedom. The 11 respondents with significantly high consistency (low chi square measure) as identified by the chi square test were combined in one subgroup, all the other respondents formed the background sample.

The demographics of the two subgroups were compared and results are given in table 5.2.6. The subgroup labelled "High cs" contains highly consistent respondents and subgroup labelled "Other" contains all other respondents. Means and standard deviations of the professional characteristics of both subgroups are given in the table. A non-parametric Mann-Whitney test is used to test for statistical significance of the differences in the mean professional characteristics between the subgroups.

Table 5.2.6

Demographic analysis of subgroups of highly consistent respondents

Subgroup		Educbu	Experi	Functio	Industr	Involve	Level	Positio	Qualifi	Sector
High cs	Mean	0.44	0.38	0.5	3	0.56	0.5	0.13	0.86	1.33
	Sd	0.53	0.52	0.53	1.32	0.53	0.53	0.35	0.38	0.45
Other	Mean	0.54	0.53	0.46	3.13	0.54	0.46	0.29	0.85	1.47
	Sd	0.5	0.5	0.5	1.31	0.5	0.5	0.46	0.36	0.5
2-tailed P		0.61	0.42	0.82	0.81	0.95	0.82	0.32	0.96	0.45
Significance		ns	ns	ns	ns	ns	ns	ns	ns	ns

Note: sd = standard deviation, ns = not significant at 5% level of significance.

As can be seen from the table, in the "data-driven" approach, of all grouping variables, Position, Experience, and Sector are closest to being significant, but none is very close to being significant. Of these, Sector had been found significant in the "theory-driven" approach. We conclude that the results of the preceding "theory-driven" approach remain unchallenged by this "data-driven" double check.

5.2.4 Analysis of respondents for unusual scatters of valuations

In most of the analyses of spread reported up to this point in section 5.2.1, 5.2.2, and the first part of section 5.2.3, respondents were grouped ex-ante, to test whether the spread of their responses to the case studies was affected by a priori defined grouping variables. In this section, respondents are grouped ex-post, according to the spread, or scatter, of their decisions on the case studies. In this section, respondents unusual in the wideness or narrowness of their scatter of responses are grouped and then analysed.

The statistical measure used to detect potential "unusualness in the scatter of responses" is the Mahalanobis distance. There are two possibilities for a respondent to be unusual in terms of his or her Mahalanobis distance. An obvious type of unusual respondent is one who has an unusually large scatter of case study valuations. This would lead to a high Mahalanobis distance. Another type of respondent who is classified as unusual is the one whose scatter of case study valuations is unusually small. This would result in a small Mahalanobis distance. The Mahalanobis distance can be thought of as a generalisation of the chi squared measure used in the previous section, and reduces to it in special cases.

The Mahalanobis distance analysis was carried out for blocks of respondents. On the average, there were 15 respondents in each of the 5 blocks. In order to focus on the respondents with clearly unusual Mahalanobis distances, it was decided to identify for each block the 3 respondents with the highest Mahalanobis distance and the 3 respondents with the lowest Mahalanobis distance (leaving on the average 9 responses in each block that were not considered to be unusual). These respondents were summarised across all 5 blocks in two groups. The 15 respondents with the highest Mahalanobis distance were summarised in the subgroup "high MD". The 15 respondents with the smallest Mahalanobis distance were summarised in the subgroup "low MD".

For the two subgroups, mean values for the 8 dichotomous variables are computed. The mean professional characteristics of both subgroups are then each compared with the mean professional characteristics of the respective background sample and any differences are tested for statistical significance.

The demographic analysis of the two subgroups with high/low Mahalanobis distance is summarised in table 5.2.7. In its first part, in the first row, the table contains the average values of the grouping variables for the subgroup with a high Mahalanobis distance. The second row of the table contains the average scores in the grouping variables for the background sample. The second part of the table contains the same information for the subgroup with a low Mahalanobis distance.

For example, the first cell entry "67" means that in the subgroup with high Mahalanobis distance, the average score in the grouping variable "Educbus" was .67. As Educbus is a dichotomous grouping variable with levels 0 and 1, this can be read as 67% of group members had a formal education in business u. The results from the significance test using the non-parametric Mann-Whitney test are given in the rows labelled "Significance".

Table 5.2.7

Demographic analysis of respondents unusual in their pattern of responses (respondents whose decisions taken on a set of case studies are have a high/low Mahalanobis distance).

Grouping variable	Educb	Experi	Functi	Involv	Level	Positi	Qualif	Sector
High MD	0.67	0.4	0.6	0.5	0.67	0.13	0.93	1.33
Background sample	0.49	0.54	0.43	0.56	0.42	0.31	0.83	1.48
Significance	ns	ns	ns	ns	s	ns	ns	ns
Low MD	0.4	0.5	0.52	0.43	0.5	0.14	0.83	0.4
Background sample	0.56	0.52	0.43	0.57	0.45	0.3	0.85	1.46
Significance	ns	ns	ns	ns	ns	ns	ns	ns

Note: MD = Mahalanobis distance, ns = not significant at 10% level of significance, s = significant at 10%.

As can be seen from the table, the subgroup of respondents who are collectively unusual in their responses differs significantly at 10% in the grouping variable "Level" from the background sample. This means that for the present sample, of the respondents with a high Mahalanobis distance, a significantly above average 67% are employed at the headquarters of the company.

We conclude from this that in the present sample it is weakly possible to predict an unusually high Mahalanobis distance from a high level in the grouping variable "Level". This means that respondents who are employed at a company's headquarters are unusually erratic in their case study valuations. This result is in weak contrast to the previous finding that respondents in this subgroup are more consistent in their judgements on their set of three case studies.

5.2.5 Summary of the findings from the experiment on spread or variance

In the present subchapter on the spread in the empirical case study valuations, firstly we considered the variance for each case study over the entire sample. The variance of the empirical valuations increases evenly over case studies A1 to A7. Over case studies B1 to B5, the change in the variance has no clear direction. Empirical valuations of case studies C1 and C2 show a high variance, which is higher for C2 than for C1.

Next, we compared the spreads in the empirical case study valuations of different subgroups performed in this subchapter. Table 5.2.8 contains the results from the sign- and F-tests (of Table 5.2.4, in rows "Unanimity": "I" (Importance), and "D" (Direction)) from the "consistency test", (of Table 5.2.5 in row "Consistency") and from the Mahalanobis distance analysis (of Table 5.2.7 in row "Unusualness").

Table 5.2.8

Comparison of measures of grouping variables' influence on spread

		Educbus	Exp	Func	Inv	Lev	Pos	Qual	Sector
Unanimity	I	2	2	1	1	ns	1	ns	1
	D	-	+	+	+		+		+
Consistency						+		-	+
Unusualness						+			

Note: +: "high-level" subgroup shows more of the property in question, -: opposite relationship

The first part of the table shows that of the important grouping variables, only (more) Business Education makes decision makers less unanimous while Function, Involvement, Position, Sector and Experience all make decision makers more unanimous. Moreover Sector (i.e. employment in consumer product-related industries) makes decision makers more consistent.

It is interesting to note that the consistency test (in row "Consistency") and the Mahalanobis-distance analysis (in row "Usualness") both provide significant results mainly for the grouping variables unimportant in the F-test. Qualification makes decision makers less consistent, and Level makes decision makers more consistent but more unusual. This seems to be a contradiction between these two analyses.

Finally we compare the grouping variables influential over the spreads of the empirical case study valuations, as identified in the present subchapter (5.2), with the grouping variables influential over the mean of the empirical case study valuations, as identified in the previous subchapter (5.1). Table 5.2.9 combines and compares tables 5.1.9 and 5.2.4

Table 5.2.9

Comparison of grouping variables influential over the mean empirical case study valuations and grouping variables influential over the spread in the empirical case study valuations

		Educb	Exper	Funct	Industr	Involve	Level	Positi	Qualifi	Sector
Mean	I	5	2	6	2	6	5	4	3	1
	D	+	+	-	n/a	-	+	+	+	+
	R	x	x	*	n/a	*	o	o	*	x
Unanimity [low variance]	I	2	2	1	n/a	1	ns	1	ns	1
	D	-	+	+	n/a	+		+		+

Note: +: higher mean/unanimity, -: opposite, *: (1) more rationality, x: (1) less rational, o: same rationality, I: Importance, D: Direction, R: Rationality.

It appears from the table that in the present sample, the grouping variables "Sector" and "Experience" are influential over both the mean empirical case study valuations and the spread in these valuations. High levels of "Sector" and "Experience" go together with "overvaluation" and lower rationality of means, and with higher unanimity. The high mean valuations from the consumer goods Sector stem from the brewing industry, whose valuations are so high that they dominate this Sector. A potential tentative explanation of the effect of Experience on the mean valuations is that it proxies seniority. Seniority might account for "generous" valuations, and high unanimity, due to high self-confidence levels and to a common high level of shared experiences among this group of respondents. We will return to this point in section 7.3.3.

In addition, from the consistency test, Sector (i.e. employment in consumer product-related industries) makes decision makers more consistent (see previous table). In contrast, the grouping variables Business Education (Educbus), Function, and Involvement all have a clear influence on the variance but are, among all the grouping variables, the least influential on the mean empirical case study valuations. This might suggest that the only effect these grouping variables tend to produce is unanimity, e.g. financial managers are more similar in their judgements than commercial managers but do not value the case studies significantly higher or lower than them.

6. FINDINGS FROM THE QUESTIONNAIRE SURVEY AND COMPARISON WITH THE FINDINGS FROM THE EXPERIMENT

6.1 Introduction

Having analysed in depth the empirical case study valuations (the experiment data) in the previous Chapter 5, this chapter examines the responses in the third part of the data set, the so-called questionnaire, or survey, data. In the first part of the chapter (section 6.2) the questionnaire responses (i.e. the (mean) answers to the questions in the questionnaire) are analysed in their own right, and in the second part (section 6.3), potential links between the questionnaire responses and the empirical case study valuations are investigated. Section 6.4 summarises and concludes the chapter.

Firstly, in section 6.2.1, we introduce the items of the questionnaire, which we call the "questionnaire variables", or "questionnaire items", i.e. the different topic items used to collect the questionnaire responses, and we perform preliminary checks for potential redundancies. Secondly, in section 6.2.2.1, we examine the mean questionnaire responses over the entire sample to examine research issue 8.

In section 6.2.2.2, we examine the mean questionnaire responses by subgroups of respondents, as defined by the grouping variables. It is of interest whether significant correlations exist between the questionnaire-responses and the grouping variables. Potential correlations could be interpreted as being caused by an influence of the relevant grouping variables on the questionnaire responses. The empirical findings in this section are used to test our hypotheses on the one hand on research issue 9 (the grouping variables' importance in explaining openness towards real options) and research issue 10 (the direction of grouping variables' influence on openness), and on the other hand on research issue 11 (the direction of the influence of openness towards real options on the mean case study valuation responses).

Finally, in section 6.3, we focus on the relationship between the case study valuations and the questionnaire-responses. Potential non-random patterns in the correlation matrix could be interpreted as being caused by an influence of the questionnaire variables involved on the case study valuation responses or vice versa. This corresponds to research issue 12.

6.2 Statistical analysis of questionnaire responses

The questionnaire (as introduced in section 4.4.2 and fully given in Appendix 4.1) was used to gather information complementary to the empirical case study valuations. In the case studies we asked for replies to imaginary valuation problems. Misunderstandings and lack of perceived realism in the case narratives were natural risks. In the questionnaire, we tried to obtain the managers' perceptions of their real world problems. In this way, we provided respondents with an opportunity to modify or reject completely the entire conceptual framework of the real options model (European, non dividend-paying) for use in general (i.e. non-commodity) capital budgeting.

Finally, the questionnaire provides an opportunity to check how realistic our case studies are. This is important to assess the meaningfulness of our laboratory findings for the "real world" (the topic of section 7.4.1).

The questionnaire includes 21 questions collecting 30 items of information (which we called questionnaire variables or questionnaire items and listed in Table 4.4) on

(1) the occurrence of growth options in the respondent's industry,

(2) the perceived realism of the assumptions underlying real options theory in general, and the chosen Black-Scholes model in particular.

(3) the perceived realism of the option parameter settings assumed in the case studies (moneyness, volatility, and maturity)

(4) general investment decision making practices in the respondents' company.

6.2.1 The questionnaire questions

In order to scan for potential associations or overlap between the questionnaire variables, we first check for correlations between the responses to the various different questionnaire variables.

6. Findings from the questionnaire survey and comparison with findings from the experiment

The responses to the questionnaire variables are at an ordinal level of measurement. An appropriate measure of the relationship between the questionnaire variables is therefore Spearman's rank correlation coefficient.

Significant correlations from the Spearman correlation analysis of responses to the various questionnaire variables were counted for each questionnaire variable. We found that many of the questionnaire variables are correlated. Some of these correlations were positive and some were negative. In order to obtain a measure for the overall extent to which a given questionnaire variable is correlated with all others, all significant correlations for one questionnaire variable are summed, regardless of their signs.

Table 6.1 summarises the results. The rows labelled "N" contains, for each questionnaire variable, the number of correlations significant at 5%. The rows labelled "n" contains the number of correlations significant at 10%. The excess of significant results for a questionnaire variable over all 30 questionnaire variables is tested using a binomial test. In this test, a questionnaire variable is deemed to be significant over all 30 questionnaire variables if the resulting Bernoulli probability P (X | n, p) is .05 or less. The number of individually significant correlations is taken as the number of binomial successes X the number of questionnaire variables (30) is taken as the number of observations n, and the overall significance level applied in the binomial test (both 5% and 10% are applied) is taken as the probability of success p. The results of the binomial test are contained in the rows labelled "Sig" in the table.

6. Findings from the questionnaire survey and comparison with findings from the experiment

Table 6.1

An indication of the extent to which individual questionnaire variables have a greater than random incidence of correlations with all other questionnaire variables.

	Perc fu	Fu r&d	Fu mar	Fu IT	Fu proc	Fu cont	Fu othe	Treat f	Fu qua	Sure pp
N	5	7	8	3	9	3	4	5	3	6
n	6	8	8	8	10	6	5	6	5	9
Sig	S	S	S	s	S	s	S	S	s	S

	Avg lif	Difficul	Fore mc	Fore co	Fore pc	Red unc	Tes tim	Sd 30	Sd	X uncert
N	3	4	6	7	6	2	6	7	5	3
n	5	6	9	9	10	4	8	8	8	5
Sig	ns	S	S	S	S	ns	S	S	S	ns

	Pl hor8	Pl hor	Dev t3	Dev t	Fu5	Fu	Single p	Don org	Add dat	Stra pol
N	6	8	5	4	5	3	6	5	2	4
n	9	13	6	5	8	4	9	5	6	2
Sig	S	S	S	S	S	ns	S	S	s	S

Note: ns = not significant at 10%, S = significant at 5%, s = significant at 10%

To judge from these data, nearly all the questionnaire variables are significantly correlated with other questionnaire variables. This should not come as a surprise. Firstly, many questions relate to the detail of company-specific or industry characteristics and so should produce patterned replies within industries. Moreover, some questions are rewordings of similar meanings.

6.2.2 Mean questionnaire responses

6.2.2.1 Mean questionnaire responses by the entire sample (Research issue 8)

We first review mean responses to the four main categories of the questionnaire variables to examine research issue 8 (the "real world" relevance of real options as defined in Table 4.8).

(1) Occurrence of growth options in the respondent's industry

40% of the investment projects in the respondents' companies were on average perceived to create potential follow-up investment opportunities. These "pioneer projects" arose (in their order of importance) "sometimes" in R&D, in process improvements and in marketing, but very rarely in information technology, as built into commercial contracts, or in other areas. Respondents, when evaluating a pioneer project, took the follow-up investment opportunities into account only qualitatively but agreed that quantitative treatment was desirable.

(2) Perceived realism of the assumptions underlying real options theory.

Respondents were only "very seldom" sure about the profit prospects for a product over its whole life. The average product life was estimated at about 19 years. Respondents were "uncertain" whether it was difficult to evaluate the PV of a project. It was on average perceived that with 90% accuracy production costs could be forecast for the longest time horizon, nearly 3 years, followed by competition (about 2 years) and market conditions

(1.5 years). Respondents were generally uncertain but tended to agree that market research and test marketing were suitable to gain fast information on the prospects for potential follow-up projects. Market research and test marketing usually took just over one year.

(3) Perceived realism of the specific option parameter settings assumed in the case studies

The respondents suggested a mean standard deviation of the PV of the cash-flows from a typical investment of 23% per annum. They were unclear whether the initial cost of follow-up investments (the exercise price of the option) is also uncertain. Respondents indicated the planning horizon in their industries to be on the average 11 years. The development time of the pioneer project (the option's maturity) until the start of the follow-up investment of 3 years (as assumed in most of the case studies) was found to be either too short and too long by different subgroups of respondents. The life cycle of the follow-up project of 5 years was perceived to be too short and would more realistically be about 11 years on average.

(4) General investment decision making practices in the respondents' companies

Most companies in the sample would look at a two-stage investment of a pioneer project and a follow-up project as a single project. (Note that although the question was formulated in general terms, the (affirmative) answers might have been influenced by the fact that the NPV of *our* pioneer project was negative). There was uncertainty about whether the decision making in the respondents' companies was organised in the way suggested in the case studies. Additional data were not considered to be an important requirement to reach a decision on the case studies, and respondents agreed that their companies included strategic goals and internal political factors in their investment decisions.

Overall, the questionnaire responses seem weakly in support of our hypothesis on research issue 8 that (a) real options are perceived to occur in real world investment decision making and (b) that the (theoretical) assumptions of the real options model are by and large perceived to be realistic. In the next section we will discuss research issues 9 and 10

6.2.2.2 Mean questionnaire responses by subgroups of respondents

Mean responses to questions about industry characteristics are of little interest when averaged across the entire sample. In this section, we therefore focus on subgroups of respondents. We try to identify the importance and direction of grouping variables' influence on the questionnaire responses on the construct "openness towards the real options approach" (to be introduced in section 6.2.2.2b), which combines the questionnaire variables (research issues 9 and 10 as defined in Table 4.8).

6.2.2.2a Identification of grouping variables influential on the questionnaire responses (Research issue 9)

In section 5.2.2 the nine grouping variables (Business Education, Experience, Function, Industry, Involvement, Level, Position, Qualification, and Sector) were used to split the sample in two (or more) subgroups of respondents. These subgroups were then analysed for potential differences in their mean valuation responses to the case studies.

6. Findings from the questionnaire survey and comparison with findings from the experiment

In this section, we examine the same subgroups for potential differences in their mean responses to the questionnaires. The aim is to identify important grouping variables (research issue 9). Both non-parametric and parametric tests are performed. We will then compare the empirical ranking of the grouping variables with our hypothesised ranking in Table 6.4.

Non-parametric correlation between questionnaire responses and the grouping variables

For the present data, both the questionnaire responses and the grouping variables are measured at an ordinal level of measurement. An appropriate non-parametric measure of the relationship between the variables is therefore Spearman's rank correlation coefficient, a non-parametric test.

We found that some of the grouping variables are correlated with (the responses to) more than one of the questionnaire variables, and that some of these correlations are positive and some negative. Given the variety in the scaling and meaning of the questionnaire questions, it seemed perfectly possible that an influential grouping variable could influence the response to one questionnaire variable in one direction and the response to another questionnaire variable in another direction. Therefore, the total number of significant correlations regardless of sign was considered an appropriate indicator of each grouping variable's influence on the (responses to the) questionnaire variables.

In table 6.2, the cell entries in the row labelled "N" are the total number of correlations significant at 5% between the grouping variable (identified by column) and any of the questionnaire variables. The cell entries in the row labelled "n" are the number of correlations significant at 10%.

The significance of a grouping variable over all 30 questionnaire variables is tested using a binomial test. In this test, a grouping variable is significant over all 30 questionnaire variables if the Bernoulli probability, P (X | n, p) for the observed number of individual relationships significant at 5% is smaller than or equals .05. The number of individually significant correlations is taken as the number of successes X, the number of questionnaire variables (30) is taken as the number of observations n, and the overall significance level (5% and 10% respectively) is taken as the probability of success p. If a grouping variable is overall significant by the binomial test, this indicated in the row labelled "Significance".

Table 6.2

Results of correlation analysis of questionnaire-responses vs. grouping variables

	Educbu	Experie	Functio	Industry	Involve	Level	Position	Qualific	Sector
N	4	3	9	10	3	3	1	4	9
n	5	4	12	11	3	5	6	5	12
Significance	S	ns	S	S	ns	ns	s	S	S
Importance	3	(6)	2	1	(7)	(5)	4	3	2

Note: S = significant at 5% level of significance, s = significant at 10% level of significance.

Again, interpretations must be cautious, as the entries in this table are not independent of each other, being affected by the mutual correlations among the grouping variables and the mutual correlations among the questionnaire variables.

Among all the grouping variables, Industry, Sector and Function show the highest number of significant correlations (10, 9, and 9 at 5% significance), followed by Business Education and Qualification, (4 at 5% significance) followed by Position (6 at 10% significance). This could be interpreted to mean that these are the grouping variables that are the most important in explaining and predicting the questionnaire responses.

A cautious interpretation of this result would note that two of the grouping variables, Sector and Industry overlap by definition, and that many of the questionnaire variables partially operationalise the details of the differences between Sectors and Industries. The resulting correlations are only to be expected. The more substantively interesting part of the correlation results is that Function and Business Education seem to have an effect on the questionnaire responses at the 5% significance level, though it is clearly vital to check that this is not an artefact due to sampling, e.g. due to there being an unusually high average level of "Function" or "Business Education" among the respondents in one of the industries or sectors. According to the principal components analysis conducted in section 5.1.1.2, there is little redundancy in the grouping variables beyond the definitional ones, i.e. the same levels of different variables do not systematically occur together. This suggests that the importance of the grouping variables Function and Business Education in the correlation analysis may not be due to sampling artefact.

6. Findings from the questionnaire survey and comparison with findings from the experiment

ANOVA of questionnaire responses by grouping variables

In order to double-check the above results of the non-parametric Spearman correlation analysis, in this paragraph we report a parametric One-Way ANOVA of questionnaire variables split by grouping variables.

The responses to most questions in the questionnaire were measured on a Likert scale of 1 to 5. This is a non-parametric measure and so, if formal inference is required, it must be analysed by non-parametric methods. For non-parametric data such as these, a parametric test would be excessively powerful, i.e. biased in the direction of rejecting the null hypothesis. However, in the present research, the main purpose of the proposed ANOVA is not to perform inference as such, but to identify potentially non-random patterns, to be further discussed and to be compared with results from other statistical tests. For this purpose, this parametric test seems adequate and its excessive sensitivity should not be a problem, provided a conservative 5% confidence interval is used, and if the results are only used to corroborate and interpret the non-parametric correlation results. (In fact, the full sample is so large (n=82), that on the one hand all parametric tests will include normal approximations, and on the other hand the test statistics themselves are converging towards the normal distribution, though their significance levels will not be those tabulated for the normal distribution (cf. Isa, 1994).

The results of the One-Way ANOVA of questionnaire variables by grouping variables are summarised in table 6.3. We mark with a large cross all 5%-significant differences in the questionnaire questions, between subgroups of respondents as defined by the grouping variables. Differences with a significance level between 5% and 10% are marked with a small cross. In the row labelled "N", the number of occurrences of differences in questionnaire responses significant at 5% is displayed for each grouping variable. In the row labelled "n", the number of occurrences of significant differences at a significance level of 10% is displayed for each grouping variable. The row labelled "Signif" gives the overall significance of the results for a grouping variable, derived as before using a binomial test and the row "ANOVA" gives the ranking of the grouping variables as identified by ANOVA. The row "Correlation" restates the ranking of the grouping variables as identified by the correlation analysis reported in Table 6.2. The row "Empirical" combines correlation analysis and ANOVA results to form the empirical ranking of the grouping variables regarding their importance for the questionnaire variables/openness. In the column labelled "H" we restate our hypothesis on the expected relative importance of the grouping variables for openness to the real options concept (from the column entitled "RI 9" of Table 4.10).

Table 6.3

Results of One-Way ANOVA of questionnaire-responses by grouping variables

	Educbu	Experie	Functio	Industry	Involve	Level	Position	Qualific	Sector
Perc fu	X		x		X				
Fu r&d	x		x		X	X	x	x	x
Fu mark			X	x					X
Fu IT		X			x			x	
Fu proc				X	X	x		x	
Fu contr						X		X	
Fu other		X							
Treat fu				X					X
Fu quan				X		x			
sure pp	X		X		X				
Avg life				X				x	
Difficul	X		x	X			X		
Fore mc					X			X	
Fore co			X	X	X			X	X
Fore pc			X	x					X
Red unc			X						
Test tim	x		X	X				X	
Sd 30				X			x		X
Sd				x			x		X
X uncer				X		X	x		x
Pl hor8				X		X		X	X
Pl hor				X					X
Dev t3				X		x			x
Dev t				X		X			X
Fu5									x
Fu		X		x				x	
Single p			X						
Don't or	x		X	X	X	x	x		X
Add dat			X	x					
Stra pol	x	X		X					X
N	3	4	9	15	7	5	1	5	11
n	5	4	12	19	8	9	6	10	15
Signif.	ns	S	S	S	S	S	s	S	S
ANOVA	(9)	7	3	1	4	6	8	5	2
Correl.	3	(6)	2	1	(7)	(5)	4	3	2
Empirical	ns	ns	3	1	ns	ns	5	4	2
H	2	1	1	n/a	2	2	1	1	1

Note: X = difference is significant at 5%, x = difference is significant at 10%, N = number of significant values at 5%, n = number of significant values at 10%, ns or ( )= not significant, S = significant at 5%, s = significant at 10%, "?" = combined importance doubtful.

6. Findings from the questionnaire survey and comparison with findings from the experiment

As might have been expected, the excessively powerful ANOVA test rejects the null-hypothesis for most of the grouping variables (in fact for all grouping variables except Business Education). However, the ANOVA results can be used to estimate the relative importance of the grouping variables by counting the number of significant results.

Overall, according to One-Way ANOVA, the grouping variables Industry, Sector, and Function (15, 11, and 9 times significant at 5%) appear to have the highest influence on the questionnaire responses. This corroborates the results of the Spearman correlation analysis for these grouping variables. The grouping variable Qualification is a distant fourth. However, for the grouping variables Business Education, Involvement and Position, the results from the correlation analysis and the ANOVA differ. According to the correlation analysis, Business Education is the third most important grouping variable (4 times significant at 5%) but it is insignificant in ANOVA. Conversely, Involvement is the fourth most important grouping variable as identified by ANOVA but it is insignificant in the correlation analysis. The grouping variable Position, which was found weakly significant (at 10%) in the correlation analysis is found, in ANOVA, to be the grouping variable which is least significant). We conclude that the true influence of the grouping variables Business Education, Involvement and Position on the questionnaire responses is doubtful.

Our hypothesised ranking was not confirmed by the empirical ranking, which shows a considerably higher variety. We note, however, that all variables hypothesised to be less important (Level, Involvement, and Business Education) turned out to be insignificant in the empirical ranking. Although a formal decision on the hypothesis might remain doubtful, this can be considered at least weak empirical evidence in favour of our hypothesis. The next research issue (10), on the direction of a grouping variable's influence on openness, will be examined in section 6.2.2.2b.

Comparison of grouping variables influential over empirical case study valuations and questionnaire responses respectively

Having established, through non-parametric correlation analysis and One-Way ANOVA, that Industry, Sector and Function are the grouping variables that have the strongest overall predictive value for the questionnaire responses, it is interesting to compare this list with the list of grouping variables that have the strongest overall predictive value for the empirical case study valuations, as established through the various statistical tests performed in sections 5.1.3.1 to 5.1.3.4 and summarised in section 5.1.3.4.

Table 6.4 lists the grouping variables influential on the empirical case study valuations and on the questionnaire responses respectively, in order of their importance.

Table 6.4 Comparison of the grouping variables' influence regarding case study valuations and questionnaire responses

Grouping variables influential over:	
Empirical case study valuations	Questionnaire responses
1 Sector	1 Industry
2 Industry	2 Sector
3 Experience	3 Function
6 Function	

As can be seen in table 6.4, grouping variables Sector and Industry are the most important grouping variables for both the empirical case study valuations and the questionnaire responses. These two variables overlap, as previously noted. It is interesting that the overlapping grouping variables Industry and Sector have a significant influence over the empirical case study valuations. On the other hand, their strong influence on the questionnaire responses seems trivial, since many questions in the questionnaire ask about specific company and industry settings.

Experience, however, is influential only over the empirical case study valuations and Function is influential only over the questionnaire responses. It seems that "Function" influences managers' attitudes towards real options, but that the resulting variations in attitudes do not influence their valuations of the case studies.

6. Findings from the questionnaire survey and comparison with findings from the experiment

One reason why a high level of Experience might make for higher case study valuations is the potentially high self-confidence of this subgroup. On the other hand, self-confidence is irrelevant for answering the questions in the questionnaire which largely request objective information, so the same factor would also explain the insignificance of Experience in explaining questionnaire responses.

The grouping variable Function, i.e. commercial vs. financial mangers, is not an important influence on the case study valuations but it does influence the responses to the questionnaire questions. Its effect on the questionnaire responses might arise because the latter make the respondents describe the investment decision making contexts they face, the perception of which might be different between the commercial or financial functions.

The grouping variable Industry is an important correlate both of the empirical case study valuations and for the questionnaire responses. Unlike the other grouping variables, which all split the sample into two subgroups, Industry categorises the sample into five subgroups (the oil industry, the aerospace industry, the telecommunications industry, the pharmaceuticals industry, and the brewing industry).

It is not clear which of the five Industry subgroups account for most of the overall significance of the grouping variable Industry in explaining the questionnaire responses. To answer the resulting question which pairs of industries show the most different questionnaire responses we performed pairwise comparisons of the questionnaire responses by the five industries. We use the multiple comparison procedure "modified

LSD (Bonferroni) test" with significance level .05. Pairs of industries whose questionnaire responses were found significantly different in the Bonferroni test are displayed in table 6.5.

Table 6.5

Results of Modified LSD (Bonferroni) test with significance level .05 for grouping variable Industry

Qu. var.	Fu proc	Treat fu	Fu quant	Avg life	Difficult	Forec co	Test tim	Sd 30
Pairs of	1-3	2-4	4-5	2-3	1-2	1-4	3-5	2-5
industries	2-3	3-4		3-4	1-3	1-5	4-5	
	3-4	4-5				2-4		
	3-5					2-5		
Qu. var.	**X uncert**	**Pl h8**	**Pl hor**	**Dev t3**	**Dev t**	**Don't org**	**Strat Pol**	
Pairs of	2-5	2-4	2-4	2-4	2-5	1-4	3-5	
industries	3-5	2-5	2-5		3-5	2-4		
	4-5	3-5						

The predominant pattern in the table is that, in many of the occupied cells, questionnaire responses by one of the first three industries are different from questionnaire responses by one of the last two industries (industries 4 and 5). Only 8 out of the 33 significant comparisons do not conform to this pattern. This finding corresponds to the division of the sample by the grouping variable "Sector" into the two Sectors capital goods Sector (industries 1 to 3) and consumer goods Sector (industries 4 to 5). It confirms that summarising the first three industries in the "low level" of "Sector" and the last two industries in the "high level" of "Sector" is efficient, and that Sector and Industry largely overlap in their practical effects as well as in their definitions.

6.2.2.2b Direction of the grouping variables' influence on the questionnaire-responses (Research issues 10 and 11)

Having identified which grouping variables have an important influence on the questionnaire responses, we were interested in examining the direction in which these important grouping variables affected the questionnaire responses and the construct of openness towards real options (which is based on the latter). This corresponds to research issue 10 (as defined in Table 4.8). Furthermore, we will examine in what direction the respondents' openness toward real options may influence their case study valuations (research issue 11 as defined in Table 4.8). We will use the empirical findings on these issues which are summarised in Table 6.7, to test our hypotheses on these issues.

As mentioned before, the four sections of the questionnaire (namely (1) the occurrence of growth options in the respondent's industry, (2) the perceived realism of the assumptions underlying real options theory in general, and the Black-Scholes model in particular, (3) the perceived realism of the option parameter settings assumed in the case studies, and (4) the general investment decision making practices in the respondents' company) mainly served to examine the extent and nature of respondents' exposure to real options-type investments, and their attitudes towards the assumptions of real options theory. In order to better be able to compare this information with the other statistical findings, we attempted to further summarise these notions into a single construct which we termed "openness towards the real options approach to investment decision making" (or shorter, "openness towards real options", or just "openness". We also used this construct to state that certain subgroups are more or less "open (towards real options)" than others).

In order to formally summarise the questionnaire variables into this construct, we examined what each questionnaire variable would imply about a respondent's exposure to real option-type investments and his or her attitude towards the assumptions of real options theory. In the row Openness in table 6.6, a questionnaire variable is assigned a plus sign if it has a suspected positive impact on the openness towards real options (vice versa for a minus sign). The underlying rationale was that exposure to real option-type investments, and agreement with the assumptions of real options theory, as measured through the questionnaire variables, would both increase a respondent's openness towards real options. In the first step of examining the direction of the important grouping variables' influence on "openness towards real options", we computed the average questionnaire responses for the subgroups of respondents as defined by the grouping variables and tested the differences between the subgroups for statistical significance. We performed a non-parametric Mann-Whitney test for the eight dichotomous grouping variables and a non-parametric Kruskal-Wallis test for the multi-level grouping variable Industry.

The Kruskal-Wallis test generally indicates whether there are significant differences among the industries. In order to detect which industries caused these significant differences, we used the results from the multiple comparison procedure Bonferroni test in table 6.5. Table 6.5 gives results for almost all of the questionnaire variables found significant by the Kruskal-Wallis test (the only exceptions were the questionnaire variables Forec pc (significant at 10%) and Sd (significant at 5%), which consequently could not be included in the present part of the analysis). For each of these questionnaire variables, in table 6.5 one industry (or very rarely two industries) was part of most of the pairs of significantly different industries, as identified by the Bonferroni test and could therefore be considered to be causing the significant differences. These industries, for each questionnaire variable, appear shaded in table 6.6.

The table contains in its columns the 30 questionnaire variables and in its rows the total sample and the subgroups of respondents, as defined by the grouping variables. Dark shaded areas in the table indicate that responses by the respective subgroups are significantly different at 5%, light shaded areas indicate significance at 10%.

Table 6.6

Significant differences in subgroups' questionnaire responses

		(1) Occurrence of growth options in the respondent's industry									
	L.	Perc fu	Fu r&d	Fu mar	Fu IT	Fu pro	Fu con	Fu oth	Treat f	Fu qua	Sure p
Openness		+	+	+	+	+	+	+	+	+	-
Average		0.4	3	2.7	2.3	2.8	2	1.7	2.2	4.1	2.3
Business Education	0	0.53	3.3	2.9	2.1	2.7	1.9	1.7	2.3	4.2	2.6
	1	0.27	2.7	2.5	2.4	2.8	2	1.6	2.2	4	2.1
Expe-rience	0	0.43	3.1	2.9	2.6	2.9	2.1	1.3	2.1	4	2.4
	1	0.36	2.9	2.5	1.9	2.6	1.8	2	2.3	4.1	2.3
Function	0	0.46	3.3	3	2.3	2.9	1.8	1.6	2.3	4.1	2.6
	1	0.32	2.7	2.4	2.2	2.6	2.1	1.7	2.2	4.1	2
Industry	1	0.53	2.8	3	2.6	3	1.6	2.3	1.9	4.3	2.6
	2	0.43	2.9	2.5	2.4	3	2.1	1.6	2.4	4.1	2.4
	3	0.3	2.3	2	1.9	1.3	1.4	2	2.6	4.3	2.3
	4	0.32	3.1	2.9	2.1	2.7	1.8	1.4	1.6	3.5	2.2
	5	0.48	3.8	3.3	2.3	3.3	2.3	1.6	2.7	4.8	2.1
Involve-ment	0	0.52	3.6	2.9	2.5	3.2	1.9	1.6	2.1	4.1	2.8
	1	0.29	2.5	2.6	2.1	2.5	1.9	1.6	2.3	4.1	2
Level	0	0.37	3.3	2.8	2.4	3	2.4	1.7	2.3	3.8	2.4
	1	0.42	2.6	2.7	2.1	2.5	1.4	1.7	2.1	4.3	2.1
Position	0	0.42	3.2	2.8	2.3	2.9	1.9	1.7	2.2	4.1	2.4
	1	0.32	2.6	2.4	2.2	2.5	2.1	1.4	2.2	3.9	2.1
Qualifi-cation	0	0.56	3.7	3.1	2.8	3.3	2.4	1.4	2.3	3.8	2.9
	1	0.37	2.9	2.7	2.2	2.7	1.9	1.7	2.2	4.2	2.2
Sector	1	0.42	2.8	2.5	2.3	2.7	1.9	1.8	2.4	4.2	2.4
	2	0.37	3.3	3.1	2.2	2.9	2	1.5	2	4	2.2

Note: [dark shading] = difference significant at 5%,
[light shading] = difference significant at 10%,
+ : pos. effect, - : neg. effect, o : no effect.

Table 6.6 (continued)

(2) Perceived realism of the assumptions underlying real option theory											
	L.	Avg lif	Difficul	Fc mc	Fc co	Fc pc	Red un	Tes ti	Sd 30	Sd	X unc
Openness		o	-	o	o	o	+	o	-	+	-
Average		18.5	3.1	1.5	2.2	2.9	3.3	1.12	3	0.23	3.3
Business Education	0	19.4	2.8	1.7	1.9	2.8	3.4	1.31	3.1	0.21	3.3
	1	17.9	3.4	1.3	2.4	3	3.3	0.97	2.7	0.24	3.4
Expe-rience	0	18.3	3.2	1.7	2.1	2.7	3.3	1.1	2.9	0.22	3.2
	1	18.8	3	1.4	2.3	3.3	3.3	1.1	3.1	0.24	3.4
Function	0	19.2	2.9	1.5	1.8	2.4	3.6	1.29	2.9	0.17	3.2
	1	17.6	3.5	1.6	2.7	3.6	3	0.86	3	0.26	3.5
Industry	1	18	1.9	2.3	3.3	3.7	3	1	3.5	0.1	2.7
	2	22.5	3.4	1.5	3.1	3.3	3.2	1.38	2.4	0.32	3.5
	3	10.1	4	0.9	1.8	3.1	4	0.6	3.1	0.2	4
	4	17.5	2.9	1.6	1.4	2.8	3.1	0.82	3.1	0.1	3.4
	5	17.5	3.1	1.6	1.4	2.1	3.8	1.64	3.6	0.13	2.3
Involve-ment	0	17.1	3.2	1.9	1.8	3	3.4	1.22	3	0.15	3.4
	1	19.9	3.3	1.2	2.5	2.9	3.4	1.07	2.9	0.27	3.3
Level	0	18.6	3	1.7	2.2	2.8	3.3	1.22	3	0.26	3
	1	18.6	3.3	1.3	2.1	3.1	3.3	0.97	3	0.2	3.6
Position	0	18.5	2.9	1.7	2.2	2.8	3.4	1.07	3.1	0.21	3.2
	1	18.5	3.8	1.1	2.2	3.3	3.2	1.5	2.6	0.39	3.7
Qualifi-cation	0	20.9	2.5	2.3	1.3	2.3	3.4	1.61	2.9	0.1	3.4
	1	18.1	3.2	1.3	2.3	3	3.4	1.05	2.9	0.23	3.4
Sector	1	19.2	3.2	1.5	2.9	3.3	3.3	1.12	2.7	0.27	3.5
	2	17.5	3	1.6	1.4	2.5	3.4	1.12	3.3	0.12	3

Table 6.6 (continued)

		(3) Perceived realism of option parameter settings assumed in the case studies						(4) General investment decision making practices in the respondent's company			
	L.	Pl hor8	Pl hor	Dev t3	Dev t	Fu5	Fu	Singl p	Do org	Ad dat	Str pol
Openness		o	o	o	+	o	o	-	-	-	o
Average		2.4	10.9	3.4	3.16	4.1	10.7	3.6	2.7	3.3	4.4
Business Education	0	2.4	11.5	3.3	3.53	4	11.1	3.5	3	3	4.5
	1	2.3	10.8	3.4	3.08	4.1	10.2	3.6	2.5	3.5	4.3
Expe-rience	0	2.4	10.8	3.4	2.89	4.1	9.1	3.6	2.5	3.1	4.3
	1	2.3	11	3.3	3.47	4.1	12.1	3.5	2.9	3.4	4.6
Function	0	2.5	10.5	3.3	3.32	4.1	10.5	3.2	3	3.7	4.4
	1	2.2	11.4	3.5	3.07	4	10.9	4	2.3	2.8	4.4
Industry	1	2	13.8	2.7	3.5	3.8	10.8	2.9	2.1	2.3	4.5
	2	1.7	14.4	3.8	3.88	4.3	11.7	3.9	2.5	3.2	4.5
	3	1.9	11.1	3.6	5	4.1	9.4	3.5	2.4	3.8	4.7
	4	2.9	6.7	2.7	2.25	3.8	7.3	3.7	3.6	3.3	4.4
	5	3.5	5.9	3.5	1.53	4	13.5	3.2	2.5	4	4
Involve-ment	0	2.4	10.7	3.4	3.38	4.1	10.5	3.6	3.1	3.5	4.4
	1	2.2	11.3	3.4	3.2	4	10.6	3.6	2.3	3.2	4.3
Level	0	2.7	9.8	3.1	2.36	4.1	10	3.4	3	3.3	4.4
	1	1.9	11.6	3.6	3.99	4	11.5	3.8	2.4	3.2	4.4
Position	0	2.4	10.5	3.3	3.33	4.1	11	3.6	2.5	3.3	4.4
	1	2.2	11.7	3.4	2.78	3.9	9.8	3.4	3.2	3.4	4.4
Qualifi-cation	0	3.2	8.1	3.7	2.64	4.2	7.3	3.2	2.7	3.9	4.4
	1	2.2	11.6	3.3	3.22	4	11	3.5	2.8	3.2	4.4
Sector	1	1.8	13.7	3.6	4.04	4.2	11	3.6	2.4	3.2	4.6
	2	3.1	6.3	3.1	1.82	3.9	10.1	3.5	3.2	3.5	4.2

Before we go on to the second step in examining the direction of the important grouping variables' influence on "openness towards real options", we reconsider which "important" grouping variables to include. The grouping variables found influential over the questionnaire responses in section 6.2.2.1 (table 6.4) were Industry, Sector, and Function.

At this point, it should be noted that, as can be seen from table 6.6, the significant differences for the grouping variable Sector provide hardly any additional information to those from the grouping variable Industry. We therefore restrict the present analysis to the grouping variables Industry and Function only.

From table 5.1.20 we concluded that the oil industry is clearly the most rational (in real option terms) in its mean case study valuation responses. The brewing industry is the least rational, while the differences between the aerospace, telecommunications, and pharmaceuticals industries are small. In the present analysis, we will therefore focus on the oil and brewing industries, as being the most contrasted in terms of their mean empirical case study valuations.

As the second step in examining the direction of the grouping variables' influence on openness, in Table 6.7, for the two subgroups of each Industry and Function, we indicate (in row "Avg. val") whether a subgroup's average value in a (significant) questionnaire variable is higher (plus sign) or lower (minus sign) than the corresponding subgroup's average value. We also restate the questionnaire variables' theoretical effect on openness, (from Table 6.6 in row "Openness"). Combining both the signs in rows "Openness" and "Avg. val" gives the direction of the questionnaire variable's influence on "Openness towards real options", as indicated in the row "Influen.". The column "Net" gives the net number of positive and negative influences for each subgroup, a measure of a subgroup's openness towards real options.

Table 6.7

Grouping variables' influence on respondents' openness towards real options

(1) "Industry"											
	Qu. var.	Diff	Test tim	X unc	Dev t						Net
	Openness	-	-	-	+						
Oil Industry	Avg val.	-	-	+	+						
	Influen	+	+	-	+						2+
Brewing Industry	Avg val.	+	+	-	-						
	Influen	-	-	+	-						2-
(2) "Function"											
	Qu. var.	Fu R&D	Fu mark	Sure pp	Difficul	X unc	Single p	Don org	Add dat		Net
	Openness	+	+	-	-	-	-	-	-		
Commerc Managers	Avg val.	+	+	+	-	-	-	+	+		
	Influen	+	+	-	+	+	+	-	-		2+
Finance Managers	Avg val.	-	-	-	+	+	+	-	-		
	Influen	-	-	+	-	-	-	+	+		2-

Note: + : positive influence, -: negative influence.

As can be seen from the table, the oil industry is more open towards real options (2 net positive influences) than the brewing industry (2 net negative influences). Generally, we can say that a "high" level of the grouping variable Industry has a negative influence on openness (we mark this with a minus sign in row "Industry"). The analysis in section 5.1.2.1 showed that the oil industry overvalued the case studies least and was therefore the most rational (in real option terms) in its decisions on the case studies (therefore this industry is both more open and more rational), while the brewing industry overvalued the case studies the most and was in that sense the least option-rational industry (brewing industry managers are less open and less rational).

Furthermore, considering Function, financial managers show less openness towards real options (2 net negative influences) than commercial managers (2 net positive influences). Consequently a high level of the grouping variable Function has a negative influence on openness (plus sign in row "Function"). However, financial managers overvalued the case studies less and decided therefore more rationally (in real options terms) than commercial managers (from 5.1.2.2) (hence the financial managers are less open and more rational).

Comparing the findings for both these grouping variables (Industry and Function) shows that our construct "openness towards real options" does not seem to be a uniformly useful predictor of respondents' valuation, and can itself not be predicted from the other grouping variables.

We now compare these empirical findings with our hypotheses on research issues 10 and 11. Our hypothesis on research issue 10, the direction of the influence of the grouping variables on openness is contained in the column labelled "RI 10" of Table 4.10. It hypothesises a positive influence of the oil industry (empirical: positive), no influence for the brewing industry (empirical: negative) and a negative influence of grouping variable Function (empirical: negative). The empirical evidence therefore seems to agree with our hypothesis.

Our hypothesis on research issue 11 (as set up in section 4.7), concerning how respondents' "openness towards real options" may influence their case study valuations is that openness tends to produce more correct valuations. This is true for oil versus brewing but not for commercial managers versus financial managers.

We perform an "additional check" for research issue 11 by comparing the various grouping variables' relative importance for openness on the one hand and for the case study valuations on the other hand. From Table 6.11 we can see that no differences in openness exist between the pairs of subgroups defined by the grouping variables Experience, Level, Involvement and Business Education. It is in accordance with the hypothesis on research issue 11 that among all grouping variables, the grouping variables Level, Involvement, and Business Education produce the least differences in the empirical case study valuations. It is in contrast to the above argument on the coincidence of openness and correct valuation that the grouping variable Experience is not important for openness but is important for the valuations. Conversely, the grouping variable Function is important for openness but not for valuation behaviour..

Given the inconclusive empirical evidence, we can neither clearly accept or reject our hypothesis on research issue 11.

We will return to these findings on a more interpretative level in Chapter 7. Our last research issue, namely the influence of important questionnaire variables on the empirical case study valuations will be examined in section 6.3.2, after having identified, in section 6.3.1, which of the questionnaire variables are the most important.

6.2.3 Spread or variance in the questionnaire responses by subgroups of respondents

In the procedure of Chapter 5, having examined the means of the questionnaire responses, we compared the spreads or variances of the questionnaire responses between subgroups of respondents, as defined by the grouping variables. However, it is probably not meaningful to examine the spread in the questionnaire responses for subgroups of respondents. We saw no particular reasons why e.g. "all senior people" should be particularly unanimous regarding the questionnaire questions (i.e. that they should answer all the questions, many of which ask about specific company (and therefore industry) settings similarly). Any statistically significant findings would be very hard to interpret and might well represent sampling artefacts. We therefore omit analysis of the spreads in the questionnaire responses.

6.3 The relationship between case study valuations and questionnaire-responses (Research issue 12)

In the previous section, we examined how attitudes towards real options are apparent from the questionnaire responses. We explained the influence of attitudes (openness) towards real options on case study valuation behaviour by measuring grouping variables' influence on both. We now examine whether questionnaire responses can be used directly to explain case study valuations. Section 6.3.1 tries to identify those questionnaire variables which are (individually) important for the empirical case study valuations. For these important questionnaire variables, and in particular for "familiarity with the case study settings", in section 6.3.2, we will test our hypothesis regarding the influence of such variables on respondents' case study valuations (Research issue 12, as defined in section 4.7).

6.3.1 Identification of the questionnaire variables that are influential over the empirical case study valuations

The objective in this section is to identify the questionnaire variables which are influential over (or more strictly, correlated with) the empirical case studies valuations. In order to check for differences between the mean empirical case study valuations of different subgroups of respondents, as defined by their questionnaire responses, both non-parametric and parametric tests are performed.

Non-parametric correlation of case study- valuation versus questionnaire-responses

In the present data, the empirical case study valuations are at an interval level of measurement, and the Likert scale questionnaire responses are at an ordinal level of measurement. Therefore, an appropriate measure of the relationship between the variables is non-parametric. Our choice was Spearman's rank correlation coefficient.

6. Findings from the questionnaire survey and comparison with findings from the experiment

We found that some of the questionnaire variables were correlated with the empirical case study valuations. Some of these correlations were positive and some negative. It is not clear that a questionnaire variable ought always act in the same sense for (valuations of) all case studies, and irrespective of the setting of other questionnaire variables. Potential interactions between questionnaire variables could lead to a given questionnaire variable's influencing the empirical case study valuations in different ways depending on the settings of other questionnaire variables. Moreover, it is conceivable that the direction of a questionnaire variable's influence depends also on the joint levels of the quantitative parameters underlying the case studies.

Therefore, it seems not impossible that an influential questionnaire variable might influence the valuation response to one case study in one direction and the valuation response to another case study in another direction. The total count of both positive and negative significant correlations was considered to be an appropriate indicator for the total influence of a questionnaire variable on the empirical case study valuations.

Table 6.8 summarises the results from the correlation analysis. The rows labelled "N" contain, for each questionnaire variable (columns), the number of correlations significant at 5% (regardless of sign) and the rows labelled "n" contain the number of correlations significant at 10% .

The tendency of a questionnaire variable to show an excess of significant correlations with the respondents' case study valuations across all 14 case studies is tested using a binomial test. In this test, a questionnaire variable is significant over all 14 case studies if the Bernoulli probability P(X | n, p) is less than or equal to .05. The number of individually significant correlations is taken as the number of successes X, the number of case studies (14) is taken as the number of observations n, and the overall significance level (5% and 10% respectively) is taken as the probability of success p. The results from the binomial test are given in the row labelled "Sig".

Table 6.8

Results of correlation analysis of case study- vs. questionnaire-responses

	Perc fu	Fu r&d	Fu mar	Fu IT	Fu proc	Fu cont	Fu othe	Treat f	Fu qua	Sure pp
N	0	2	0	2	2	0	0	1	1	2
n	1	3	0	3	2	0	1	2	3	2
Sig.	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	Avg lif	Difficul	Fore mc	Fore co	Fore pc	Red unc	Tes tim	Sd 30	Sd	X uncert
N	0	1	0	1	1	0	1	1	0	0
n	1	1	0	2	1	1	1	2	2	0
Sig.	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	Pl hor8	Pl hor	Dev t3	Dev t	Fu5	Fu	Single p	Don org	Add dat	Stra pol
N	3	1	0	0	1	0	3	1	4	2
n	4	1	0	2	1	2	3	2	5	3
Sig.	S	ns	ns	ns	ns	ns	S	ns	S	ns

Note: ns = not significant at 10%, S = significant at 5%.

The only questionnaire variables found significant (at 5%) by correlation analysis of case study-versus questionnaire-responses are "Pl hor 8", "Single p", and "Add data". We will explain these variables and interpret this finding after an additional double-check, using ANOVA, in the next section.

ANOVA of case study valuations by questionnaire responses

In order to double-check the results from the non-parametric Spearman correlation analysis, a parametric One-Way ANOVA of case study valuation responses by questionnaire variables is performed.

A basic assumption underlying the analysis of variance is that several sample means are obtained from normally distributed populations having the same variance. However, the test procedure has been found to be relatively unaffected by violations of the normality assumption provided the populations are unimodal and the sample sizes are approximately equal (Kazimir, 1988). The assumption of unimodal populations seems reasonable for the subgroups as defined by the questionnaire variables, since the set of all the valuation responses to most of the case studies had been shown to be approximately normal, (cf. section 5.1.2.1).

The results of the One-Way ANOVA of mean empirical case study valuations when grouped by questionnaire variables are summarised in table 6.9. Differences significant at 5% in the case study valuations between the subgroups of respondents as defined by the questionnaire variables are marked with a large cross. Differences with a significance level of 10% are marked with a small cross. In the column labelled "N", the number of occurrences of differences significant at 5% for each questionnaire variable is displayed and in the column labelled "n", the number of occurrences of differences significant at 10% is displayed. The column labelled "Sig." gives the overall significance of the results for each grouping variable, derived as before using a binomial test.

Table 6.9

Results of One-Way ANOVA of case study by questionnaire responses

	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2	N	n	Sig
Perc fu	-	-	-							-	-	-	-	-	0	0	ns
Fu r&d				X		X							x		2	3	ns
Fu mark															0	0	ns
Fu IT					X							X			2	2	ns
Fu proc												X	X		2	2	ns
Fu contr															0	0	ns
Fu other													x		0	1	ns
Treat fu		X			x			X							2	3	ns
Fu quan															0	0	ns
Sure pp	x														0	0	ns
Avg life					X					X				X	3	3	S
Difficult															0	0	ns
Fore mc												X		X	1	1	ns
Fore co											X	x	X		2	3	ns
Fore pc								X		x					1	1	ns
Red unc															0	0	ns
Test tim								X	X						2	2	ns
Sd 30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ns
Sd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ns
X uncert															0	0	ns
Pl hor8			x			X			x			X			2	4	s
Pl hor				x		X									1	2	ns
Dev t3															0	0	ns
Dev t															0	0	ns
Fu5			X		x										1	2	ns
Fu															0	0	ns
Single p	X												X		2	0	ns
Don't or								x							0	1	ns
Add dat							x		X				x		1	4	s
Stra pol				X		x		X							2	3	ns

Note: X = significant at 5% level of significance, x = significant at up to 10% level of significance, N = number of X's, n = number of X's and x's, ns = overall not significant at 10% , S = overall significant at 5%, s= significant at 10%.

6. Findings from the questionnaire survey and comparison with findings from the experiment

As shown in the table, the only questionnaire variables that were found overall significant by ANOVA were Avg life (at 5% significance), Pl hor8, and Add data (both at 10% significance).

For six of the questionnaire variables, the measurement scales used might well account for the low significance. The questionnaire variables that are measured on continuous scales such as years (Test tim, Pl hor, Dev t, and Fu), or as a proportion (Perc fu), or as a standard deviation (Sd) have a very high number of levels. Because of this, it is hard to find sufficient frequencies for each level of these questionnaire variables in the present sample. To sum up, it is not realistic, given the present sample size, to obtain significant ANOVA results for those of the questionnaire variables that are not measured by 5- or 6-point Likert scales.

A comparison of the ANOVA with the preceding correlation analysis shows that questionnaire variables "Pl hor 8" and "Add data" are significant in both analyses. Questionnaire variable "Single p", which is significant in the correlation analysis, is close to being also overall significant (it is twice individually significant) in the ANOVA. In the next section these three questionnaire variables will therefore be examined regarding their influence on the empirical case study valuations (Research issue 11). The questionnaire variable "Avg life", which is significant in ANOVA, is far from being significant in the correlation analysis and will therefore not be further analysed.

6.3.2 *Direction of a questionnaire variable's influence on the empirical case study valuations*

In this section, we will use the empirical findings on the important questionnaire variables, to test our hypothesis on research issue 12. Our hypothesis on the first important questionnaire variable, Pl hor 8 (from section 4.7), states that familiarity with the case study settings should generally lead to more correct (in B-S terms) case study valuations.

The questionnaire question corresponding to questionnaire variable Pl hor8 is (from Appendix 4.1):

> "A planning horizon of 8 years is too long for my industry"
>
> (1 = strongly disagree, to 5 = strongly agree)

Pl hor8 is positively correlated with respondents' valuations of case studies A3 and C1 (both overvalued) and negatively correlated with respondents' valuations of case studies A4 (valued correctly) and A6 (undervalued). The positive correlation (with A3 and C1) means: the more the respondents are used to a planning horizon shorter than eight years in their own industry the higher they value these case studies. For case study C1 the reason seems clear: C1 is the only case study with a shortened planning horizon (six years instead of eight years). Respondents who are used to short planning horizons in their own work possibly "overreact" on recognition of this familiar investment situation, and they increase the value they put on it. The text of case study A3 relates to a Polish test market and a Russian market follow-up. Managers who are used to short planning horizons might be habitually more adventurous (because the investments they actually face are more easily reversible) and therefore more keen on this venture-like investment.

The negative correlations (with A4 and A6) mean: the more respondents are used to a planning horizon of eight years or longer, the more they "like" investments A4 and A6. The text of case study A6 is on micro chip production. Planning horizons tend to increase the farther the industry is away from consumer products. Accordingly, respondents from capital goods industries might overreact (overvalue) on recognition of the familiar microchip investment.

The empirical evidence is inconclusive regarding the hypothesis that familiarity with the case study settings leads to more correct case study valuations. We therefore neither accept nor reject this hypothesis.

In order to double-check this conclusion, we consider which of the case study parameter settings the respondents were on average most familiar with, according to the questionnaire variables (which had not been found important in section 6.3.1).

In questionnaire item "Sd", respondents estimate a volatility of 23% for a typical investment. The case studies with a volatility closest to this value are case studies B1 (17% volatility) and B2 (32% volatility). From Table 5.13, cases B1 and B2 are overvalued (167% and 195%) which is more than the average overvaluation (79%).

6. Findings from the questionnaire survey and comparison with findings from the experiment

In questionnaire item "Dev t", respondents estimate the development time until a pioneer project can lead to a follow-up investment (the time-to-maturity of the real option) to be on the average 3 years and 2 months. In questionnaire item "Test tim", respondents estimate that market research and test marketing usually take 1 year and 1 month. The mean of questionnaire item "Dev t" implies that respondents are used to the development time of 3 years used in the case studies of the A- and B-sequences, and the mean of questionnaire item "Test tim" implies that respondents are also used to the 1-year test marketing (as described in case study C1). The average respondent is not used to the 5 years development time used in case study C2. For case study C2 we found an overvaluation (86%) which is similar to the average overvaluation (79%).

Again, the empirical evidence is inconclusive for our hypothesis that familiarity facilitates more correct valuations.

Our hypothesis on the second important questionnaire variable, single p, (from section 4.7) is that respondents who do not look at the pioneer project and the follow-up project as two separate projects will make less correct (in real option terms) (smaller) valuations. (We note that although the question was formulated in general terms, the subjects' answers might have been influenced by the fact that the NPV of *our* pioneer project was negative).

The questionnaire question corresponding to questionnaire variable Single p is (from Appendix 4.1):

"We would count the NPV of a first (pioneer) project as a cost of/contribution to the second (follow-up) project, and we would look at the two investments as a single project."

(1 = strongly disagree, to 5 = strongly agree)

The variable single p is positively correlated with A1 (which is valued correctly) and negatively correlated with A3 and C1 (which are overvalued). The statement "Single p" was intended by the researcher to represent the opposite of the real options concept in that it does not allow for an option value arising from flexibility. Respondents holding this view are on this interpretation likely to look at NPVs as the determinant of the case study valuations.

Case study A1 (positively correlated with Single p) has a negative NPV, but the theoretical option value is positive. Our hypothesis is that the less a respondent adheres to options theory, the lower should he or she value this kind of investment (negative correlation). The observed pattern of responses is evidence against this hypothesis (assuming that respondents interpret the statement in the sense intended by the researcher).

Case studies A3 and C1 (negatively correlated with Single p) have NPVs of zero whereas the option values are positive. Due to the small differences between option value and NPV, respondents sympathising with the option view might find these two case studies particularly acceptable and might be willing to apply their option perspective.

6. Findings from the questionnaire survey and comparison with findings from the experiment

Overall the empirical evidence seems to suggest that our hypothesis on the second important questionnaire variable should be rejected.

Our hypotheses on the third important questionnaire variable, Add data, (from section 4.7) is that low decision confidence expressed as a wish for additional data, leads to smaller valuations or that the higher this valuation, the more unsure the respondents feel about that valuation.

The questionnaire question corresponding to questionnaire variable Add data is (from Appendix 4.1):

> "No decision is possible without additional data."
>
> (1 = strongly disagree, to 5 = strongly agree)

Add data is positively correlated with respondents' valuations of case studies B2, B3, B4, C1, and C2 (which are all overvalued). The significantly positive correlation suggests that the higher the (excessive) value the respondents attach to these case studies, the more unsure they feel about their decision. This feature might be explained by more basic psychological considerations than real options theory such as perception biases (e.g. a higher value is perceived as less certain/more risky).

Overall, we accept our hypothesis on the third important questionnaire variable.

This concludes the hypothesis testing for our twelve research issues. After a summary of some important empirical patterns and the hypothesis tests performed in Chapters 5 and 6 (in sections 6.4 and 6.5) we will in Chapter 7 turn to comparing and discussing on a more interpretative level, the hypothesis tests performed.

6.4 Summary of some of the findings from the survey and the experiment

Industry and Sector are overlapping grouping variables and have strong influences over both the empirical case study valuations (cf. section 5.1.3.4) and the questionnaire responses. The grouping variable Experience is influential only over the empirical case study valuations and grouping variable Function is influential only over the questionnaire responses.

The oil industry shows more openness towards real options and also decides more rationally (in real options terms) (i.e. cautiously) on the case studies than the brewing industry. Financial managers show less openness towards the real options than commercial managers. However, financial managers decide more rationally (in real options terms) (i.e. cautiously) on the case studies than commercial managers.

The questionnaire variables "Planning horizon of 8 years" (Pl hor 8), "Single Project" (Single p) and "Additional data" (Add data) were influential over some of the empirical case study valuations. The probable implications of this are that attitudinal factors do influence respondents' real option valuations.

6.5 Summary of the results of the hypothesis tests of chapters 5 and 6

We can now summarise the hypothesis tests (listed in table 4.8) performed on our twelve research issues, in chapters 5 and 6. Table 6.10 contains the results for the first research issue.

Table 6.10

Hypothesis test (research issue 1)

	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2	N	n
H_0: EV ≤ NPV						X	X								2	2
H_1: EV ≥ OV		X	X		X			X	X	X	X		X	X	9	7
NPV≤ EV ≥ OV	X			X								X				

Note: EV: empirical valuation, OV: (theoretical) option value, N: number of case studies (including C1-2) for which hypothesis is accepted, n: number of case studies (excluding C1-2) for which hypothesis is accepted.

From the table, we accept the alternative hypothesis H_1 that the real options approach describes the empirical valuation behaviour better than the NPV approach.

In passing, we note that we accept our hypothesis on research issue 2, namely that higher mean empirical valuations tend to have a higher standard of deviation.

6. Findings from the questionnaire survey and comparison with findings from the experiment

The hypothesis tests on the valuations and attitudes of subgroups of respondents (research issues 3 to 10) are summarised in Table 6.11. Table 6.11 is based on Table 4.10 and contains additionally our empirical findings (in the columns labelled "E") and the results on the hypothesis tests (in the columns labelled "R").

Table 6.11 Hypotheses tests concerning subgroups of respondents

Grouping Variables				Research Issues																							
				High Valuation								Unanimity								Consistency				Openness			
				RI 3 Importance				RI 4 Direction				RI 5 Importance				RI 6 Direction				RI 7 (Direction)				RI 9 Importance		RI 10 Direction	
				H4	H5			H6	H7			H8	H9			H10	H11			H12	H13			H15		H16	
				H_0	H_1	E	R	H_0	H_1	E	R	H_0	H_1	E	R	H_0	H_1	E	R	H_0	H_1	E	R	H_1	E	H_1	E
Business environ -ment			Sect	1	2	1	H_0	+	+	+		1	2	1		-	-	+		-	-	+		1	2	+	ns
	Indu stry	Capital Goods	Oil	n/a	n/a	2			4	5														n/a	1	+	+
			Aero						4	3																-	ns
			Telec						2	2																-	ns
		Cons. Goods	Pha						1	4																+	ns
			Brew						3	1																0	-
Profess -ional Exper -ience	Seniority		Exp	1	1	2		+	+	+		1	1	2		-	-	+		-	-	ns		1	ns	+	ns
			Pos	1	1	4		+	+	+		1	1	1		-	-	+		-	-	ns		1	5	+	ns
			Fun	3	5	6	H_1	-	-	-		3	5	1	H_0	+	+	+		+	+	ns		1	3	-	-
			Lev	2	3	5	H_1	-	+	+	H_1	2	3	ns	H_1	+	-	ns	ns	+	-	+	H_0	2	ns	+	ns
			Invo	3	4	6	H_1	-	-	-		3	4	1	H_0	+	+	+		+	+	ns		2	ns	-	ns
Educational Background			EdBs	2	3	5	H_1	-	+	+	H_1	2	3	2	H_0	+	-	-	H_1	+	-	ns		2	ns	+	ns
			Qua	2	3	3	H_0	-	+	+	H_1	2	3	ns	H_1	+	-	ns	ns	+	-	-	H_1	1	4	+	ns
							H_1				H_1				H_0				H_1				-				

6. Findings from the questionnaire survey and comparison with findings from the experiment

As can be seen from the table, our hypotheses based on real option considerations (H_1's) describe the empirical findings better than the NPV-based hypotheses (H_0's) for 3 out of 5 research issues (research issues 3, 4 and 6) and both are equal for one research issue (research issue 7). This confirms our results from research issue 1.

Concerning research question 1 ("Correspondence") we can therefore state that for our particular sample, under our particular experimental conditions, the real options approach is superior as a description of behaviour to the NPV rule. In Chapter 7, we will discuss whether we can say that real option theory actually describes the data *well*, especially given the misvaluations of many of the case studies.

Concerning research issue 3, the alternative hypothesis is accepted for grouping variables Sector, Experience, and Qualification, which were all correctly expected to be important, and for grouping variable Function, which was correctly expected to be unimportant. H_1 is rejected for grouping variable Position, which was expected to be important but is not.

Concerning research issue 4, H_1 is always correct.

Concerning research issue 5, the null hypothesis (NPV-rule superior) is accepted for the grouping variables Position and Sector, which are correctly expected to be important. H_0 is rejected for grouping variables Level and Qualification, which are expected to be important but are not.

6. Findings from the questionnaire survey and comparison with findings from the experiment

Concerning research issue 6, the alternative hypothesis is right for grouping variables Business Education, Function, Involvement and Qualification. H_1 is wrong for grouping variables Sector, Experience and Position.

Concerning research issue 7, the alternative hypothesis is right for grouping variable Qualification, but wrong for grouping variables Level and Sector.

Concerning research issue 10, the hypothesis is right for the oil industry and for grouping variable Function, but wrong for the brewing industry.

In Chapter 7, we will interpret these findings.

The empirical findings suggest that (a) real options are perceived by our subjects to occur in the "real world" and that (b) the assumptions of real option theory are perceived as acceptable by our respondents (research issue 8).

We can neither clearly accept or reject the hypothesised positive direction of the influence for the respondents' openness towards real options on their case study valuations (this hypothesis is accepted for the oil industry but must be rejected for commercial managers) (research issue 11).

Finally, from examining the influence of important questionnaire variables on the empirical case study valuations (research issue 12), we neither accept nor reject the hypothesis that familiarity facilitates rationality, reject the hypothesis that unwillingness to look at pioneer and follow-up projects as two separate projects, and accept the hypothesis that the higher the respondents' valuations, the more unsure they feel about their decision.

In Chapter 7 we will discuss how to answer research question 1 ("Correspondence") (from research issues 1 and 3-7), research question 2 (from research issues 8 and 9-12), and research question 3 (from research issues 1-12) and address any additional issues that have arisen.

7. DISCUSSION OF FINDINGS AND CONCLUSION

7.1 Introduction

In this final chapter, we initially recapitulate our research questions against the background of the academic literature (based on Chapter 2) and against the research approach used (based on Chapter 4). We then attempt to answer the research questions from the results from the hypothesis tests (as reported in Chapters 5 and 6). We will also consider observed patterns not foreseen in the research hypotheses. Finally, we conclude by comparing the laboratory results with the "real world", consider limitations of the study, such as sample bias, and give directions for future research.

7.2 Recapitulation of the research approach

The present research applies a behavioural methodology to study managerial decisions involving real growth options. The two alternative theoretical frameworks we consider to value real growth options are the NPV-rule and real options theory. Additionally, we consider several "behavioural factors" i.e. variables which are not part of the formal models. Real option theory stresses management's flexibility for changing the scale and scope of (certain) investment projects even once they are underway. It highlights the similarity of this flexibility with the flexibility provided by financial options, and suggests the use of financial option pricing theory to evaluate such real options, i.e. investments in non-financial, i.e. real assets which allow some flexibility. Real growth options are investments which are prerequisites for follow-up investment opportunities and are considered to be analysable by the European non-dividend-paying financial call option model.

Many capital budgeting authors (cf. section 2.2.3, e.g. Dixit and Pindyck, 1994, Kemna, 1991, Barwise et al. 1987, Kester, 1984, Myers, 1984) assert or assume the consistency of management's intuition with real options theory implying that managers already act according to the new theory without having been taught it. However, this consistency of managers' intuition with real options theory has not been systematically tested so far. This is the first body of literature the present study seeks to contribute to.

Secondly our research also contributes to the debate in the human information processing literature in that it examines decision makers' (laboratory) investment decision making behaviour in terms of a new normative model, real options theory. Our behavioural research methodology has similarities with methods in both Bayesian and lens model research.

Thirdly, contributing to the (systems) implementation literature (section 2.4), the present study can be regarded as an inquiry into the applicability of a particular form of real options theory (growth options modelled as non dividend-paying, European options) to corporate investment decision making. At this level, the researcher can help to assess how easily the new technique of real options theory can be implemented to support companies' strategic decision making. In case the theory is already acceptable to their managers (without having been taught it), it should be straightforward for companies to accept a formal theoretical framework for assessing those aspects of an investment proposal that so far have been hard to capture. If the theory and managers perceptions prove inconsistent, it would have to be considered, given real options theory's theoretical superiority over the traditional (qualitative) analysis of the strategic dimension of projects, whether it is worth introducing (not an issue in the present research). For the case that it is desirable to implement real options theory, the present study can provide insights into how best to implement it/teach it.

The research questions are threefold. Firstly, it is investigated whether, and to what degree, decision makers value hypothetical investment projects containing growth options in accordance with the NPV-rule or with real options theory (and/or any additional factors) ("Correspondence"). Secondly, we examine how far the normative (European, non-dividend-paying) real options model is relevant to the "real world" investment situations it tries to model ("Relevance"). Thirdly, we examine whether there are any differences in valuation behaviour and attitudes towards real options between the different subgroups in our sample ("Acceptability"). We "operationalised" the three research questions in twelve issues (in Table 4.8) for which we set up 18 testable hypotheses (in section 4.7 and Table 4.10) in Chapter 4).

In order to evaluate the three research questions/the eleven research issues) we use a behavioural research methodology which has two main strands.

The first strand of the research methodology is deductive, related to Bayesian research, and uses an experimental design in the form of having managers decide on a set of investment case studies containing growth options and comparing the answers with a European, non dividend-paying real options model. It is designed to shed light on the first and third research questions.

In the second strand of the research methodology which is more inductive, we used a questionnaire survey to examine the occurrence of growth options in the respondents' company, the perceived realism of the business tasks used in the experiment (both in terms of their structure and in terms of their parameter settings) and the perceived realism of the assumptions underlying the real options model. The experiment tries to answer the second and third research questions, how far the normative, (European, non dividend-paying) real options model is relevant to the "real world" situations it tries to model.

Our sample consists of 82 respondents from nine very large British companies in five industries (oil, aerospace, telecommunications, pharmaceuticals, and brewing industries). The data per respondent, gathered in personal visits or by post, include the respondent's valuations of a subset of the 14 investment case studies, the respondent's answers to the 21 questions of the questionnaire, and nine professional characteristics, or grouping variables (which provided the main vehicle for the analysis of the third research question). These grouping variables (Industry and Sector, Experience, Position, Level, Function, and Involvement, Qualification and Business Education) can be interpreted as potentially affecting the quality of a respondent's "gut feeling" concerning investment decision making.

In order to shed light on the first research question ("Correspondence"), we compared the respondents' mean valuations of the 14 case studies with the theoretical values suggested by the NPV-rule (for the case that respondents do not perceive the optionality in the case studies) and with the theoretical option values (for the case that respondents do perceive optionality) (research issue 10). In section 4.7, from the behavioural economics and IS implementation literatures, we identify seven behavioural factors which might influence the valuations without being part of either the (basic) NPV-rule or real option models. We used these behavioural factors to predict case study valuation differences between subgroups. In this way, we could set pairs of NPV- and real options-based hypotheses on research issues 3-7 to obtain additional checks on research question 1. Overall, we found that for our sample and experiment, the real options approach describes the valuation behaviour relatively better than the NPV-rule. Whether it also corresponds with the empirical valuations in an absolute sense will be discussed in section 7.3.1.

7.3 Discussion of the statistical findings

In this section, we first (in section 7.3.1) use the findings of Chapter 5 to shed some light on potential reasons for the overvaluations (in both NPV and real options terms) in many of the case studies ("Correspondence"). In section 7.3.2, in discussing the findings of Chapter 6, we will answer the second research question, how far our option pricing model is relevant to the "real world" investment situations it tries to model ("Relevance"). In section 7.3.3, we will use findings from chapters 5 and 6 to examine the third research question whether valuations and attitudes by different subgroups of respondents differ ("Acceptability").

7.3.1 Correspondence (Research question 1)

Having partly answered the first research question ("Correspondence"), by finding that decision makers' decisions on hypothetical investments are better described by real options theory than by the NPV-rule (cf. section 6.5), we now turn to discussing the level of, and the patterns in, the empirical case study valuations.

7.3.1.1 Level of empirical case study valuations

In section 5.1.1.1, we found average overvaluations (relative to the B-S option value) of 79% (if measured over all 14 case studies), of 47% (if measured over the A- and B-sequence case studies, and omitting, as discussed, the potentially less meaningful C-sequence results), and of 11% (for the "most relevant" case studies as discussed, i.e. if the very misvaluation-prone figures for "outlying" case studies A1, A2, B1 and B2 are excluded). The last figure can, given the generally high level of noise, be interpreted perhaps in a somewhat "ad hoc" way as approximately correct valuation.

Moreover, the overall relationship between empirical valuations and theoretical option values for the A- and B-sequences indicate (taken together) three times significant undervaluation (A4-6) and three times significant overvaluation (B1-3). This can be interpreted as an average correct valuation (in terms of the B-S real options model).

As the answer to our first research question ("Correspondence") we could conclude that in our sample, for our experiment, case studies were valued correctly in B-S terms, with a potential slight tendency towards overvaluation. This can be regarded as evidence confirming the claims in the literature for a correspondence between managers' intuition and real (growth) option analysis (e.g. Dixit and Pindyck, 1994, Kemna, 1991, Barwise et al., 1987, Kester, 1984, Myers, 1984).

In order to deal with the potential (and perhaps overall not large) tendency towards overvaluation, we first reconsider alternatives (to B-S) theoretical valuation frameworks (as discussed in section 4.7). First of all we note that the observed overvaluation in real option terms cannot be well explained by the NPV-rule, since in most case studies, unrealistically low discount rates would be needed to produce an NPV close to the observed valuations.

The second alternative framework we consider is decision tree analysis (DTA). Real options theory can be considered a special case of decision tree analysis. The B-S model is just a simpler and more direct way to arrive at identical values to those of a (properly specified) decision tree (see Appendix 3).

Thirdly, from section 4.7, we recall that if the optionality (asymmetry) in our case studies is taken into account properly, volatility is always advantageous, irrespective of risk tolerances (cf. Morris et al., 1991).

Finally, the fourth theoretical alternative to B-S in the face of overvaluation are additional real options or different real option models. As discussed in section 3.4.1.2, option pricing models that would lead to higher theoretical option values are compound options (cf. Kemna, 1993) and/or (additional) (multiple) operating options (cf. Trigeorgis 1993a). It is possible that respondents intuitively assume an additional option to wait to invest at the maturity of the growth option (implying an additional American option leading to a compound option situation), and/or multiple operating options (the option to expand the scale of the follow-up project, the option to close down the follow-up project, etc.), which would increase their valuations. We tried to check for the former option by identifying case studies whose narratives were thought to most strongly suggest the opportunity to delay the investment after maturity. Those case studies were B5, A7, B2, and C2. Of these two were overvalued, but two were undervalued. This suggest that the option to wait was not perceived by the respondents.

Including (multiple) operating options is a possible theoretical alternative to simple B-S as an explanation of apparent overvaluation. However, this is completely arbitrary, as neither the amount, nor the set-up of the potentially perceived operating options could be concluded from the case study narratives. A more realistic class of alternative option pricing models which can imply option values higher than B-S are these option pricing models which allow the volatility of the asset to be stochastic (so called stochastic volatility (SV) option pricing models, cf. e.g. Hull and White, 1988).

Beder (1994) reports comparing a Black-Scholes model with a Hull and White model to value a swaption (an option on a swap) in July 1994, and finds an almost 5 per cent differential in the pricing results when all raw data inputs were held constant. Although a discrepancy of this size would be substantial in a trading environment, it is far smaller than the differences in valuation which the present experimental design is detecting from the respondents. Specifically, it seems that switching from the B-S to the Hull and White model could reduce only a part of the overvaluation (which is 11% for the most important case studies). However, because differences between B-S and stochastic volatility models critically depend on the moneyness of the option, we will reconsider SV option pricing models after the discussion of the detailed pattern of under and over-valuation in the three sequences of case studies.

Compared to B-S, SV option pricing models require additional information/assumptions regarding the relationship between volatility and asset price and can normally only be solved using numerical techniques (e.g. Monte Carlo simulation or a series expansion). This makes them less accessible for the corporate capital budgeting practitioner.

We conclude from the discussion so far that, in the face of over-valuation, no single alternative *theoretical* framework seems clearly more attractive than the B-S model. We note, however, that several of the discussed issues (risk aversion, additional operating options) might be suited to complement the basic B-S analysis in explaining our results.

We therefore consider behavioural factors which could help to explain overvaluations (in B-S terms) in our sample. Note that it is legitimate to do so despite the fact that in theory an option has the same value to every investor (especially regardless of his or her risk attitudes cf. Appendix 3). This is because we asked our respondents to apply their "gut feeling" to the case studies, which is naturally affected by individual factors.

We argue that the seven behavioural factors, as identified in section 4.7, might account for any potential empirical valuations above the B-S option values. They are thought to be positively related to a high valuation. The seven behavioural factors are: overgenerosity/over-optimism, misinterpretation of boundaries, risk-fondness, perception of additional real options, perception of learning effects, use of (certain) valuation heuristics, and overreaction. As noted, in section 4.7, the behavioural factors are based on empirical findings from the area of HIP-research and behavioural economics (cf. section 2.3).

We have confirmed B-S against the background of the empirical findings as the theoretical valuation framework with a descriptive accuracy than the NPV-rule (and having identified behavioural factors that have been shown to have affected decision making contexts similar to our investment case studies). Next, in order to detect any unhypothesised effects and presence of behavioural factors we consider the pattern of over-and under-valuation (in B-S terms) in the 14 case studies.

7.3.1.2 Pattern of over -and under-valuation

Our global null hypothesis for the pattern of over- and undervaluation (in B-S terms) for the entire sample across the 14 case studies is that there are no patterns.

In the A-sequence of case studies, in which we varied the expected PV of the follow-on project's cash flows (moneyness of the option), cases A1 to A3 had in theory low intrinsic values of zero, A4 and A5 had the highest time values, and A6 and A7 had very high intrinsic values and very low time values. Case studies A1 and A4 were valued correctly by respondents. Over the sequence of case studies A2 to A5, the discrepancy between the empirical valuations by the respondents and the theoretical option values was positive and rose in absolute terms (with the exception of case A4). Case studies A6 to A7, however, had a significant negative discrepancy.

A possible explanation of this pattern is that respondents place too much weight on (i.e. overvalue) the time value of the option (which is driven ultimately by volatility and is highest for case studies A3 to A5) and they place too little weight on (i.e. undervalue) the intrinsic value of the option (which corresponds roughly to the NPV of the follow-up project, i.e. the expected PV of the follow-up project's cash flows minus the PV of the follow-up project's initial investment).

It can be argued that this explanation is consistent with the well-known observation that Anglo-Saxon decision makers, in NPV-terms, underinvest (cf. e.g. Hayes and Garwin, 1982). The pattern in the empirical case study valuations seems to confirm that respondents undervalue the NPV of the follow-up projects in the case studies. Moreover, they appear to overvalue the time value component of the option values, and thereby, appear to be prone to over-investment where a large proportion of the option value is time value (as in case studies A2, A3, and A5 and in the B- and C- sequences which are indeed consistently overvalued).

Our explanation of the overvaluation of the time value is as follows. The *overvaluation of case studies A2, A3 and A5 above their NPV* might be explained as being due to the explicit narrative description of the follow-up investment opportunity in the case studies. In the questionnaire survey, the respondents maintained that in their real-world investment decisions, they took follow-up investment opportunities into account qualitatively. Through the explicit description of the follow-up project in the case studies, the respondents might be led to quantify their considerations of follow-up investments more than usual. In this way, a second source of quantitative investment value is being recognised by the decision makers, which, to judge by the empirical case study-valuations, is very important to the managers in our sample. The interpretation so far suggests that it would be desirable for managers to recognise more rationally the second source of investment value (the time value) in the real-world investment situations they face by moving from a qualitative to a quantitative treatment of follow-up investment opportunities. We will argue later in this chapter that it should be possible to train them to do so. At present, they may be overvaluing this component of value.

The *overvaluation of case studies A2, A3 and A5 above their B-S option value* might be due to the fact that managers behave "euphorically", i.e. they overreact to some "novelty factor" on recognising this second source of investment value. This interpretation is of course a lens-type argument, not a Bayesian. It corresponds to findings in behavioural finance of overreaction in financial markets (cf. De Bondt and Thaler, 1985).

Case studies B1 to B4, (in which we varied only the volatility of the expected PV of the follow-up project's cash flows), were all overvalued and case study B5 was undervalued. The fact that the slope of the empirical regression is only insignificantly different from the theoretical one hints that volatility, as described in the case studies, is perceived by respondents, and that respondents may vary their (biased) valuations very roughly in line with the real options model.

This also means that, in contrast to the recommendations of traditional discounted cash flow (DCF) analysis, respondents are not downvaluing those investments which have a higher volatility of cash flows. (Note, however, that DCF analysis assumes a fixed mean for the future returns, not a randomly varying mean, and variance in DCF or CAPM is not equivalent to volatility in OPT).

Case studies B1 to B4 were overvalued, but this behaviour broke down at extreme volatilities (case study B5 was undervalued). This represents a parallel to the empirical valuations of the A-sequence case studies, where A2, A3 and A5 were overvalued, A1 and A4 were valued correctly, and A6 and A7 were undervalued. It seems that in extreme situations (very high or low PV, very high volatility), respondents' valuations are too conservative. While for the A-sequence we argued that this behaviour might be motivated by the differential treatment of intrinsic and time values, here we argue that the comparatively low valuation for B5 is due to a volatility (81%) which is perceived by most respondents as being "too high". Two meanings of this are possible. On the one hand, respondents might find this volatility unrealistic, on the other hand, respondents might find the uncertainty implied by the high volatility unacceptably "risky" leading them to suddenly mis-perceive asymmetry and to equate volatility with risk (departure from irrelevance of risk tolerance).

Case studies C1 and C2 are both overvalued by the respondents, but C2 more so than C1. The differences between the case studies C1 and C2 are an increase of the development time (maturity), and in consequence of that, higher initial investment costs of the follow-up project, and also a consequent increase in the volatility of the expected PV of the follow-up project's cash flows.

In real options theory, the underlying reason why a longer time-to-maturity is positively related to the option value is that the same stochastic process leads to a higher overall effective volatility if the time horizon is increased. This is the link to the option value. In case studies C1 and C2, the volatility is increased in per year terms from $\sigma = 0.26$ (C1) to

σ = 0.59 (C2), and is also increased by the longer time horizon. The volatilities over 3 years, the volatilities over one and five years in case studies C1 and C2 would correspond to, are roughly 0.15 for C1 and 0.75 for C2.

The high empirical valuation of case study C2 suggest that the negative effect on the option value of the increase in the follow-up project's effective initial investment cost is more than offset for the respondents by the beneficial effects on the option value of longer maturity and/or higher volatility. However, in doing so respondents "overshoot", i.e. their valuations are too high. As noted before, the C-sequence results might be less meaningful due to limitations in human information processing.

The clear sequence of increased valuation from case C1 to C2 is stronger than the only slightly increasing trend in the B-sequence. This might mean that in the present sample, respondents perceive the higher volatility that is implied by a longer development time (maturity) more clearly as a positive factor for the value of the investment than volatility varying over a fixed maturity time.

One might conclude from this that respondents realise intuitively that a longer time horizon is beneficial for the option. This recognition might stem from managers' experience that longer projects have a better chance to benefit from improved profit prospects than shorter projects. It may be that a formally expressed volatility, even in the simple form presented in the case studies, is a concept most managers are not (yet) used to, but that an increase of volatility, as associated with the concrete variable of longer time horizons, is easier for managers to relate to.

We now reconsider a stochastic volatility (SV) option pricing model as an alternative to B-S. SV option pricing models (e.g. Hull and White, 1988) generally differ from B-S (which assumes constant volatility) to different degrees depending on the moneyness of the option. Moreover, in SV option pricing models, three different assumptions regarding the relationship between volatility and asset price are possible: no correlation, positive and negative correlation.

When correlation is positive, the SV option pricing model produces option values for out-of-the money call options which are higher than the B-S values. This is because an increasing asset price tends to increase volatility, making it more likely than under Brownian motion that very high asset prices will occur.

Higher theoretical out-of-the money option values is certainly a very appealing feature given empirical overvaluation of case studies A2, A3, B1-B4, and C1 and C2, which are all out-of-the money options. However, the amount of the "improvement" compared to B-S (in the order of 5% as noted before) fails to explain fully the actual overvaluations in our sample (11% for the most important case studies). Moreover, the actual correlation of asset and volatility has to be positive, otherwise the SV option pricing models fit with our data would be worse than the B-S models.

Due to some appealing properties, we suggest SV option pricing models, and particularly their positive correlation variant, for future research.

Our empirical findings can be seen to contribute to the human information processing (HIP) literature in two ways. Although the level of the valuations is fairly close to the B-S model (overvaluation of the most "relevant" case studies of just 11%), the pattern of over- and undervaluation suggests that strictly speaking, the normative model considered (the B-S model) is found not to be used. This corresponds to the results of the majority of studies in the so-called "Baysian" research tradition. However, as evident from the A- and B- sequences, the respondents' valuations are closer to the theoretical model for parameter settings that they are relatively more familiar with. This is in line with one of the central findings of the "lens" model HIP research.

Finally, we compare our results for the mean empirical valuations with the findings of the anonymous (1995) author who asked 44 respondents' to express their level of agreement with statements on the influence of the option model parameters on the value of the real option, as prescribed by option pricing theory, and found that on exercise price and maturity, only few disagreed with the real option model prescriptions, on volatility over half agreed with the prescription, and on interest rates, less than half agreed.

Our research approach allowed us not to have to rely on respondents' self-assessment, but to measure managers' "agreement" with the real option model prescriptions as implied in their case study valuations over a range of option model parameter settings. (Additionally, we can also make statements about the level of the valuations.) Our results indicate that agreement concerning the effect of "moneyness" on the option value depended on the level of moneyness. (Instead of the exercise price we varied the asset's price). Varying volatility did not have the effect predicted by theory. Varying maturity had the effect prescribed by theory but at a strongly overvalued level.

7.3.2 Relevance (Research question 2)

In Chapter 6, we reported the findings from the questionnaire responses which we will discuss in this section to answer the second research question, how far the normative (European, non-dividend paying) real options model is relevant to the "real world" investment situations it tries to model ("Relevance"). This can be covered by complementing research issue 8 with research issues 9-12 (as defined in table 4.8).

7.3.2.1 Critical points in questionnaire results

In section 6.2.2.1 we accepted our hypothesis on research issue 8, and find that real options are perceived to occur in the "real world" and that the assumptions of real option analysis are found to be fairly realistic by our respondents.

In order to further deal with this research issue, we consider critical points in the questionnaire results (as presented in section 6.2.2.1).

On the one hand, 40% of all general (i.e. non-commodity) investment projects are perceived to have follow-up projects. On the other hand, follow-up projects are only referred to as arising at the most often "sometimes" (in R&D projects). This strikes us as a potential contradiction. We would have thought that 40% of the time was "often". One possible interpretation for this is that respondents intuitively put down the high number of 40%, but because they do not formally think in real options-type investment terms in their day-to-day investment decisions, they are unable to allocate this high number to a particular business area.

The wide-spread agreement among the respondents that it is desirable to apply quantitative, instead of the current standard of qualitative, treatment of follow-up investment opportunities, signals openness to a quantitative framework such as real options theory. The fact that the respondents agreed that the profit prospects for a product were "very seldom" certain over its whole life suggests that they might prefer a decision-making approach that places little weight on this information (real options theory only uses the current price/PV of the cash flows from the follow-up project as an initial value which is then allowed to change over time) as opposed to an approach that relies on forecasting profit/prospects/cash flows (DCF).

These managers estimated that production costs (which contain the initial investment in the form of depreciation) could be forecasted accurately for longer ahead than competition or market conditions (affecting the future cash flows). This can be interpreted as a confirmation of the real options theory assumption that the initial investment of the follow-up project can be assumed to be fixed and known at the outset (while the PV of the cash flows is allowed to change over time).

Managers tended to agree that the information gained in market research and test marketing could help to shed more light on the prospects for potential follow-up projects. This is in line with the interpretation in real options theory that the option value is partly due to information arriving while waiting.

The average perceived volatility figure for the cash flows of projects is 23%. This seems to be rather low, and might be below the actual average volatility of cash flows from investment projects in industry. This apparent underestimation of volatility, which would in turn let real options appear less attractive, might be one reason for managers' low recognition of real-options-features in their real-world investment decisions.

Further evidence for managers' failure to notice real-options-features in their real-world investment decisions is the agreement on average that they would normally look at the two entries of pioneer project and follow-up project as a single project. However, it is not certain that this statement can only be interpreted in an irrational way, interpretation denotes irrationality, and it does not empirically correlate with irrationally low valuations.

Our use of the growth option structure in the case studies was not perceived as inappropriate by the respondents. This was expressed through their opinion that their companies' decision making did not fundamentally differ from the approach hinted at in the case studies, and also because the respondents did not on average express a strong requirement from them for additional data.

As the most important additional insight from the above discussion of critical points in the questionnaire responses, it appears that the respondents generally were very open to the real options approach to investment decision making. However, they seemed to lack the experience, training, etc. to identify real options as such within their own decision making activity.

We could confirm that real options occur in general (i.e. non-commodity) capital budgeting. The assumptions of real option analysis are perceived quite realistic by our general managers. These two findings confirm previously not empirically tested opinions by several capital budgeting authors e.g. Hodder and Riggs, 1982, Bierman and Schmidt, 1990, Copeland et al., 1990, Brealey and Myers, 1991 and many real option authors Myers, 1984, Kester, 1984, Aggarwal, 1991, Kemna, 1993, Dixit and Pindyck, 1994 and Trigeorgis, 1996, that real option analysis "*shows great promise for solving a wide set of interesting and **useful** problems*", (Copeland and Weston, 1988, p. 430), ,

We now use various insights from research issues 9-12 to complement and double-check the above conclusion.

7.3.2.2 Questionnaire variables' influence on the case study valuations

In research issue 9, we identified the grouping variables Industry, Sector, and Function as being influential over the questionnaire responses and the construct "openness towards real options". We examined the direction of a potential influence of each of these grouping variables on "openness" (research issue 10) and compared the influence of openness on the empirical case study valuations (research issue 11).

Our finding that oil managers are more "open" towards real options ideas than brewing managers seems to confirm common knowledge. Oil-related investments are considered an ideal candidate for the application of real options theory, since much of the uncertainty in cash flows of oil-related investments is due to the volatility of the oil price, which is relatively easily quantifiable and hedgeable (cf. Sick, 1991). Note that this should even be true for the non-commodity area of the industry, e.g. retailing, where most of our respondents from the oil industry worked. One of the oil companies in our sample had internal documents on the application of real options theory to the company's investment decisions. In the case of the oil industry, "openness" goes together with high "rationality" in empirical valuations. Finally, relating the findings back to research question 2 ("Relevance"), this might imply that real option theory is more relevant to the oil industry than to the brewing industry because its assumptions are better met by oil industry investment projects.

Conversely, financial managers show less openness towards the real options approach to investment decision making than "commercial" managers, but they also decide more rationally than "commercial" managers. It appears that financial managers' perception of investment opportunities is strongly influenced by their current capital budgeting framework, which is based on the DCF approach. This might lead them to discard real option assumptions. On the other hand, the financial managers decide more rationally on the case studies. This represents a contradiction to the hypothesis for research issue 11. This can be seen to support the opinion that financial managers "*act smarter than they talk*" (Barwise et al., 1987). Using this expression conversely our findings seem to suggest that, commercial managers "talk smarter than they act".

In research issue 12, we tried to test whether individual important questionnaire variables can explain the case study valuations.

Questionnaire responses revealed a respondent's attitude towards the assumptions of real options theory and revealed the investment parameter settings that a respondent thought normal in his or her industry. We compared the questionnaire responses and the empirical case study valuations and looked for significant correlations between both. We found that familiarity with the investment parameter settings of the case studies and agreement with the assumptions of real options theory both had significant effects on the case study valuations.

However, the directions of the significant correlations between the empirical case study valuations and the questionnaire variable indicate that "familiarity with a case study setting", contrary to our expectations, does not tend to influence the case study valuations in a clear direction. We observed familiarity leading to higher valuation of overvalued case studies, higher valuation of undervalued case studies, lower valuation of overvalued case studies and undervaluation of undervalued case studies. Familiarity, in the present sample, therefore sometimes leads to more rationality and sometimes leads to less rationality.

In the interpretation of the implications of the questionnaire, it sometimes proved difficult to determine if the respondent was familiar/unfamiliar with the textual scenario of a case study or with the chosen quantitative parameter settings of a case study. Unfortunately, in the present research design, only one text case study/story was used per quantitative parameter setting. It would be an interesting field for future research to try to separate the effects of variations in the case study texts and in the quantitative parameter settings. This could be achieved by using various case study texts for the same parameter settings (e.g. the ones used in the present study), and see whether and how mean empirical valuations would be affected.

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7.3.3 Acceptability (Research question 3)

Having answered research question 1 ("Correspondence"), from research issue 1, complemented by research issues 3.7 and research question 2 ("Realism") from research issue 8, complemented by research issues 9-12 roughly in favour of real option analysis, we now turn to answering research question 3 ("Acceptability"), i.e. whether there are any differences in valuation behaviour and in attitudes towards real options between different subgroups in the sample.

This question is particularly important for assessing the likely training requirements in real option theory of particular subgroups if they were to be implemented in a company's capital budgeting process. Following our model of potential training requirements in real option analysis (as developed in section 4.7 and displayed in Figure 4.2, we will use the grouping variables to look for both variations of case study valuations (research issues 3-7) and of questionnaire responses within the sample (research issues 9 and 10).

We used our results on the grouping variables' importance regarding their effect on the empirical case study valuations (research issues 3 and 5) and the direction of this effect (research issues 4, 6 and 7 in section 7.3.1) to gain additional evidence on research question 1. We now consider the grouping variables in their own right (sections 7.3.3.1 and 7.3.3.2) and then use the results for the subgroups to arrive at a detailed picture of likely difficulties in implementation of real option analysis (section 7.3.3.3).

7.3.3.1 Levels of valuations by different subgroups

First we consider the level of the empirical case study valuations. For each case study and grouping variable, we measured both the direction of the influence on the valuations (positive or negative) and whether the influence would increase, decrease or have no effect on relative valuation rationality (proximity of the empirical valuations to the B-S option values) (research issue 4). This also allowed us to determine a ranking of the grouping variables' importance regarding their influence on the case study valuations (research issue 3). For research issue 4, our real option-based alternative hypothesis was accepted for all grouping variables (cf. Table 6.11).

The most influential grouping variable is "Sector". This means that among all the grouping variables used to classify the respondents, the respondents classified as being from different "Sectors" are most likely to decide differently on a case study. This grouping variable summarises the five categories of the grouping variable Industry into two categories, namely the capital goods "Sector" (Industries 1, 2, and 3 higher valuations) and the consumer-goods "Sector" (Industries 4 and 5 lower valuations).

The next most important grouping variables are Industry and Experience. The importance of Industry can be understood by considering the fundamentally different nature of each of the industries in the present sample (oil, aerospace, telecommunications, pharmaceuticals, and brewing industries). On the other hand, it is remarkable that all the different aspects distinguishing industries from each other (products, markets, industry rules of competition and so on), which might as well have been expected to be partly offsetting, do in fact lead to a clear direction of the influence on the empirical case study valuations. The findings suggest that the different characteristics which define an industry, diverse as they might be, add up to a distinctive industry character, causing an "industry-effect" in the valuations.

All levels of the variable Industry produced valuations above the theoretical option value but to a different extent. The oil industry showed the smallest overvaluation, the pharmaceuticals industry the second smallest, the aerospace industry the third smallest, the telecommunications industry the second highest, and the brewing industry by a long way the highest valuations. Only the valuations by the brewing industry were significantly above the average valuations by the entire sample.

The oil and pharmaceuticals industries are known to have applied real options theory in their investment decision making (e.g. Kemna, 1993 on the oil industry and Nichols, 1994 on the pharmaceuticals industry). It is interesting that these industries decide most rationally on the case studies. One reason could be that the previous applications have alerted managers to the meaning of real option theory.

The participating company in the next most rational industry, the aerospace industry, is known for its financial sophistication. From the information given in the personal interviews, it seemed that even the non-financial managers in this company are very financially skilled, and might therefore have adapted a view on investments similar to that of financial managers (for who we notice a general tendency towards smaller valuations, see the grouping variable Function below).

The reverse argument can be used for the least rational industry, the brewing industry. The brewing industry, and the participating company in particular, is known to be mature and marketing-driven. From the information given in the personal interviews it seemed that even the financial managers in this industry are very marketing-orientated and therefore might have adopted a view on investments similar to that of commercial/marketing managers (for whom we notice a tendency towards high valuations, see grouping variable Function below).

The equal second most important grouping variable for the case study valuations is Experience (measured in years of employment in a business environment and coded as a "high level of Experience" (higher valuations) and a "low level of Experience" (lower valuations)). We note that the level of Experience which a respondent has seems to affect his or her valuations more than their position in the hierarchy of an organisation (grouping variable Position).

The third most important grouping variable is Position (i.e. whether employed in a "director" position (higher valuations) or "manager" (lower valuations) position). Although years of employment in business and career advancement are not necessarily related, the grouping variable Position might capture similar properties of "seniority" to the grouping variable Experience.

A priori, we expected that the grouping variables Experience and Position would have similar or overlapping effects, as is indeed found. As most of the case studies are overvalued, a positive influence normally implies even more overvaluation and thus a less rational decision (in B-S terms). This was true for the grouping variable Experience, while Position overall had no significant effect on rationality. It appears that a relatively high Position in the organisation or a high level of (Business) Experience may have led respondents to value the investments higher than other respondents. The positive influences of high levels of Experience and Position on the valuations might be due to the fact that these grouping variables can both be interpreted as proxies for seniority and for increased (self-)confidence of the respondent.

The fourth most important grouping variable is Qualification (postgraduate qualification or not). It is interesting to note that an additional degree or professional qualification had a positive influence on the empirical case study valuations. The fifth most important grouping variable is Level (employment in a business unit vs. in a company's headquarters; positive effect). Perhaps the employees in a company's headquarters are on the average to be more managerially sophisticated than their colleagues in a business unit.

The grouping variable Level had a positive influence on the valuations but not enough to change respondents' degree of rationality (valuations were neither closer to, nor farther away from, the B-S values), while the grouping variable Qualification had a positive influence on valuations, and at the same time increased a respondents' degree of rationality (valuations were closer to B-S). Consequently, while the grouping variable Level had no clear impact on respondents' rationality, the grouping variable Qualification increased the irrationality, i.e. more education actually led to better judgements. (This might be due to the more structured approach that better educated individuals might on average take to decision making).

The grouping variables Function (commercial position vs. finance position), Involvement (high vs. low involvement in investment decision making) and Business Education (formal business education or not) had not been found to have a significant influence on the case study valuations.

In sum, the finding of a negative influence of a particular grouping variable on the empirical case study valuations normally implied a more ("option-") rational decision, i.e. less overvaluation. This was the case for the grouping variables Function and Involvement (although their influence was insignificant). Respondents working in the finance function valued the case studies lower than respondents working in commercial functions. This corresponds to the well-known notion that financial managers are generally more cautious than commercial managers. Interestingly, a higher Involvement in investment decision making also led to more cautious decisions.

7.3.3.2 Spread in valuations by subgroups

The different concepts of spread considered were "unanimity" and "consistency" of empirical valuations respectively, operationalised as variance around the mean response (possibly an irrational response (in B-S terms)), variance around the B-S value.

In research issues 5 and 6, we examined the variance of the empirical case study valuations. As our measure is the standard deviation around the mean empirical valuation, it measures the "unanimity" of (subgroups of) respondents in their valuations in terms of proximity to each other, rather than the "accuracy" of the respondents in terms of proximity of their empirical valuations to the theoretical option value.

The grouping variables most important for predicting unanimity in the empirical valuations (research issue 5) were Sector, Function, Involvement, and Position, followed by Business Education and Experience. A high level in each of these grouping variables (except Business Education, which implies a higher variance) implied greater unanimity (i.e. a lower variance) of respondents' empirical valuations (research issue 6). Note that for research issue 6 our real option based hypothesis had to be rejected for Sector, Experience and Position (cf. Table 6.11).

High levels of Experience and Position could mean that respondents are more used to making investment decisions, and this might be a reason for the unexpectedly unanimous valuations by the subgroups with high levels of these grouping variables. The same effect could be true for grouping variable Involvement. This effect had been expected under our hypothesis. The supposedly more cautious subgroup of financial managers showed less variance in their valuations. This seems intuitively plausible (and was expected under our hypothesis). A potential reason for this could be that financial managers might adhere to a comparatively widely accepted framework of financial management (and they are offering smaller absolute valuations). The low variance for a high level of Sector was unhypothesised, as the high level of Sector contains the marketing-orientated brewing industry, members of which might possess less of a shared framework of decision making, and show higher absolute valuations.

In research issue 7 we used the term consistency to describe an individual respondent's empirical valuations over the (usually) three case studies that he or she answered. We accepted the NPV-based hypothesis on each grouping variable's influence on consistency.

In contrast to our (real options-based) hypothesis, a high level of the grouping variable Sector (i.e. employment in consumer-product-related industries) made respondents more consistent (i.e. lower spread). As we hypothesised, a high level of Qualification made respondents less consistent. Contrary to our hypothesis a high level of the grouping variable Level made respondents more consistent.

This means that respondents from the consumer goods Sector which is known to be more marketing-orientated, are individually very consistent in their (over)valuations (which compares interestingly with this subgroup being highly unanimous as identified in the last paragraph). The subgroup of respondents who possessed a postgraduate qualification value the case studies more rationally (i.e. less optimistically, see above), but are also more erratic in their judgements. Respondents working in corporate headquarters generally decide more consistently on the three case studies (without differing in their mean valuations from the subgroup working in business units).

7.3.3.3 Likely acceptance and training needs

An important question that can be addressed from the results for the subgroups is whether training in real option analysis is necessary and for whom. This is an important question in MIS implementation research (e.g. Zmud, 1979, Hirschheim and Newman, 1988, Aydin and Price, 1991).

As a general conclusion, the regression analyses of the A- and B-sequence empirical valuations versus the theoretical option values suggest that the empirical valuations are noisy, but are not overall significantly different from the theoretical option values. Consequently, adapting real options theory as a capital budgeting tool would in effect only require formalising the managers' current intuitive valuation behaviour. This, of course, should be an easier task than to implement a theory perceived as counter-intuitive.

The next consideration is whether training can and should be used to better the patterns or over- and undervaluation observed in the case studies. In cases A6 and A7, the problem might be the undervaluation of the NPV, which is independent of real options theory. In most instances it will be desirable to improve on this. From the discussion of the questionnaire findings, the single most important skill managers should be taught is to identify the real option-type structures in the investment projects they must decide on.

To answer the question as to which groups of managers need training most, we can use the grouping variable analysis. The high valuations implied by the important grouping variables such as Sector and Experience, in the present sample, leads to an above average overvaluation of the case studies and therefore to less rational decisions.

If as suggested in section 7.4.1 the valuations in the "real world" would be similar to the laboratory valuations, "high level" subgroups in these grouping variables (experienced managers in consumer industries) would then be the target groups for training in real option analysis with a focus on lowering their valuations.

Conversely, finance managers, managers highly involved in investment decision making, and managers with a postgraduate qualification appear more rational in most of the present laboratory study (see research issue 3). The intuition of these "high level" subgroups could be made accessible to other subgroups through training in real options theory. As far as differences between industries are concerned, if the (under laboratory conditions) "euphoric" brewing industry in the real world still offered valuations above the theoretical option values, it would be a candidate for receiving training on more conservative valuations for real options.

In section 4.7, we hypothesised that concerning training requirements in real options theory, high unanimity and high consistency of valuations are only desirable if the valuations (roughly) have the level prescribed by real option theory. In the case of misvaluation, low unanimity and low consistency would be preferable as this might indicate that respondents are confused which should make them more receptive to real options training.

Applying this rationale to the empirical findings, the subgroups for which implementation of the real options framework should be easiest are subgroups with high levels of Function and Involvement. Both subgroups have a roughly correct level of valuation and additionally both show high unanimity. Next, the high-level subgroups of Business Education and Qualification tend to overvalue, but the former shows low unanimity and the latter shows low consistency. For these subgroups, teaching might be relatively easy. Finally, for the high-level subgroups of Sector, Experience, Position and Level, we found a tendency toward high valuations (over valuations) and at the same time high unanimity and/or high consistency. This hints that the disagreement with the real options framework is highest in these subgroups, which might make training in real options difficult.

We recall that oil managers decide relatively rationally (in B-S terms) on the case studies. A potential reason for that might be their relatively high experience in taking risky gambles. If one agrees that this experience implies that they can make superior (intuitive) judgements on risky projects, real options would provide a framework to make this intuition accessible to managers in other industries.

7.4 Generisability, limitations and future research directions

7.4.1 Comparison of laboratory and "real-world"

The question we address in this section is what, if any, "real world" decision behaviour the findings of this (part-laboratory) study might predict (i.e. "generisability of the findings"). We will distinguish between "absolute" and "relative" aspects of "real world" decision behaviour. By absolute decision behaviour we understand as the actual mean level of the empirical valuations. By relative decision behaviour we understand the valuation by one subgroup of managers relative to those by another subgroup of managers.

A crude method of assessing the degree of realism that the respondents perceived in the textual structure of the case studies, in the quantitative option parameter settings, and in the Black-Scholes option model's assumptions (which influenced the structure of our case studies), is to look at the average responses to the questionnaire variables. As discussed before, (research issue 8) the textual structure of the case studies, and the option parameter settings of most of the case studies were reported to be realistic by the respondents. A potential exception is that the volatilities of many of the case studies (e.g. 45% in the A-sequence) are above the average volatilities that respondents reported for their own projects (23%). The B-S option model assumptions were not reported as strongly unrealistic by the respondents.

It could be argued that the realism for the respondents of the case studies and the generisability of their valuations are positively related.

In terms of absolute valuation behaviour, we might try to generalise from the laboratory results, to place managers' decision making behaviour in the "real world", i.e. in their everyday investment decision making environment, between the two extremes of "overvaluation even in OPT-terms" (towards which there seems to be a tendency in the present study) and "undervaluation in NPV-terms" (i.e. the alleged irrational investment behaviour in the Anglo-Saxon economies, as reported by e.g. Hayes and Garwin, 1982).

Although overvaluation may not be significant overall, in our laboratory, most of the individual case studies show marked overvaluations. A critical question for the generalisation of the laboratory results is therefore whether this overvaluation would also happen in the "real world". Another critical question is whether the observed "pattern" of over- and undervaluations would prevail in the "real world", i.e., whether real world valuations would imitate laboratory valuations in a "parallel shift", i.e. each (over and under-)valuation by the same relative amount, or whether the valuations of the "extreme" case study settings, i.e. very low/high PV of cash flows (case studies A1, A6, and A7), or very high volatility (case study B5), would change differently from the valuations of "less extreme" case study settings. Four different hypotheses seem possible, which could be an area for future research.

The first hypothesis, on the lines of the lens model, is that the most extreme parameter settings used in our experiment were so extreme they took the respondents out of a "familiar" range of less extreme parameter settings in which their valuations though biased, had at least a *consistent* bias away from the theoretical values. Thus, the valuations of the case studies with extreme parameter settings should be untypical. For example, respondents might lose confidence, resulting in undervaluation. The evidence from the analysis of the mean questionnaire responses suggest that, in the B-sequence, respondents are most used to the parameter settings of the first four case studies. The average estimated volatility in the respondents' investment projects is 23%, which makes the volatility of 81% in case study B5 seem extreme. Using this interpretation alone, the occurrence of the real world undervaluations in unfamiliar circumstances would be just as seen in our case studies. ("Although the level of the valuations might be different").

The second hypothesis is that decision making behaviour in the real world will be most similar to the laboratory valuations only in "extreme" (i.e. extremely risky) situations. These extreme situations might more realistically simulate real-world psychological decision- and justification pressures. This might have caused the respondents to decide less "automatically" and more "realistically" (i.e. more as they normally do) on the riskiest case studies (an "anti-lens" interpretation). If this consideration holds, real world decision making behaviour may show valuations close to, or below, the B-S values, as seen in our "extreme" case studies.

A possible third hypothesis is that the pattern of correct valuation or even under valuation at the "extremes" is caused by a differential treatment of intrinsic and time values, and possibly by the existence of "too high" volatilities. Moreover, the sample is potentially self selective for high receptiveness, or openness, to the real options framework and this sample bias might be the reason for the apparent overvaluations of the time values (on the "overreaction" phenomenon of behavioural economics). (However, the present study failed to establish an unambiguous link between openness to option theory and rationality of valuations of the case studies.)

A potential fourth hypothesis, in line with Bayesian research, would be that respondents indeed follow a rational model for their valuations, but that the rational model assumed by the researcher is not the one respondents are actually using.

Common sense suggests that in a real-world situation, with "real" potential consequences for the decision makers, valuations might be somewhat lower, because managers can be expected to be generally more cautious.

The second generalisation issue, that of the relative behaviour of subgroups in the "real world" as opposed to the laboratory, depends on any tendency of subgroups of respondents to change their laboratory decision making behaviour more or less strongly when real world investment decisions are concerned. Common sense suggests that for the potentially more cautious oil and finance managers, if compared with brewing industry and commercial managers, differences between laboratory and real world valuations might be relatively small. ("Finance managers are always cautious"). For similar reasons, high levels of the "seniority" variables Experience and Position might imply smaller differences between laboratory and real world behaviour. However, these considerations are highly speculative and cannot be checked in the present research design.

Clearly the generalisability of the present results to "real world" decision making is an open issue, and a potentially rich topic for future research.

7.4.2 Limitations of the study

Due to the fact that our case studies had to be intelligible to a broad audience of general managers in a short period of time, the research was limited to simple growth options, Compound options, or multiple, interacting options were not suitable to be described in our simple investment case studies.

An obvious limitation of the study is the unknown generalisability of the results. By using a "quasi-experiment" rather than a "true experiment", and cautious interpretation, complementary personal interviews and questionnaire survey, an attempt was made to maximise validity.

Another potential limitation of the present study stems from the fact that each respondent only valued a subset (normally three case studies) from the 14 case studies. This makes it problematic to draw conclusions across all 14 case studies. In some stages of the analysis, analysing the valuations across all 14 case studies was simply not possible because the statistical procedures required data entries for all possible combinations of dependent and independent variables (e.g. multivariate ANOVA). In these cases, the analyses could only be performed for blocks of responses.

The question then was whether the results obtained for different blocks could validly be compared. Reassuringly, the demographic analysis (i.e. the comparison of the respondents' professional characteristics in) across the five blocks showed that the blocks did not differ significantly on any of the grouping variables. Therefore, differences in statistical results between the blocks need not be due to demographic differences.

A different limitation is that due to the limited sample size (n = 82) and due to the very unequal numbers of participants from the different companies, the analysis in the present study could not be performed for individual companies but was limited to the industry-level. Conversely, it appears to be problematic to generalise from only one participating company in the aerospace and brewing industries to these industries as a whole, even if the companies were regarded as "typical" companies in their respective industries. We could, however, reject any potential generalisation which fails to hold even across these small samples within one company.

A different analytical problem stemmed from the fact that certain subgroups, as defined by the grouping variables Industry and Qualification occurred with very small frequencies. For example, only 7 and 9 of the 82 respondents were from the oil and telecommunications industries respectively, and only 11 respondents did not have a postgraduate/professional qualification. The small size of some subgroups, ultimately due to small sample size (n=82), resulted in some of the tests (e.g. test of normality) lacked results for some of the case studies. When interpreting the results in chapters 5 and 6, this limitation was taken into account by treating the subgroups in question with extra care.

Another potential problem was the fact that the textual (non-quantitative) aspects of the case studies differed (more or less strongly) across all 14 case studies. In addition to the quantitative option model parameters that were varied from case study to case study, the variations in these textual aspects might have unintentionally caused variations in valuation behaviour between the case studies.

The factor analysis of the empirical case study valuations described in section 5.1.3.6 can be used to clarify this point. Real options theory would predict that only one factor should be found significant in most blocks since, in the theoretical experimental design, only one option parameter is usually being changed in any block of case studies. Only in two of the five blocks was a single factor found dominant in the valuations. However, it was possible to identify special circumstances in the three other blocks which might account for the multiplicity of factors.

Of course, generalisations from the present research are limited to the population from which the sample was drawn. As described in the methodology chapter, we limited the target population of the study to managers in non-financial and for-profit organisations. We exclude, for example, decision makers who have no business experience.

The last limitation we consider here is potential sample bias. This problem is different from the question of the definition of the relevant population. Potential sample bias could manifest itself through the nine grouping variables used to split the sample, for example if certain grouping variables occur only in basic combinations (e.g. "all respondents in the oil industry are finance managers"). This possibility was checked by analysing the nine grouping variables for principal components in section 5.1.2.2. As the number of factors observed was nearly as high as the number of grouping variables, and two of the grouping variables (Industry and Sector) strongly overlap by definition anyway, sample bias, as apparent in the respondents' professional characteristics, seemed unlikely. However, it seemed likely that there was sample bias in the form of all the respondents' being particularly receptive to the real options framework, and being partly self-selected on this basis.

7.4.3 Directions for future research

Similar growth option case studies could be valued using other option pricing models, e.g. stochastic volatility option pricing models (especially with positive correlation between volatility and asset price) European, dividend-paying models, or a compound option model. Moreover other option types could be examined, e.g. the option to wait.

Future research could shed some light on the four rival hypotheses in section 7.4.1 concerning the relationship of patterns observed in the laboratory and of real world investment decision making behaviour.

Another opportunity for research on the same lines is to apply the research design to other companies, industries, and countries. For example, it would be fascinating to replicate the present research in countries with a purportedly different investment decision making behaviour, such as Japan.

Future research could attempt to refine the present approach by isolating the effect of changing the textual and narrative features of the cases, while holding constant the quantitative parameter of the case studies

Having demonstrated that it is meaningful and instructive to form the construct "openness towards real options", this construct could be re-used (and refined) in future research.

A methodological finding of the present research is that the combination of a quasi-experiment and a descriptive-analytical questionnaire seems to work well for the present research question, this constitutes, particularly in the finance area, a potentially underused research approach. A similar research approach could be used to assess the applicability of normative theories in other areas.

7.5 Summary and conclusion

The present study has used a behavioural methodology to study managerial decisions involving real options (in non-commodity investments). We examined three research questions ("Correspondence", "Relevance", and "Acceptability").

The first research question ("Correspondence") is whether, and to what degree, decision makers decide on hypothetical investment projects in accordance with the NPV-rule or with the real options framework (whose values are identical to those by a (properly specified) decision tree analysis (DTA)).

Regression analyses of the empirical case study valuations on the theoretical option values showed that overall, the theoretical values and the empirical valuations over the A- and B-sequences of case studies do not differ significantly. This can be considered as evidence for the claim that managers (at least under laboratory conditions) can take decisions similar to those of the real options framework without having been taught it (but their valuations are considerably higher than the NPV of the case studies).

A possible explanation of the detailed pattern of over- and undervaluation in the A-sequence is that respondents place too much weight on the time value of the option (driven ultimately by volatility) and too little weight on the intrinsic value of the option (which corresponds roughly to the NPV of the follow-up project).

Follow-up investment opportunities (growth options) seem to be valued highly, as is apparent from the valuations of the case studies, in which they are explicitly described. On the other hand, the respondents seemingly find it unusual to identify follow-up investment opportunities in their own, real world investments.

Empirical valuations for the B sequence of case studies were very noisy. However, respondents, in their response to volatility, are apparently not acting on the traditional view that volatility (variance) is bad for an investment. A formally expressed volatility, as presented in the case studies, may be a concept that most managers are not (yet) used to, but volatility, as associated with the more concrete variable of longer time horizons, does seemingly increase the valuation of the option in the direction required by theory in the C cases.

The second research question ("Realism") is how for the normative (European, non-dividend-paying) real option model is relevant to the "real world" investment situations it tries to model. We find that growth options are reported to actually arise in practice. In general, the assumptions of our special real options model (European, non dividend-paying) are perceived as fairly realistic.

Oil managers show a high degree of openness towards real options and small laboratory valuations. Commercial managers are more open towards the real options approach than financial managers but show higher valuations (these are less rational in the present laboratory task). This might be due to the fact that they use their "gut feeling", not financial tools, for the decisions. It is unclear from our data whether "openness" towards real options ideas implies more rational valuations (in B-S terms) or not.

Managers willing to look at a pioneer and a follow-up project as two projects show higher (laboratory) valuations and managers desiring additional data show lower (laboratory) valuations.

The third research question ("Acceptability") is whether, and in which way, there are differences in valuation behaviour and in attitudes towards real options between different subgroups in the sample, as defined by our nine grouping variables. This resembles a question frequently raised in MIS implementation research. The grouping variable that is most influential over the empirical case study valuations is Sector. This means that among all the criteria used to classify the respondents, the respondents classified as being from the capital goods sector on the one hand, and from the consumer goods sector on the other hand, are most likely to decide differently on a case study. Sector summarises the variable Industry, the second most important grouping variable. Among the five different individual industries, the oil industry and the pharmaceuticals industries overvalue the case studies least (and therefore show the most rational valuations). These industries are already partly using the real options framework in capital budgeting. The brewing industry shows the highest (and least rational) valuations.

The next most important grouping variable is Experience, which makes decision makers more optimistic, less rational, and as a group more unanimous. The same is true for another important grouping variable, Position, except that Position does not significantly affect rationality. These grouping variables could proxy for seniority, and they may imply high self-confidence and more shared experience.

To conclude from their valuation behaviour, subgroups for which comparatively little training of the real framework seems likely to be required are financial managers (when compared to commercial managers) and managers currently formally involved in investment decision making (when compared to those who are not). Subgroups which it should be relatively receptive to real options training are managers with a business degree and managers with a degree plus an additional qualification. Subgroups that might show most resistance to real options (training) are managers in the consumer goods sector, experienced managers, directors and managers who work in a company's headquarters.

Concluding remarks

Various capital budgeting authors have asserted or assumed that managers' intuition is consistent with the real growth options framework. The present study set out to collect systematic evidence on this claim, for comparison with the anecdotal evidence of these authors.

For a particular form of real option, namely growth options, modelled theoretically as European, non dividend-paying financial options, and for a particular set of assumed parameters and textual case narratives, we find that practising decision makers only approximately agree with the valuations presented by real options theory. They show tendencies to overvalue growth options, but in an erratic way, and become more conservative when the option is far in or out of the money, or when volatility is extremely high. Overvaluation seems to be a function of "Industry", being lowest in the oil industry, and of (business) "Experience" and "Position", being highest for more senior people.

In general, the results of the present study, do not reject the claim that management's intuition is at least more compatible with the real options framework than with traditional NPV.

In the questionnaire responses, respondents report that some of the assumed parameter values used in the case studies are more realistic than others. It is notable that their valuations are most conservative for the cases which they report that they are least likely to encounter in their work, namely very far out of the money options and very deeply in the money options, and very high volatilities.

Respondents seemed directly and indirectly well disposed, receptive, or "open" to real options concepts (presumably as a sample they were partly self selected on this basis).

These results bear on the general research into the human intuitive decision making (human information processing literature). As in so many so-called "Bayesian" studies, a normative model is found not to be strictly used. However, the respondents here tend to judge fairly consistently with the theoretical model (typically with an upward bias and with considerable noise) over a range of parameter values which is relatively more familiar to them. This is the general finding of much of the school of "lens" school of empirical decision research.

Implications of the research for real world capital budgeting include that training is needed, and is likely to be acceptable to managers. Potentially, underinvestment could be explained by an inability on the part of our respondents to perceive option values in their real world investment decision making environment. Choosing teams of decision makers might hope to reduce the variance (but not the bias) of intuitive option valuations.

Avenues for future research include using alternative real options models, developing specific tests for the realism of findings from laboratory research, and applying the research design to other companies, industries, and countries.

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A3.1 Risk-neutral valuation

Replication-derived real option models, (i.e. those (derived) using "risk-neutral valuation") assume that investors are risk neutral. At first glance, this seems to be in contrast to other areas of financial economics, where it is generally assumed that individuals are risk averse. In this section, we first discuss whether risk-neutral valuation requires any restrictive assumptions about investors' risk attitudes. We then demonstrate, for the example of one of our case studies, how options can be valued under the assumption of risk-neutrality. In the second part of Appendix 3 we will discuss how managers might value the same project using risk-adjusted discount rates (i.e. not assuming risk neutrality).

A3.1.1 Discussion of the concept of risk-neutral valuation

Financial economics normally assumes that all individuals are risk averse (e.g., Copeland and Weston, 1988). E.g. Swalm (1966), in a laboratory study of utility functions of 100 employees, confirms risk aversion empirically.

In replication-derived option pricing models, however, risk neutrality is assumed. In what follows, we will examine the assumption of risk neutrality in option pricing (following Hull, 1993). We will further examine whether this assumption places restrictions on investors' risk-attitudes. According to the focus of the present study, we discuss these issues for the Black-Scholes (B-S) option pricing model (Black and Scholes, 1973), although risk-neutral valuation is also used in the whole of contingent claims analysis (CCA).

Risk neutral valuation is the crucial tool in replication-derived option pricing models. It is implicit in the Black- Scholes differential equation (1) because the equation does not include any variables that are affected by investors' risk preferences. The variables in the equation are the current stock price S, time t, stock price volatility σ, and the risk free rate of interest r (f represents the option value).

$$\frac{\delta f}{\delta t} + r S \frac{\delta f}{\delta S} + \frac{1}{2}\sigma^2 S^2 \frac{\delta f^{2}}{\delta S^2} = \qquad \text{(A3.1)}$$

All these variables are independent of investors' risk preferences. If the expected return of the stock was included, the Black-Scholes differential equation would not be independent of risk preferences. This is because the value of the expected return of the stock is influenced by individuals' discount rates, which are affected by risk preferences. In general, the higher the level of an investors' risk aversion, the higher the discount rate, and the higher the required return on a risky investment. The expected return on the stock happens to drop out in the course of the replication-derivation of the B-S equation, since it is assumed possible to hedge away all of the risk by market transactions (delta hedging).

The fact that the Black Scholes differential equation is not affected by risk preferences simplifies the task of solving it. If risk preferences are not part of the equation, of course they cannot affect its solution. Therefore, when solving the Black Scholes differential equation, any of the three types of risk preferences (risk-aversion, risk-neutrality, risk-fondness) can be assumed. In particular, it is possible to make the simplifying assumption that all investors are risk neutral, and this assumption is normally used in pedagogical explanations of the B-S model.

In a risk neutral world, the expected return on any security is the risk free rate of interest r. This is due to the fact that risk neutral investors do not require risk premiums. In a world where investors are risk neutral, the present value of any cash flow can be calculated by discounting its expected value at the risk-free rate. The assumption of risk neutrality may or may not be realistic, but it permits the valuation of options by the B-S model, even in cases where it is not possible to produce a genuinely "risk free" equivalent of the option by making offsetting market transactions.

However, "*it is important to realise that the risk neutrality assumption is merely an artificial device for obtaining solutions to the Black Scholes differential equation. The solutions that are obtained are valid in all worlds, not just those where investors are risk neutral. When we move from a risk neutral world to a risk averse world, two things happen. The expected growth rate in the stock price changes and the discount rate that must be used for payoffs from the derivative security changes. It happens that these two effects always offset each other exactly*" (Hull, 1993, p. 222).

Arguments that a large publicly owned firm should be essentially risk neutral (e.g., Smith and Nau, 1995) are therefore not necessary in order to apply replication-derived option pricing models. Moreover, we believe that these arguments are not generally valid for capital expenditure decision making, since capital investment are decided on by groups of managers (who are likely to be risk averse) rather than by the firm as a whole. It is even questionable whether the firm as a whole can be taken as risk-neutral, as it is made up of individual members who have been shown to be risk-averse (Swalm, 1966).

In real options theory, risk, in the particular form of the volatility of the underlying asset, is a positive factor in the determination of a real option's worth. If two real option-containing investment opportunities have identical expected PVs of future cash flows, the investment opportunity with the more volatile cash flows will have the higher option value. At first sight, one might conclude that investors, in order to value investments in this way, would have to be risk lovers.

However, this assumption is not necessary. The positive relationship between option value and risk is due to an asymmetry between potential upside gains and downside losses when an option matures. If a project's NPV increases over the life of the option, large gains can be realised by exercising the option. If, however, the project's NPV becomes negative at the time of maturity, losses can be cut simply by choosing not to exercise the option. In this way the only loss for the option holder is the cost that had been incurred in acquiring the option. The existence of a choice to exercise or not to exercise the option means that higher risk (in the form of volatility of the asset on which an option exists) increases the gain that can potentially be realised without equally increasing the potential loss. It is therefore rational for all investors, irrespective of their risk tolerances, to prefer options on assets of higher volatility, because in real options situations, the investor faces no higher risk from a higher volatility, provided appropriate hedges can be constructed by market transactions.

To conclude, neither the assumption of risk neutrality in replication-derived option pricing models market transactions, nor the apparent risk fondness seemingly implied by the prescriptions of option pricing theory (in the form of the positive relationship between volatility and option value) run in fact counter to the basic assumption of investors' risk aversion, which is a fundamental assumption of financial economics and a demonstrated empirical fact for many decision makers.

A3.1.2 Example

We now demonstrate for the parameter settings in our case study A3 (S = 10m, X = 12m, σ = 0.45, T-t = 3, r_f = 0.06) how options can be valued under the assumption of risk-neutrality. Beforehand, we have to define the expected (risk-adjusted) rate of return from the underlying asset of the case study, an investment project in the health care sector. As a rough-and-ready estimate, we use the CAPM expected return from health care stocks at the London Stock Exchange just prior to the time of data collection. This was given by the Risk Measurement Service of London Business School (1994) (following Brealey and Myers, 1991, pp. 162-163) and leads to a risk premium of 8%

$$\mu = r_f + \beta(r_m - r_f) \quad \text{(A3.2)}$$

$$\mu = 6\% + 0.81 \times 8\%$$

$= 12.5\%$

A particularly simple assumption allows only two states for the asset price at the time of maturity T (simple binomial decision tree model). We show that a riskless arbitrage argument and risk-neutral valuation give the same option value (following Hull, 1993).

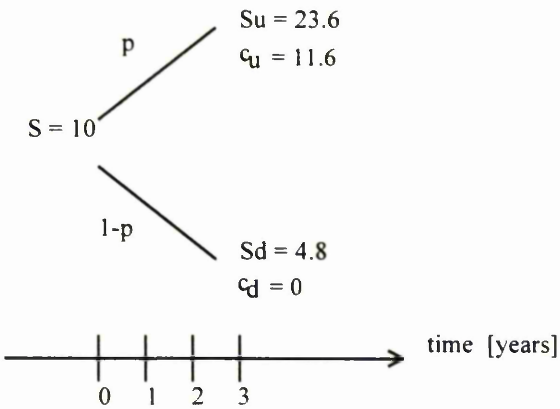
Riskless arbitrage argument

The current price of the underlying asset for case study A3 is S = £10m and it is known that at the end of the life of the option of 3 years the price will be either Sd = £4.8m or Su = £23.6m (i.e. the price will be $£10\text{m} \times e^{(\mu-\frac{\sigma^2}{2})(T-t)}e^{\pm\sigma\sqrt{T-t}}$) (A3.3)

The European call option in the case study allows us to buy the asset for £12m after 3 years. If the price of the underlying asset turns out to be £23.6m, the value of the option is Cu = £11.6m, but if the asset price turns out to be £4.8m, the value of the option Cd is zero. This is illustrated in Figure A3.1(values are in million pounds).

Figure A3.1

Asset price movements for case study A3



Next, consider a portfolio consisting of a long position in α shares and a short position in one call option. The value of this portfolio is 23.6 α - 11.6 if the asset price moves up and 4.8 α if it moves down. When α is chosen as 0.62, these two values are equal:

$$23.6\ \alpha - 11.6 = 4.8\ \alpha = 2.96 \quad \text{(A3.4)}$$

For $\alpha = 0.62$, the portfolio is riskless, because regardless of what happens its value after three years will be 2.96. The current value of the portfolio with $\alpha = 0.62$ is:

$$10 \times 0.62 - c = 6.2 - c$$

where c is the current value of the call option. Riskless portfolios must, in the absence of arbitrage opportunities, earn the risk-free rate of interest. Our risk-free interest rate of 6% compounded over three years is $e^{0.06 \times 3} = 1.2$. We can therefore determine the current value of the call option as:

$$1.2\ (6.2 - c) = 2.96$$

$$c = -\frac{2.96}{1.2} + 6.2$$

$$c = 3.7$$

Note that to arrive at this option value, the probabilities of the stock moving up to £23.6m and down to £4.8m have not been used since for a hedged portfolio they are irrelevant. These probabilities form the basis of risk-neutral valuation, which we will discuss next.

Risk-neutral valuation

We consider the same portfolio of underlying asset and option. For risk neutral investors, the expected asset return must be the risk-free interest rate, in our case 20% over three years. The probability p of an upward movement (and the probability 1-p of a downward movement) can therefore be determined from the requirement to match this rate of return:

$$23.6\ p + 4.8\ (1-p) = 10 \times 1.2 \quad \text{(A3.5)}$$

To satisfy this equation, p must be 0.38. Using this value of p, the expected value of the call option on its maturity in 3 years is:

$$0.38 \times 11.6 + 0.62 \times 0 = 4.41.$$

This is the expected terminal value of the call option to the risk neutral investor. The current value of the call option is this future value discounted over 3 years at the risk-free interest rate:

$$\frac{4.41}{1.2} = 3.7.$$

This value, which applies to risk-neutral investors, is the same as that derived using riskless arbitrage arguments in the previous paragraph, which applies to investors of all possible risk attitudes.

Binomial tree

So far we have explained the arguments underlying replication-derived option pricing models using the most simple binomial model which makes the (unrealistic) assumption that only two discrete asset prices are possible at the end of the life of the option. A more realistic binomial model, the so-called binomial tree, assumes that asset price movements are binomial in a short period of time of length Δt (cf. Cox et al.., 1979). It can be shown that in the limit as $\Delta t \rightarrow 0$, this (discrete-time) binomial model of asset price movements becomes the geometric Brownian motion which underlies the (continuous-time) B-S option pricing model (which will be used in the present study). We will next demonstrate, using the parameter settings of our case study A3, how risk-neutral probabilities and the risk-neutral interest rate are used in binomial trees (following Hull, 1993). The binomial tree option valuation procedure is as follows: Initially, the life of the option of 3 years is divided into three time intervals of length one year. In each of the three years, the asset price, from its initial value at the beginning of the year is assumed to make either, with probability p, an up movement to value Su or, with probability (1-p), a down movement (d) to value Sd.

The parameters p, u, and d must be determined such that they give the observed values for the mean and the variance of asset price changes in any time interval $\Delta t = 1$ year. As in the simple binomial model at the end of the life of the option, using risk-neutral valuation, the expected value of the asset price at the end of each time interval Δt can be expressed as:

$$Se^{r\Delta t} = p\,Su + (1-p)\,Sd \quad \text{(A3.6)}$$

or: $e^{r\Delta t} = pu + (1-p)\,d.$

Since the variance of a variable Q is defined as $E(Q^2) - [E(Q)]^2$, where E denotes the expected value, it follows that the variance of the asset price at time Δt is:

$pS^2u^2 + (1-p)S^2d^2 - S^2\,[pu + (1-p)d]^2$ (A3.7)

or:

$S^2\,[e^{\mu\Delta t}\,(e^{\sigma\sqrt{\Delta t}} + e^{-\sigma\sqrt{\Delta t}}) - 1 - e^{2\mu\Delta\sigma}]$

By expanding e^x in series form $ex = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \ldots$ and by ignoring terms of order Δt^2 or higher, the variance of the asset price is $S^2\,\sigma^2\,\Delta t$. Using A3.7, it follows that:

$\sigma^2\ \Delta t = pu^2 + (1-p)d^2 - [pu + (1-p)d]^2$ (A3.8)

Standard binomial trees usually satisfy:

$u = \frac{1}{d}$ (A3.9)

The three conditions (A3.6), (A3.8), and (A3.9) imply that:

$u = e^{\sigma}\ \sqrt{\Delta t}$ (A3.10)

$d = e^{-\sigma}\ \sqrt{\Delta t}$ (A3.11)

$p = \frac{a-d}{u-d}$ (A3.12) with $a = e^{r\Delta t}$

For our case study A3, the binomial tree parameters are therefore:

$u = e^{0.45} = 1.57$

$d = e^{-0.45} = 0.64$

$p = \frac{e^{0.06\times3} - 0.64}{1.57-0.64} = 0.45$

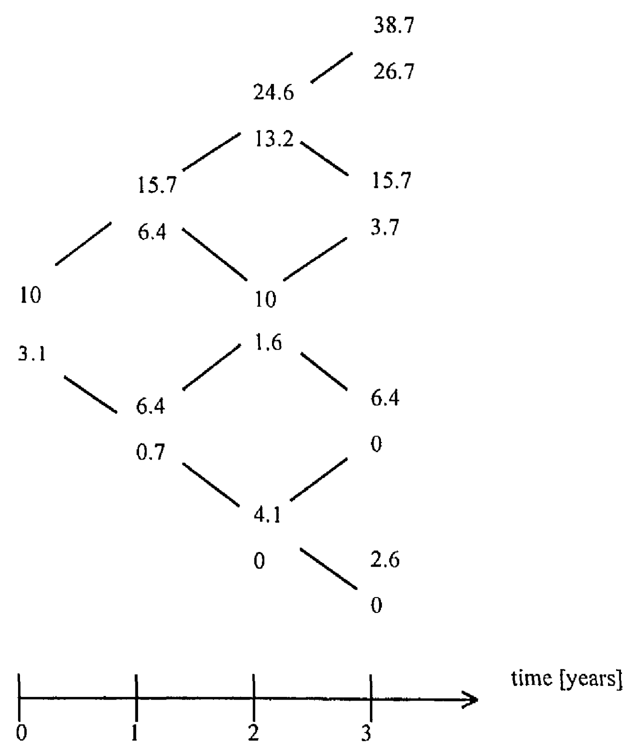
$1-p = 1 - 0.45 = 0.55$

Once the tree of asset prices is determined by applying u and d to the initial asset price of £10m, to calculate the option value, in the first step, in each branch of the tree, the expected value of the option at the time of maturity T is calculated as the expected stock price at time of maturity minus the exercise price. In the second step, the expected values obtained at each node are repeatedly discounted over one year until the present time is reached using the risk-free interest rate r as the discount rate (assuming that the expected return from the stock is the risk-free rate of interest r, rather than the actual expected return of the stock).

The binomial tree for our case study A3 is illustrated in Figure A3.2. At each node, the first number is the asset price and the second number is the option value.

Figure A3.2

Binomial Tree for case study A3.



The option value using a binomial tree with $\Delta t = 1$ year is £3.1m.

A3.2 Risk-adjusted valuation

After having discussed risk-neutral valuation in the previous section, in this section we discuss various risk-adjusted valuation heuristics and compare them to risk-neutral methods.

A3.2.1 "Naive" NPV

First, we calculate the ("simple" or "naive") NPV of the case studies, i.e. the NPV ignoring the flexibility/asymmetry implicit in the growth option situation. In table 4.3.1 we compare it with both the B-S option value and the intrinsic value in Table Additionally, we give the approximate annual returns of the follow-up investment R_{Fu} and of the pioneer and follow-up projects taken together R_{p+Fu} (with X discounted at the risk-free rate and assuming an investment of 2.5 for the pioneer project, which has zero value after 3 years) as:

$R_{Fu} = \frac{NPV/5}{PV(X)/2} \times 100$ (A3.13) and

$R_{p+Fu} = \frac{3}{8} \times \frac{-2.5/3}{2.5/2} \times 100 + \frac{5}{8} R_{Fu}$ (A3.14)

Table A3.1

NPV, option value, intrinsic value and return of case studies.

	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2
Intrinsic value	0	0	0	0	8	13	18	0	0	0	0	0	0	0
NPV	-7.5	-5	0	5	10	15	20	0	0	0	0	0	0	0
OV(T)	0.06	0.5	3	6.8	11.1	15.7	20.4	1.2	2.2	3.8	4.6	5.2	1	4.9
R_{Fu} [%]	-30	-20	0	20	40	60	80	0	0	0	0	0	0	0
R_{p+Fu}[%]	-44	-37.5	-25	-12.5	0	12.5	25	-25	-25	-25	-25	-25	-25	-25

As can be seen from the table, the NPV and the theoretical option value differ substantially, except for case studies A4 to A7. Consequently, the case studies most suited to discriminating between adherence to NPV/option pricing respectively are the first three A-sequence case studies and the B- (and C-) sequence case studies. Note that the difference between the NPV and the intrinsic value in case studies A4 to A7 is because the exercise price X enters the intrinsic value max(0, S-X) at its "face" value (at maturity) of £12m, but enters the NPV calculation at its discounted (at the risk-free rate to the present) value of £10m. Also note that hardly any cases except cases A5 to A7 are clearly attractive on presently expected NPV grounds alone.

A3.2.2 Decision tree analysis

First, we consider the potential theoretical reasons for applying option pricing theory, as opposed to traditional decision tree analysis, to the valuation of growth option investment projects. Second, we exemplify option-theory-adjusted decision tree analysis for our case study A3.

Decision science aims at taking into account the possibility that decisions can be taken after the moment of the initial investment decision, as uncertainty resolves itself. Decision tree analysis helps management to structure this decision problem by mapping out all feasible alternative actions, contingent on the possible states of nature. After that, the monetary values for all the different paths of combinations of all sequences of actions can be computed. Decision tree analysis is theoretically sound, and is particularly useful for valuing sequential investment decisions.

Its main shortcoming, however, is the difficulty of determining the appropriate discount rate to be used to discount the cash flows arising in the different branches of the decision tree. When there are options involved, the risk adjusted discount rate varies in a complex way over time. The risk of an option changes as the value of the underlying asset changes. An option that is in the money (price of underlying asset greater than exercise price) is safer than one that is out of the money (price of underlying asset greater than exercise price) (Brealey and Myers, 1991). Consequently, the correct risk-adjusted discount rate is different for the different branches of a tree that contains an option.

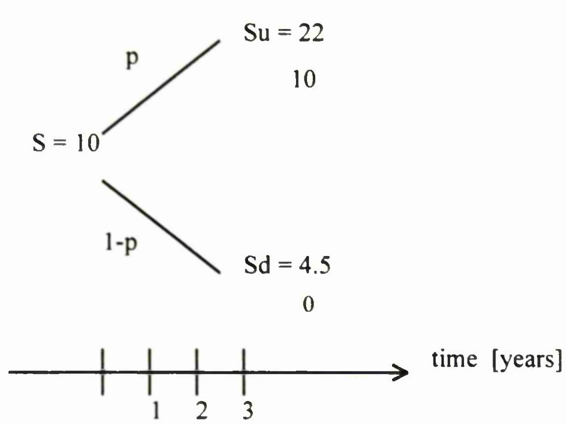
In contrast, in replication-derived contingent claims analysis (CCA), the probabilities of the branches are transformed so as to allow the use of a single risk-free discount rate throughout all branches of the tree. Apart from the use of transformed probabilities and a risk-free discount rate, the method of contingent claims analysis is operationally identical to traditional decision tree analysis. Calculating option values by the binomial method involves the same process as solving decision trees (setting up a binomial tree of asset prices and determining the option value by working backwards through the tree). Replication-derived real options analysis can therefore be seen as a special, economically adjusted version of decision tree analysis, in that it recognises market opportunities to trade and borrow (Trigeorgis and Mason, 1987).

We now demonstrate three different approaches to valuing our case study A3 which all use risk-adjusted discount rates.

First, we consider only two states for the asset price at the time of maturity, namely the $\pm\sigma$ limits of the asset price after three years. Setting $u = e^{0.45\sqrt{3}}$ gives u = 2.2 and setting $d = e^{-0.45\sqrt{3}}$ gives d = 0.45. This is illustrated in Figure A3.3.

Figure A3.3

Simple binomial risk-adjusted analysis of case study A3

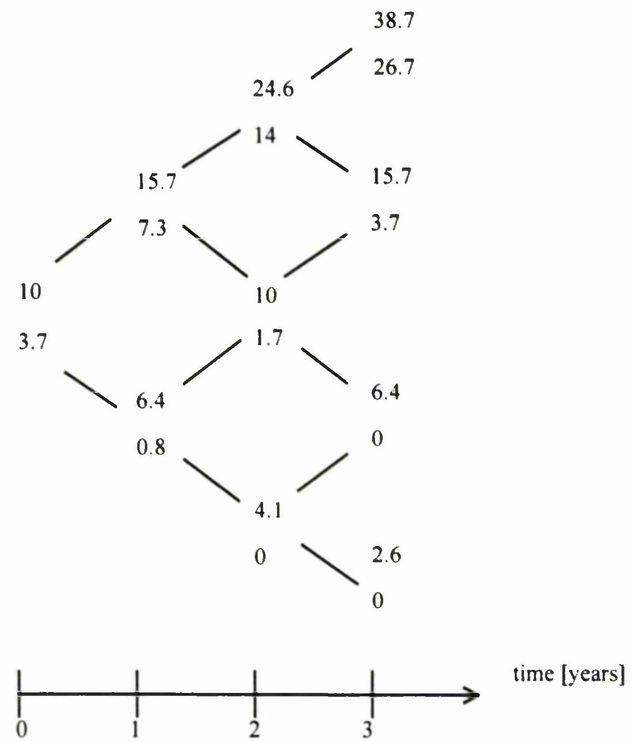


For an exercise price of 12, the option value at maturity is either 10 or 0. To compute the profitability of up and down movements and to discount option values at maturity to the present we use the risk-adjusted expected rate of return from the underlying asset of 12.5% (as identified in the previous section). Using $p = \frac{e^{0.125 \times 3} - d}{u - d} = 0.57$, we arrive at an option value of 5. We note that this option value is based on the rate of return which is adjusted to the risk of the underlying asset, not to the risk of the option. However, as e.g. Brealey and Myers (1991) note, an option is always riskier than the underlying stock. The correct risk-adjusted rate to discount the option values at maturity to the present would therefore have to be higher, leading to a lower current option value. Our option value of 5 could therefore be regarded as an upper bound for the true option value.

We now return to the binomial tree with yearly binomial movements as introduced in the previous section. If we leave the risk-neutral world of the previous section, two things happen to the discounting of the option values at maturity to the present. Instead of risk-neutral probabilities, we use "actual" ones. Instead of discounting at the risk-free rate, we use a risk-adjusted discount rate. The new, risk-adjusted probability of an up movement is $p = \frac{e^{0.125} - d}{u - d} = 0.53$ (and the probability of a down movement 1/p is 0.47). Using these risk-adjusted probabilities and discount rate, we arrive at the decision tree of Figure A3.4

Figure A3.4

Decision tree for A3, constant risk-adjustment

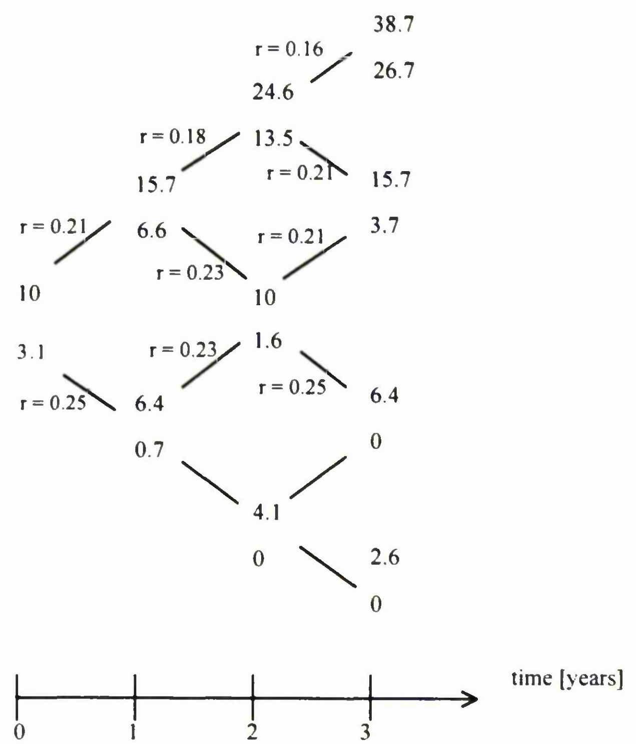


Again, the option value of 3.7 can only be considered an upper limit of the true option value. This is because the risk-adjusted discount rate is known to be too low, with the correct risk-adjusted discount rates being difficult to determine.

Example: Branch-specific risk-adjusted discount rates r satisfying the condition that an option that is out of the money is safer than one that is out of the money (Brealey and Myers, 1991) and chosen to produce the same option value of 3.1 as calculated by the risk-neutral binomial tree (in the previous section) are given in Figure A3.5

Figure A3.5

Decision tree for A3, moneyness specific risk-adjustments



A3.2.3 A distribution-based valuation heuristic

Although asked to decide intuitively on the case studies, respondents were afterwards always asked which, if any, heuristics they used when valuing the case studies. Making use of the distributional information given in the research instrument, a remarkable heuristic was given by a respondent in the first telecommunications company of the study. The heuristic multiplies the estimated probability of S being higher than X with the estimated mean of this part of the lognormal distribution and arrives at valuations very close to the theoretical option values (see table A3.2).

Table A3.2

Distribution-based valuation of case studies

	Information Used					Heuristic	Option Value	B-S theoretical option value
	15%	68%			15%			
		Lower Bound	Mean	Upper Bound				
A1		1.1	2.5	5.5		0.9 × 0 + 0.1 × (10 - 10) =	0	0.06
A2		2.3	5	11		0.85 × 0 + 0.15 × (13 - 10) =	0.45	0.5
A3		4.5	10	22		0.5 × 0 + 0.5 × (15 - 10) =	2.5	3
A4		7	15	33		0.3 × 0 + 0.7 × (20 - 10) =	7	6.8
A5		9	20	44		0.2 × 0 + 0.8 × (25 - 10) =	12	11.1
A6		11	25	55		0.15 × 0 + 0.85 × (30 - 10) =	17	15.7
A7		14	30	66		0.1 × 0 + 0.9 × (35 - 10) =	22.5	20.4
B1		7.5	10	13		0.5 × 0 + 0.5 × [(13 - 10) × 1/3] =	0.5	1.2
B2		6	10	17		0.5 × 0 + 0.5 × [(17 - 10) × 1/3] =	1	2.2
B3		4	10	27		0.5 × 0 + 0.5 × [(27 - 10) × 1/3] =	3	3.8
B4		3	10	34		0.5 × 0 + 0.5 × [(34 - 10) × 1/3] =	4	4.6
B5		2.5	10	41		0.5 × 0 + 0.5 × [(41 - 10) × 1/3] =	5	5.2
C1		7.7	10	13		0.5 × 0 + 0.5 × [(13 - 10) × 1/3] =	0.5	1
C2		2.7	10	37		0.5 × 0 + 0.5 × [(37 - 10) × 1/3] =	4.5	4.9

- Letter to "gatekeepers" -

[Address]

[Date]

Dear [Name],

Real Options Theory and Investment Decision Making

I am a PhD researcher at Manchester Business School, having previously studied at the University of St. Gallen, Switzerland. I am working on "real options theory". This new extension of derivatives theory, which has already revolutionised financial markets, should have important effects on corporate investment decision making. The questions are how far managers are ready and willing to use the new tools, and how far managers already use similar ideas on a common-sense basis. Shell and other leading companies have begun work on this.

The research will ask managers to take a small set of imaginary investment decisions, and to answer additional questions about how realistic they think the case studies are. This should take about an hour for each manager and can take the form of a personal interview or of posting a questionnaire, and assisting by telephone, if required. The target overall number of interviews is minimum about 10 and up to 25 managers from your organisation. There are no "right" or "wrong" answers. The goal is to assess how useful the new ideas are, and to identify the problems of disseminating them. Details of the study's findings will be made available to you after data analysis at the end of 1995.

I would like to interview managers from two or more different functions, e.g. financial control, plus strategic planning plus/or any other you recommend. It is important to talk to decision makers in several functions, not only finance, and this is why I am approaching yourself in the first instance, for permission to approach several functions heads. Given your approval, I would go on to contact the nominated functions heads of your company in late January/early February 1995.

The project forms the main part of my PhD course at Manchester Business School and would be in the strictest of confidence. Dr. Sydney Howell at the address below would be happy to confirm this.

Thank you in advance.
Yours sincerely,

Axel Jägle
Doctoral Programme Researcher

- Letter to participants -

[Address]

[Date]

Dear [Name]

Real Options Theory and Investment Decision Making

I am a PhD researcher at Manchester Business School. I am working on "real options theory". This new area in capital budgeting should have important effects on corporate investment decision making. The questions are how far managers are ready and willing to use the new tools, and how far managers already use similar ideas on a common-sense basis.

I understand from [Name] that you would be willing to participate in my study. I enclose my research instrument and a self-addressed envelope.

The research instrument contains an introduction and a prime example, three investment cases and a questionnaire about the cases. The research instrument should be self-explainatory and completion should take about three quarters of an hour.

If you have any problems with the research instrument or any questions about my research or real options theory in general, do not hesitate to contact me at Manchester Business School on 0161 275 6547.

I would appreciate it if you could send the filled-in cases and questionnaire back to me by 31 May. A summary of the findings from my sample of approximately 100 managers will be available at the end of the year.

I am looking forward to learning about your choices in the investment cases and questionnaire. Thank you very much for taking part in my project.

Yours sincerely

Axel Jägle
Doctoral Programme Researcher

MANCHESTER BUSINESS SCHOOL
Doctoral Programme

Using the Intuition of Investment Decision Makers to Evaluate the Usefulness of Real Options Theory

1. Introduction
2. Investment Case Studies - The Common Structure
3. Investment Cases
4. Questionnaire

Axel Jägle

[Date]

1. Introduction

Thank you for taking part in my research project. The research will ask you to put a value on a set of three imaginary investment situations that are replications of investment situations arising in business. Then, you will be asked to answer additional questions about how realistic you think the investment cases are.

Note that there are no "right" or "wrong" answers to the investment cases. The goal is not to have you sit an "examination". The aim of the investment cases is to capture many managers' "gut feeling" regarding investments, i.e. your opinion and intuition about investments, developed through your experience in a business environment.

Previous studies of investment decision making showed that, in many situations, managers' decisions are not well described by Discounted Cashflow Analysis (the NPV criterion). The question now is whether real options theory is a better model of your decisions. If so, managers will be able to justify and communicate their investment decisions more easily in the future with the help of real options theory. Moreover, it would be clear that real options theory should be included in business school curricula.

The target participants are not only managers who are formally or informally involved in investment decision making, but also managers who are not at all involved in investment decision making. This is in order to detect potential differences.

My analysis of the responses will try to detect differences among a large sample of managers and compare all choices with a real options model.

As all three investment cases share the same structure, a general introduction to the cases follows. It should not be neccesary for you to do any arithmetic. The information given will be in the strictest of confidence and will only be used for research purposes.

If you are unsure about the investment cases, please make any additional assumptions you need in order to achieve a decision (please indicate your assumptions), or telephone me on 0161-275-6547 to clarify the cases. Or you can state your difficulties in the questionnaire, which asks explicitly about any problems you find with the investment cases.

Please return the completed cases and questionnaire to me using the attached business reply envelope.

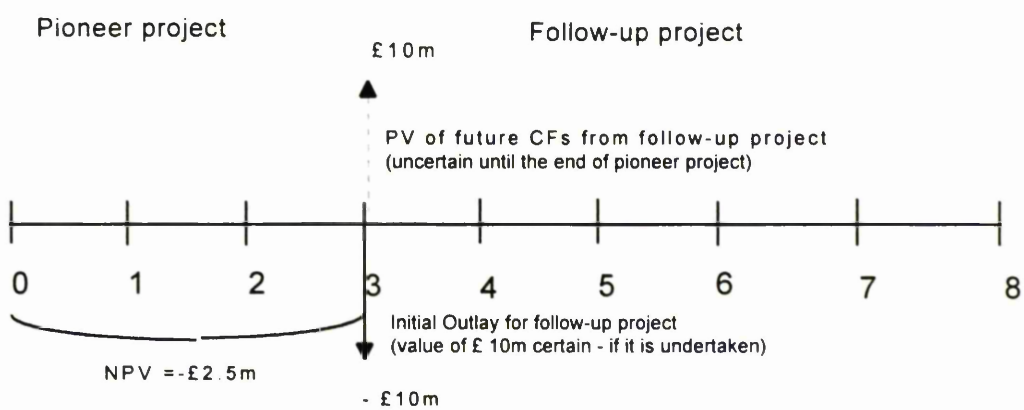
Many thanks for your participation.

2. Investment Case Studies - The Common Structure

The following investment cases describing investment opportunities all have a common structure, as follows:

A **pioneer project** takes three years (in most cases) and leads to a negative Net Present Value (NPV, is the sum of cash inflows and outflows) of - £ 2.5 m. The pioneer project is known to open up a follow-up investment opportunity after three years.

To undertake the **follow-up project**, an initial outlay of £ 10m is necessary (with this investment having zero terminal value at the end of the follow-up product's life-cycle of 5 years). The Present Value (PV) of the future cash flows from the follow-up project is uncertain, although its expected (average) value would be, under current economic conditions, £10m in many of the investment cases.



(Note that positions of cash flows in diagram symbolise effective dates, but cash flows are all discounted to time 0.)

However, the PV of the follow-up project is uncertain. We assum that it moves in line with a known portfolio of securities which can be bought or sold in the financial market.

Concerning its future value, at present, it is only known that the PV will lie with a certain probability in a certain range. As an approximation, the upper and lower value of the range that the PV will lie in at the end of year 3 with about 70% probability is indicated in each case study. Note that the indicated range is not the highest/lowest values possible. Actual values can be higher or lower than this range respectively with a probability of 15%.

If you are acquainted with basic statistics, you will find these facts represented in the diagram of a lognormal distribution below:

(just ignore the diagram if you don't find it immediately enlightening)

Undertaking the pioneer project therefore creates for the company the choice, in year 3, to undertake the follow-up project or not, depending on whether prospects for the product have turned out favourable or poor up to year 3.

Note that the fact that the PV of the future cash flows of the follow-up project is highly uncertain can be beneficial for the company, because a high PV at the end of year 3 means undertaking the follow-up project with high potential gains, whereas a low PV would only lead to a loss of the pioneer investment, because in this case the company would not make the follow-up investment anyway.

Case A1
(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

A chemical process improvement in your rubber plant would lead to cost reductions but would be very expensive to implement. Therefore, it has a negative NPV of - £ 2.5m.

However, the experience with the new chemical process will finally, after fine-tuning the process during three years, allow your company to start production of a new rubber type which has previously been too expensive to produce. The production and marketing of the new rubber type will require an initial outlay of £ 10m, which will have a zero terminal value at the end of the new rubber type's product life-cycle of five years. The PV of the cash flows excluding the initial outlay from the five-year-long commercialisation phase of the new rubber type is subject to uncertainty because profit prospects for the product change. The mean of the PV would be £2.5m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the PV will lie between £ 1.1m and £ 5.5m.

The chemical process improvement therefore offers the choice either to invest in the production of the new rubber type in three years if conditions turn out favourable or not to invest if conditions turn out poor.

Additionally, the DTI has indicated that there might be funds available to support the chemical process improvement.

- What would be the government subsidy that you would require in order to carry out the process improvement? (You would require less than £2.5m if you expected a positive value from the follow-up project. Negative numbers mean you would be willing to pay money for the right to do the process improvement, e.g. by bidding for a licence to do it; all numbers are in million pounds.)

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case A2

(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

You are employed by an East European state railway company. Due to your government's policy to invite Western direct investment, your company has just been forced to supply the rail network for a joint venture with a Western partner, aimed at setting up tramways in a major city. Your part in the joint venture is expected to yield a negative NPV of £ -2.5m, and the contract locks you into making a loss of this amount.

Additionally, you have the right to buy out the Western partner for a fixed price of £ 10m after three years. After 8 years, the control over the tramways will be transferred to the transport department, without compensation for your railway company. The PV of the cash flows excluding the initial outlay from the tramways during five years is subject to uncertainty due to uncertain profit prospects of the project. The mean of the PV would be £5m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the PV will lie between £2.3m and £11m.

The joint venture contract therefore offers you the right to buy out your Western partner for £ 10m if market conditions turn out favourable, or to leave your Western partner committed if conditions turn out poor.

A private transport company in your country has expressed interest in taking over your rights and obligations under the contract. But they have indicated that they would like a "sweetener" payment to compensate them for the costs and risks involved.

- What size of sweetener (if any) would you offer to get rid of this deal? (You would offer less than £2.5m if you reckoned a positive value could be achieved from buying out the Western partner. Negative figures mean you'd want them to pay you for taking over the contract; all numbers are in million pounds.)

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case A3

(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

A British consumer goods company is considering whether to market test its line of body care products in Poland. The NPV from this market test is estimated to be - £ 2.5m.

However, a considerable amount of market know-how and skills could be gathered through the market test, allowing the company to tackle the Russian market in a follow-up project in 3 years time. The initial (sunk) investment cost of following up the Russian market would be £ 10m. The PV of the cash flows excluding the initial outlay from the Russian market during the body care line's life-cycle of five years is subject to uncertainty due to unstable profit prospects for the product in Russia. The mean of the PV would be £10m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the PV will lie between £ 4.5m and £ 22m.

The development of the Polish market therefore offers the company the choice either to enter the Russian market in 3 years if conditions turn out favourable or to stay out if conditions turn out poor.

As an alternative, you could decide not even to invest in the Polish market, but instead, at a cost of £12.5m and at very predictable revenues, introduce a new product into your existing (UK) market.

- How high would the NPV of the cash flows from the UK project have to be, for you to do this in preference to undertaking the Polish test market? (To answer this, estimate how valuable the option to tackle the Russian market is and subtract the price of acquiring this option (£ 2.5m). All numbers are in million pounds.)

more than:

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case A4

(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

Your company produces toothbrushes and you are interested in entering the Swiss market. A Swiss family has offered to sell you their family firm in two stages. The first step would be a down payment of £ 2.5m which is not returnable. This would give you a three year option on the right to buy the firm.

The second stage payment would be £ 10m after three years, but you are not obliged to go ahead at this stage. The Swiss company's activities, together with your marketing skills, lead to an earnings value of the company (i.e. the discounted value of all future net cash flows of the company) which is subject to uncertainty due to unstable profit prospects for the product. The mean of the PV would be £15m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the earnings value will lie between £ 7m and £ 33m.

By making the down payment of £ 2.5m now, you would gain the choice to go on to spend a future £ 10m on the Swiss company if conditions turn out favourable. You could instead decide to invest £ 12.5m immediately in a cost-cutting technology for your UK toothbrush production. Since the UK market will support an established and successful product, its NPV can be estimated exactly.

- How good a return (NPV of cash flows) would the cost-cutting technology for your toothbrush production have to offer you, in order to make you walk away from investing in the Swiss company? (To answer this, estimate how valuable the option to buy the Swiss company is and subtract the price of acquiring this option (£ 2.5m). All numbers are in million pounds.)

more than:

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case A5

(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

Your foodstuffs company has contracted a group of scientists to do basic research on pet food for the next three years. However, pet food is outside your core business area of human foods. A non-competing pet food producer has just made an offer to buy all the rights (esp., the right of commercialisation) in the research and to take over completely the laboratory and its running costs, which will be £ 2.5m over the next three years. It is certain that it will be possible to use the findings, expected after 3 years, to produce a new pet food.

Commercialisation of the new pet food requires an initial outlay of £ 10m for development, plant, marketing and distribution. After five years, the new pet food will be outdated, leading to a zero terminal value of the assets connected to it. The PV from the commercialisation of the pet food over its product life-cycle of five years is owing to unknown competitive and market movements. The mean of the PV would be £20m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the PV will lie between £ 9m and £ 44m.

The pet food lab therefore offers the choice either to invest £ 10m in the commercialisation of the new pet food if conditions turn out favourable, or to leave the pet food production if conditions turn out poor.

- What selling price for the lab would you expect to achieve? (It can be assumed that the bidder has the same information like you; therefore neither of you will get a bargain. A negative number means you would be willing to pay the pet food producer a "sweetener" as an inducement to take over the lab; all numbers are in million pounds.)

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case A6
(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

A well-known conglomerate is about to introduce a first-generation microchip. The NPV from commercialising the chip will be - £2.5m. However, the expertise gained in the development of the microchip can be used to launch a second-generation microchip in three years.

Launching the second-generation microchip will require an initial outlay of £ 10m, which will have a zero terminal value at the end of the microchip's product life-cycle in five years. However, market prospects for, and therefore the expected PV of the cash flows from, the second-generation microchip are subject to uncertainty. The mean of the PV would be £25m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the PV will lie between £ 11m and £ 55m.

The first-generation microchip therefore offers the choice either to invest in the second-generation micro chip if conditions turn out favourable or to walk away if conditions turn out poor.

The conglomerate owning the project intends to focus itself more on its low-tech businesses. Therefore, the conglomerate may be willing to sell all rightsin, and all know-how for, the intelligent microchip. Your company is interested in buying the microchip business. It can be assumed that your couterparty has the same information like you; therefore none of you will get a bargain.

- What would you be willing to offer the conglomerate for the project? (Negative numbers mean the conglomerate would have to offer you money to take the lab off them; all numbers are in million pounds.)

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case A7
(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

Your company was awarded the rights to a new tarpaulin material developed from space research. Setting up a production line for the tarpaulin would cost £ 2.5m. It is clear that selling the tarpaulin as a raw material would just cover production costs.

However, capitalising on the experience gained in producing the raw material, it would be possible to set up a second production line for different shapes of ready-to-use pieces of the material, and this would take three years. This will require an initial outlay for plant, machinery and marketing of £ 10m, which will have a zero terminal value at the end of the ready-to-use material's product life-cycle, five years after its launch. Market prospects for the new material and therefore the expected PV from producing it are subject to uncertainty. The mean of the PV would be £30m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the PV will lie between £ 14m and £ 66m.

The raw tarpaulin material from space research therefore offers the choice either to go on to the ready-to-use material if conditions turn out favourable, or not to produce the ready-to-use material if conditions turn out poor.

However, your company suffers currently from a cash shortage. After having exhausted all available bank credit lines, it has been decided to introduce an investment stop and even to sell assets. You know that an established tent manufacturer is interested in buying all rights in, and production facilities for, the new tarpaulin material. It can be assumed that your couterparty has the same information like you; therefore none of you will get a bargain.

- What would you consider as a realistic selling price for selling the project? (Negative numbers mean you would actually be willing to pay someone to take the project off you; all numbers are in million pounds.)

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case B1

(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

Your company is a wholesale bakery, specialising in muffins. The NPV from a proposed test of the Belgian market is estimated to be - £ 2.5m.

However, after a phase of three years of acquiring market know-how about continental European eating habits and distribution methods, the French market could eventually be tackled. The cost of entering the French market will be £ 10m. Because muffins belong to the generally very stable food sector, the profit prospects for muffins are only moderately unstable. The mean of the PV would be £10m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the PV of the cash flows from the French market will lie between **£ 7.5m and £ 13m**. The mean of the PV will be £ 10m.

The test in the Belgian market therefore offers the choice to either enter the French market if conditions turn out favourable or to stay away if conditions turn out poor. As a less risky alternative, you could decide not to invest in the Belgian market but instead, at a cost of £12.5m, invest in a cheaper bread-wrapping process for your UK sales.

- How profitable (in terms of the NPV of cash flows) would the UK bread-wrapping process have to be, in order for you to invest in it, and cancel the Belgian test marketing? (To answer this, estimate how valuable the option to tackle the French market is and subtract the price of acquiring this option (£ 2.5m). All numbers are in million pounds.)

more than:

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case B2
(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

Your company is a utilities company. The NPV from a proposed new prototype windmill would be - £ 2.5m.

However, knowledge gained in the development and running of the prototype windmill could enable your company to build a full production windfarm in three years. Building a full production windfarm will require an initial outlay of £10m while the scrap value of the wind farm after a useful life of five years will be zero. The PV from the full production windfarm is subject to the moderate uncertainty in economic and competitive conditions typical to the utilities industry. The mean of the PV would be £10m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the PV will lie between **£ 6m and £ 17m**.

The development of the prototype windmill therefore offers the choice either to develop and include the full production windfarm in your energy production if conditions turn out favourabe or to leave it if conditions turn out poor.

As an alternative, you could decide to accept a government contract to do the development of the first-generation windmill for them with the government taking all costs, risks, rights, and profits.

- At what price would you prefer the government contract to doing the development on your own account? (To answer this, estimate how valuable the option to build the full production wind farm is and subtract the price of acquiring this option (£ 2.5m). It can be assumed that your couterparty has the same information like you; therefore neither of you will get a bargain. Negative numbers mean you would enter the contract even if you had to compensate the government; all numbers are in million pounds.)

more than:

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case B3
(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

You are the hardware supplier in a mobile telephone joint venture. The contract locks you into spending an amount of £ -2.5m over the next three years on the technical facilities without sharing any of the profits.

Additionally, you have the right to buy out the software supplier for a prespecified amount of £ 10m after three years. At the end of 8 years from now, the joint venture's mobile telephone product will have been overtaken by events, leading to a zero terminal value of all the assets of the joint venture. The earnings value (i.e. the discounted value of all future net cash flows of the company) of the joint venture is uncertain due to unknown profit prospects for mobile telephones. The mean of the PV would be £10m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the earnings value will lie between **£ 4m and £ 27m**.

The joint venture arrangement therefore offers the right to buy out the software supplier for £ 10m if conditions turn out favourable or to leave the software supplier committed if conditions turn out poor.

- What, in your opinion, would be a realistic price at which to sell your rights and obligations in the joint venture to an interested firm? (It can be assumed that your couterparty has the same information like you; therefore neither of you will get a bargain. Negative figures mean that you would pay to get rid of your stake in the joint venture; all numbers are in million pounds.)

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case B4
(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

A non-competing pharmaceutical company has a veterinary remedy which also has a human remedy as a possible spin-off. The cost of testing the veterinary remedy for human use would be -£ 2.5m.

There is no doubt that the remedy will eventually be accepted for human use, but the tests are an essential requirement and this will take three years. The initial outlay for commercialisation of the human remedy is known to be £ 10m, which will have a zero terminal value at the end of the remedy's product life-cycle in five years. As the returns from pharmaceuticals projects vary considerably, the expected PV from the human remedy is subject to uncertainty. The mean of the PV would be £10m under current economic conditions. It is also known that, with a probability of about 70%, in three years' time, the PV will lie between **£ 3m and £ 34m**.

The testing of the veterinary remedy at a cost of £ 2.5m will create the choice either to go on to invest £ 10m in producing the human remedy if conditions turn out favourable or not to invest if conditions turn out poor.

- What would you offer the pharmaceuticals company for all rights to the veterinary remedy? (It can be assumed that your couterparty has the same information as you; therefore neither of you will get a bargain. Negative numbers mean you would take on the project only if the other company would pay you for doing so; all numbers are in million pounds.)

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case B5
(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

You are operating in the extremely volatile building and construction sector. Buying land in a rural area has cost you £ 2.5m.

However, it might be possible to use the land for construction of a residential area in 3 years. The construction will cost £ 10m. The PV from selling over five years the flats, houses, and office space in the residential area is subject to very high uncertainty. The mean of the PV would be £10m under current economic conditions. It is also known that, with a probability of about 70%, in one year's time, in three years' time, the PV will lie between **£ 2.5m and £ 41m**.

Buying the land therefore offers the choice either to transform it into residential area for £ 10m if conditions turn out favourable or not to develop the land if conditions turn out poor.

You know your council is interested in buying rural land in your area.

- What size of offer would you expect the local council to make to buy the site from you? (It can be assumed that your couterparty has the same information like you; therefore neither of you will get a bargain. Negative numbers mean you would be willing to invest this amount in the property before the sale in order to get rid of it; all numbers are in million pounds.)

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case C1
(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

A British consumer goods company is considering whether to introduce its new disposable nappy in Portugal. The NPV from this market introduction project is estimated to be - £ 2.5m.

However, a considerable amount of market know-how and skills would be gathered through the market introduction, allowing the company to tackle the Spanish market in a follow-up project. Yet, due to strong interest by rival companies in the Spanish market, fierce competition is to be expected. Therefore you have to decide on whether to enter Spain after one year. The initial marketing cost of following up the Spanish market would be £ 10m. The Present Value (PV) of the cash flows coming in during the life-cycle of the disposable nappy of five years in the Spanish market (excluding the initial outlay) is subject to uncertainty. The mean of the PV would be £ 10m under current economic conditions. It is also known that, with a probability of about 70%, **in one year's time** the PV will lie between £ 7.7m and £ 13m.

The Portuguese market introduction therefore offers the company the choice either to enter the Spanish market in a year's time if conditions turn out favourable or to stay out if conditions turn out poor.

As an alternative, you could decide not to invest in the Portuguese market but instead, at a cost of £12.5m, introduce a new product into your existing (UK) market. The NPV of a new product introduction in the UK can be estimated quite exactly.

- How high would the NPV of the UK project have to be, before you would do this in preference to undertaking the Portuguese market introduction ? (To answer this, estimate how valuable the option to tackle the Spanish market is and subtract the price of acquiring this option (£ 2.5m). All numbers are in million pounds.)

more than:

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

- Add any comment if you like:

Case C2

(All companies are imaginary firms.
All numbers are discounted to the present.)

Please read the case description below, then choose one of the values offered.

Your small Japanese research company has a new idea for an expensive but highly effective adhesive. The NPV of developing the adhesive to production stage and selling it in the low-margin world market for normal glue would be - £2.5m.

However, your company knows that the adhesive is the missing link in the assembly of improved dentures an American company specialising in dental technology working upon. The initial outlay to set up a factory that assembles improved dentures using the adhesive will be £ 10m, which will have a zero terminal value at the end of the denture's product life-cycle after five years. The expected PV from the assembly of the improved denture using the adhesive is subject to uncertainty. The mean of the PV would be £ 10m under current economic conditions. It is also known that, with a probability of about 70%, **in five years' time**, the PV will lie between £ 2.7m and £ 37m.

Developing the adhesive to production stage therefore offers the choice either to invest £ 10m in the assembly of dentures if conditions turn out favourable or not to invest if conditions turn out poor.

- You have been asked to determine the net value the adhesive has to the American company to determine a selling price (It can be assumed that your couterparty has the same information like you; therefore neither of you will get a bargain. Negative numbers mean you would be willing to pay money to get rid of the project; all numbers are in million pounds.)

-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

any other value:

Add any comment if you like:

4. QUESTIONNAIRE

Section 1: Occurence of growth options in your company.

(1) Of the above, the investment cases *most similar* (in financial terms) to investment situations arising in my own firm are (in what respect?):

(2) Of the above, the investment cases *most different* (in financial terms) from investment situations arising in my own firm are (in what respect?):

(3) Of all investment projects in your company, what is the percentage of investment projects that create potential follow-up investments (i.e. that are pioneer projects themselves)?

0-10%
0-20%
20-30%
30-40%
40-50%
50-60%
60-70%
70-80%
80-90%
90-100%

(4) "Pioneer" investment projects, that create potential follow-up projects arise in my company in the following areas: (please circle how often, using the following rule: 1 = Never, 2 = Very seldom, 3 = Sometimes, 4 = Very Often, 5 = Always)

- R&D	1	2	3	4	5
- Marketing/test markets	1	2	3	4	5
- IT investments	1	2	3	4	5
- Process improvements	1	2	3	4	5
- As explicit agreements in contracts	1	2	3	4	5
- other (please specify):	1	2	3	4	5

(5) When evaluating a pioneer project, follow-up investment opportunities are taken into account in my company (please tick):

- not at all

- qualitatively (how?):

- quantitatively (how?):

(6) "It is desirable to estimate the potential gains from follow-up investment opportunities quantitatively." (please circle your degree of agreement or disagreement on the following list):

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

Section 2: Realism or Unrealism of the assumptions underlying real options theory.

(7) "In my industry, at any point in time, we are sure about the profit prospects for a product over the whole length of its life" (please circle which applies below):

1 = Never
2 = Very seldom
3 = Sometimes
4 = Very Often
5 = Always

- which is the average life of a product in your industry? (fill in)

...years

(8) "It is difficult to evaluate the PV of a project" (please circle):

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

- in what ways?:

(9) (a) "In my industry, market conditions can be forecasted with 90% accuracy for (please tick the longest horizon):

less than 1 year:
1 year
2 years
3 years
4 years
5 years or more."

(b) "In my industry, competition can be forecasted with 90% accuracy for (please tick the longest horizon):

less than 1 year:
1 year
2 years
3 years
4 years
5 years or more."

(c) "In my industry, production costs can be forecasted with 90% accuracy for (please tick the longest horizon):

less than 1 year:
1 year
2 years
3 years
4 years
5 years or more."

(10) "We needn't simply wait for time to pass in order to get more information: if we invest more in e.g.market research and test marketing we can learn the prospects for a follow-up project faster (please circle).

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

-how long do these activities usually take?

.... years

Section 3: Determinants of option value.

(11) "In my industry, the PVs of cash flows are more predictable than the 30% yearly standard deviation assumed in many of the cases."(please circle).

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

- if possible, give a more realistic estimate of the standard deviation, or if you prefer, your (70% probable) range for the high and low PV of cash flows for a typical investment after 1 year (e.g. 7m to 13m):

(12) "The actual initial cost of the follow-up investment is also uncertain" (please circle):

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

(13) "A planning horizon of 8 years is too long for my industry" (please circle):

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

- A realistic horizon is:

(14) (a) The development time of a pioneer project until the follow-up investment can be taken (3 years in most of the case studies) is unrealistic for my industry (please circle).

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

- A more realistic value would be:

(b) The life cycle of the follow-up investment (5 years) is unrealistic for my industry (please circle).

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

A more realistic value would be: . . . (please fill in).

Section 4: Investment decision making in your company.

(15) We would count the NPV of a first (pioneer) project as a cost of /contibution to the second investment, and we would look at the two investments as a single project (please circle):

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

(16) We simply don't organise decision making this way (please circle):

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

If 3-5, please describe your organisation's process for a comparable problem. Use a continuation sheet if necessary.

(17) No decision is possible without additional data (please circle)

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

- please state the additional data that in your company you would need and could get before taking the investment decision:

(18) We also take into account strategic goals and internal or external political factors (please circle):

1 = Strongly disagree
2 = Disagree
3 = Uncertain
4 = Agree
5 = Strongly agree

- Please give an example of how each factor might affect the decision.

(19) Did you use any particular mathematical capital budgeting or other decision making technique to decide your answers to the investment cases?

(20) How did you reach your results (please describe any rules of thumb or other procedures)?

(21) If you could not decide on one or more of the cases, what was your major difficulty?

Section 5: General information about yourself.
(The information given is used for statistical/research organisational purposes only and will be in the strictest of confidence)

[A] Job title:

[B] Industry:

[C] Approximate size of business unit:

[D] I am formally involved in investment decision making in my company (please circle):

1 = Never
2 = Very seldom
3 = Sometimes
4 = Very Often
5 = Always

- in what way(s)?

[E] I am informally involved in investment decision making in my company (please circle):

1 = Never
2 = Very seldom
3 = Sometimes
4 = Very Often
5 = Always

- in what way(s)?

[F] I have been working in my present department for (please circle):
1 = less than 7.5 years
2 = between 7.5 and 15 years
3 = between 15 and 22.5 years
4 = more than 22.5 years

[G] I have been working in business for (please circle):

1 = less than 7.5 years
2 = between 7.5 and 15 years
3 = between 15 and 22.5 years
4 = more than 22.5 years

[H] My education includes (please tick):

- degree:
  in:
  - Arts (Geography, History, Languages)
  - Economics
  - Business Studies/Management Science
  - Other social science
  - Law
  - Maths
  - Science
  - Engineering/Technology
  - Other:

- post-graduate course(s):

- professional qualification(s):

- other relevant studies or courses (please specify)

Please add any comments if desired:

Please attach your letterhead or your business card if you would like to receive a summary of the findings.

Thank you very much for your time and effort.

Appendix 4.2: Coding of grouping variables

Grouping variable Involvement was aggregated from the information given in questions D and E in the questionnaire according to the rule: 0.6 D + 0.4 E. This was in order to classify managers with a very high degree of informal involvement and some formal involvement in the high involvement group. The resulting value "I" was used to form the two levels of Involvement as:

0 = $I < 3.5$

1 = $I \geq 3.5$.

In Appendix 5.1 (the data set), empirical values for D, E, and I are in the following columns:

D = INV_F (fourth last column),

E = INV_INF (third last column), and

I = IN_F_INF (second last column).

Grouping variables Business Education and Qualification were derived from question H. Business Education was coded as:

1 = degree in Economics or Business Studies/Management Science

0 = other

Qualification was coded as:

1 = postgraduate course(s) or professional qualification(s)

0 = other

Experience was coded from question G in the questionnaire as:

0 = 1,2

1 = 3,4

In Appendix 5.1 (the data set), the emprical values for G are given in column:

G = EX_B (last column),

NO	CO	SECTOR	INDUST	LEVEL	FUNCT	POSIT	INVOLV	EXPERI	EDUCBU	QUALIF	A1	A2	A3	A4	A5	A6	A7
1	1	1	1	1	1	0	1	0	0	1	.	.	.	.	.	.	20.0
2	1	1	1	1	1	0	1	0	1	1	0.1	-0.2	3.5	.	.	.	.
3	1	1	1	0	0	0	1	0	1	1	.	.	.	0.0	.	.	.
4	1	1	1	0	0	0	1	1	1	1	.	.	.	.	.	.	.
5	1	1	1	0	0	0	.	1	0	0	.	.	.	5.0	13.0	9.5	.
6	2	1	1	1	0	0	0	1	1	1	-0.5	.	5.0	.	.	.	.
7	2	1	1	1	0	0	0	1	0	1	.	.	.	.	.	.	12.5
8	3	1	2	1	1	0	1	0	1	1	.	.	.	.	.	.	.
9	3	1	2	1	1	0	0	1	1	1	0.5	5.5	2.5	.	.	.	.
10	3	1	2	1	1	0	1	0	1	1	.	.	.	.	.	.	9.5
11	3	1	2	1	1	.	0	0	0	.	.	.	.	7.0	15.0	13.0	.
12	3	1	2	1	1	0	1	1	1	.	.	.	.	.	.	.	.
13	3	1	2	1	1	1	1	1	1	1	.	.	.	.	.	.	15.5
14	3	1	2	1	0	1	1	1	0	1	.	.	.	0.0	12.5	7.5	.
15	3	1	2	1	0	0	1	0	1	1	.	.	.	9.5	22.5	13.5	.
16	3	1	2	1	0	0	1	0	1	1	0.5	2.0	3.0	.	.	.	.
17	3	1	2	1	0	0	0	0	0	.	.	.	.	.	.	.	.
18	3	1	2	1	.	0	1	1	0	1	.	.	.	.	.	.	.
19	3	1	2	0	1	0	1	0	1	1	.	.	.	.	.	.	20.0
20	3	1	2	0	1	1	1	0	0	1	.	.	.	5.0	10.0	10.5	.
21	3	1	2	0	1	1	1	0	1	0	.	1.5	3.0	.	.	.	.
22	3	1	2	0	0	1	0	0	0	1	.	.	.	6.0	14.5	12.5	.
23	3	1	2	0	0	1	1	1	0	1	.	.	.	.	.	.	.
24	3	1	2	0	0	0	0	0	0	0	.	.	.	.	.	.	.
25	3	1	2	0	1	0	1	1	1	1	0.0	0.5	2.0	.	.	.	.

NO	CO	SECTOR	INDUST	LEVEL	FUNCT	POSIT	INVOLV	EXPERI	EDUCBU	QUALIF	A1	A2	A3	A4	A5	A6	A7
26	3	1.	2	0	1	1	1	1	1	1	.	.	.	.	.	.	.
27	3	1	2	0	1	0	1	1	.	1	.	.	.	.	.	.	.
28	3	1	2	0	0	0	0	1	0	1	.	.	.	.	.	.	6.0
29	3	1	2	0	0	0	0	1	0	1	.	.	.	8.5	16.5	.	.
30	3	1	2	.	0	0	0	0	1	1	.	.	.	.	.	.	.
31	3	1	2	0	0	0	.	1	0	1	.	.	.	.	.	.	.
32	3	1	2	0	1	1	0	0	1	1	.	.	.	.	.	.	4.5
33	3	1	2	0	1	0	1	1	1	1	.	.	.	.	.	.	.
34	3	1	2	0	0	0	1	.	1	1	0.0	2.0	4.0	.	.	.	.
35	3	1	2	0	0	0	0	0	0	0	.	.	.	.	.	.	9.5
36	3	1	2	0	0	1	1	1	0	1	.	.	.	.	.	.	.
37	4	1	3	1	1	1	1	1	1	1	0.5	2.0	4.0	.	.	.	.
38	4	1	3	1	1	0	0	0	0	1	.	.	.	.	.	.	14.0
39	4	1	3	1	1	0	1	1	1	0	.	.	.	.	.	.	.
40	4	1	3	1	0	1	1	0	0	1	.	.	.	.	.	.	.
41	4	1	3	1	0	0	1	1	0	1	.	.	.	.	.	.	12.5
42	4	1	3	1	0	0	0	1	0	1	.	.	.	5.5	15.5	15.5	.
43	4	1	3	1	0	0	0	0	0	1	-1.0	0.5	2.5	.	.	.	.
44	4	1	3	1	0	0	1	1	1	1	.	.	.	.	.	.	.
45	5	1	3	0	1	0	0	0	1	1	-1.0	0.0	5.0	.	17.5	5.0	12.5
46	6	2	4	0	1	1	1	1	1	1	.	.	.	5.0	14.0	12.5	.
47	6	2	4	0	1	0	.	0	1	1	0.0	0.5	4.5	.	.	.	.
48	6	2	4	0	1	0	1	1	1	.	.	.	.	.	.	.	14.0
49	6	2	4	0	0	0	0	0	0	1	.	.	.	.	.	.	.
50	6	2	4	0	0	1	0	1	0	1	.	.	.	.	.	.	.

NO	CO	SECTOR	INDUST	LEVEL	FUNCT	POSIT	INVOLV	EXPERI	EDUCBU	QUALIF	A1	A2	A3	A4	A5	A6	A7
51	6	2	4	0	0	1	0	1	1	1	0.0	3.5	4.0	.	.	.	.
52	6	2	4	0	0	0	0	0	0	0	.	.	.	.	.	.	.
53	6	2	4	0	0	0	0	1	0	0	.	.	.	4.0	11.5	10.5	.
54	6	2	4	0	.	0	0	1	0	1	.	.	.	.	.	.	.
55	6	2	4	0	0	0	0	0	0	1	.	.	.	.	.	.	11.5
56	7	2	4	0	1	0	0	0	1	1	.	.	.	5.5	10.5	14.5	.
57	7	2	4	0	1	0	.	1	1	1	0.0	4.5	5.5	.	.	.	.
58	7	2	4	0	0	0	0	0	0	0	.	.	.	3.5	.	6.5	.
59	7	2	4	0	0	0	0	1	0	1	.	.	.	.	.	.	.
60	7	2	4	0	0	0	1	0	0	.	.	.	.	.	.	.	.
61	8	2	4	1	1	1	0	1	0	1	0.5	.	.	.	.	.	.
62	8	2	4	1	1	0	1	1	1	1	.	.	.	.	.	.	15.5
63	8	2	4	1	1	.	1	0	1	1	.	.	.	.	.	.	.
64	8	2	4	1	1	0	0	1	0	1	.	.	.	8.5	12.5	13.0	.
65	8	2	4	1	0	0	0	0	1	1	.	.	.	.	.	.	.
66	8	2	4	1	0	1	1	1	1	1	.	.	4.5	.	.	.	.
67	8	2	4	1	0	0	1	0	1	1	-1.0	1.0	4.0	.	.	.	.
68	9	2	5	1	1	1	1	1	.	.	.	4.5	3.5	10.5	17.5	.	.
69	9	2	5	1	1	1	0	0	.	.	0.0	0.0	4.5	9.5	19.5	.	.
70	9	2	5	1	1	1	0	1	.	.	.	2.5	4.5	7.5	17.5	12.5	20.5
71	9	2	5	1	1	1	1	1	1	1	.	.	.	.	.	.	16.5
72	9	2	5	1	1	1	1	1	1	1	0.0	0.0	5.0	10.0	22.5	.	.
73	9	2	5	1	1	0	1	0	1	1	.	.	.	.	.	.	.
74	9	2	5	1	1	0	.	1	1	1	.	.	.	.	.	.	.
75	9	2	5	.	1	0	0	0	0	1	.	.	.	.	.	.	.

NO	CO	SECTOR	INDUST	LEVEL	FUNCT	POSIT	INVOLV	EXPERI	EDUCBU	QUALIF	A1	A2	A3	A4	A5	A6	A7
76	9	2	5	0	0	1	1	0	1	0	.	.	.	.	.	.	.
77	9	2	5	0	0	0	0	1	0	1	.	.	.	8.5	14.5	14.0	.
78	9	2	5	0	0	0	1	0	0	1	.	.	.	.	.	.	.
79	9	2	5	0	0	0	0	0	1	0	.	.	.	.	.	.	.
80	9	2	5	0	0	0	0	0	1	1	.	.	.	.	.	.	20.5
81	9	2	5	0	0	0	1	.	0	1	.	.	.	.	.	.	.
82	9	2	5	0	0	0	1	0	0	0	1.0	1.0	5.0	.	.	.	.

NO	B1	B2	B3	B4	B5	C1	C2	PERC	FU_RD	FU_MA	FU_IT	FU_PR	FU_CO	FU_OT	TREAT	FU_QU	SURE
1	0.0	5.0	.	.	.	.	.	1.00	.	.	.	.	.	.	2	4	.
2	.	.	.	.	.	.	.	0.05	1	4	3	2	1	1	1	4	2
3	.	.	.	.	.	2.5	5.0	0.10	1	3	4	3	1	1	1	5	4
4	.	.	6.5	12.5	3.0	.	.	0.03	.	.	.	.	.	2	3	4	2
5	.	.	.	.	.	.	.	0.70	4	3	2	3	4	4	2	.	.
6	.	.	.	.	.	.	.	0.90	4	3	2	4	1	1	2	5	3
7	3.0	7.5	.	.	.	.	.	0.90	4	2	2	3	1	5	2	4	2
8	1.0	.	.	.	.	2.5	2.5	0.70	4	3	2	3	4	1	2	4	3
9	.	.	.	.	.	.	.	.	4	1	3	4	1	1	2	5	2
10	-1.5	.	.	.	.	.	.	0.30	3	1	3	3	2	1	2	4	3
11	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	5	.
12	.	.	5.0	8.0	6.0	.	.	0.05	1	2	3	2	1	3	3	4	2
13	8.0	7.5	.	.	.	.	.	0.05	1	3	2	2	1	1	3	5	1
14	.	.	.	.	.	.	.	0.90	1	4	1	4	1	1	3	4	3
15	.	.	.	.	.	.	.	0.05	2	3	3	3	1	1	1	4	2
16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4	1
17	.	.	5.0	7.0	6.0	.	.	0.90	4	3	2	3	1	1	2	3	3
18	.	.	.	.	.	7.0	9.0	0.40	3	4	1	2	1	2	1	4	3
19	7.0	5.5	.	.	.	.	.	0.08	3	3	2	2	2	1	3	5	3
20	.	.	.	.	.	.	.	0.30	2	1	1	1	3	1	3	5	1
21	.	.	.	.	.	.	.	0.50	4	2	4	4	3	1	2	2	2
22	.	.	.	.	.	.	.	0.65	4	4	3	4	3	1	3	4	2
23	.	.	7.5	6.5	.	.	.	.	4	2	3	3	3	1	3	4	2
24	.	.	.	.	.	5.0	8.0	0.70	4	4	3	4	2	1	.	3	4
25	.	.	.	.	.	.	.	0.30	3	4	2	4	2	5	3	5	2

NO	B1	B2	B3	B4	B5	C1	C2	PERC	FU_RD	FU_MA	FU_IT	FU_PR	FU_CO	FU_OT	TREAT	FU_QU	SURE
26	.	.	.	.	.	.	.	0.50	1	1	1	1	1	4	3	4	.
27	.	.	.	.	.	3.5	8.0	.	.	.	.	.	.	.	3	.	2
28	6.5	.	.	.	.	.	.	0.80	4	3	3	4	2	1	3	4	3
29	.	.	.	.	.	.	.	0.05	3	1	2	3	2	3	2	4	5
30	.	.	7.5	9.0	4.5	.	.	0.35	2	2	2	4	3	2	.	5	3
31	.	.	3.5	10.5	7.0	.	.	.	.	.	.	.	.	.	3	3	.
32	-2.0	.	.	.	.	.	.	0.60	2	3	4	4	3	1	2	4	2
33	.	.	.	.	.	9.0	5.5	0.15	2	1	1	2	3	2	2	.	1
34	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.
35	4.0	7.0	.	.	.	.	.	0.60	4	2	4	4	3	1	.	5	3
36	.	.	3.0	5.5	5.0	.	.	0.50	5	4	2	2	3	1	1	4	3
37	.	.	.	.	.	.	.	0.10	2	1	2	1	3	3	3	5	1
38	1.5	6.0	.	.	.	.	.	0.40	3	3	2	1	1	3	2	5	3
39	.	.	.	.	.	2.5	6.5	.	.	.	.	.	.	.	.	4	2
40	.	.	4.5	8.5	8.0	.	.	0.05	1	1	1	1	1	3	3	5	1
41	5.0	5.5	.	.	.	.	.	0.05	1	1	1	1	1	2	3	5	2
42	.	.	.	.	.	.	.	0.85	4	4	3	2	2	1	3	5	2
43	.	.	.	.	.	.	.	0.75	4	2	3	1	1	1	3	4	4
44	.	.	.	.	.	6.0	7.0	0.10	1	2	1	2	1	1	3	.	.
45	0.0	.	.	12.5	5.0	12.5	5.0	0.10	.	2	.	.	.	.	1	1	3
46	.	.	.	.	.	.	.	.	4	2	3	3	4	1	1	1	3
47	.	.	.	.	.	.	.	0.01	2	1	1	1	2	1	1	1	2
48	4.0	6.0	.	.	.	.	.	0.05	3	2	2	3	3	2	2	.	2
49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	3	2
50	.	.	.	.	.	.	.	0.00	.	.	.	.	.	.	1	.	4

NO	B1	B2	B3	B4	B5	C1	C2	PERC	FU_RD	FU_MA	FU_IT	FU_PR	FU_CO	FU_OT	TREAT	FU_QU	SURE
51	.	..	.	.	.	.	.	0.10	.	.	.	.	.	.	2	4	.
52	.	.	.	.	2.0	6.5	15.0	0.05	4	2	3	3	3	1	2	4	3
53	.	.	.	.	.	.	.	.	4	3	1	3	2	2	.	3	4
54	.	.	3.5	6.0	2.5	.	.	0.20	3	2	3	3	3	1	.	.	3
55	5.5	6.0	.	.	.	.	.	0.10	.	.	.	.	.	.	1	2	3
56	.	.	.	.	.	.	.	0.35	4	3	2	4	2	1	3	5	1
57	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	5	1
58	.	.	.	.	.	.	.	1.00	1	4	3	3	1	1	1	.	.
59	.	.	.	.	.	.	17.0	0.50	4	4	1	1	1	1	3	.	.
60	.	.	5.0	9.5	2.5	.	.	0.70	3	4	2	3	1	2	2	4	.
61	.	.	.	.	.	3.5	5.5	0.20	1	3	1	3	1	1	1	5	1
62	4.5	5.5	.	.	.	.	.	0.20	2	3	2	2	1	2	1	4	.
63	.	.	2.5	5.5	2.5	.	.	.	.	.	.	.	.	.	.	.	1
64	.	.	.	.	.	.	.	0.70	4	3	1	3	1	2	2	5	2
65	.	.	0.5	0.5	1.0	.	.	0.80	4	4	3	3	1	3	2	4	2
66	.	.	.	.	.	7.5	12.5	0.15	3	3	3	2	1	1	1	2	2
67	.	.	.	.	.	.	.	0.25	3	4	3	3	2	1	1	4	2
68	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
69	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4
70	.	.	3.5	5.5	3.0	3.5	16.0	.	.	.	.	.	.	.	.	.	.
71	4.0	8.5	.	.	.	.	.	0.20	2	2	2	2	1	1	2	.	2
72	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
73	.	.	.	.	.	5.0	9.0	0.25	4	4	3	4	3	1	2	5	2
74	.	.	4.0	10.0	4.0	.	.	0.40	3	2	2	3	2	2	2	5	2
75	.	.	5.0	7.0	4.0	.	.	0.75	4	4	3	4	3	1	3	5	3

NO	B1	B2	B3	B4	B5	C1	C2	PERC	FU_RD	FU_MA	FU_IT	FU_PR	FU_CO	FU_OT	TREAT	FU_QU	SURE
76	.	.	.	.	.	.	.	.	4	3	2	3	2	1	3	4	2
77	.	.	.	.	.	.	.	0.80	5	4	2	4	3	3	.	.	3
78	.	.	.	.	.	.	.	0.50	4	4	1	3	2	1	3	5	1
79	.	.	10.5	12.5	3.0	.	.	0.35	4	5	3	3	2	1	3	5	3
80	3.5	7.5	.	.	.	.	.	0.55	4	2	3	4	3	3	3	5	1
81	.	.	.	.	.	8.5	13.5	.	.	.	.	.	.	.	3	5	1
82	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4	.

NO	AVG_L	DIFFI	FC_MC	FC_CO	FC_PC	RED_U	TEST	SD30	SD	X_UNC	PL_H8	PL_HO	DE_T3	DE_T	FU5	FU
1	.	1	1	5	5	3	.	5	.	4	2	.	2	.	2	.
2	15.0	1	5	3	3	5	0.75	5	0.10	2	1	12.5	1	.	4	7.5
3	20.0	2	3	5	1	2	.	4	.	2	4	5.0	2	.	4	3.0
4	20.0	4	3	3	5	4	0.25	3	.	2	2	.	2	.	4	15.0
5	.	1	.	.	.	2	1.00	.	.	3	.	.	4	2	.	.
6	15.0	2	1	1	5	3	.	2	.	4	2	17.5	4	5	4	17.5
7	20.0	2	1	3	3	2	2.00	2	.	2	1	20.0	4	.	5	.
8	.	4	3	5	5	1	.	3	.	4	1	25.0	4	5	5	.
9	22.5	5	1	2	3	4	0.75	3	.	4	1	12.5	5	5	5	17.5
10	20.0	2	2	4	5	4	1.00	4	0.23	3	2	10.0	4	5	4	10.0
11	20.0	.	4	4	5	2	1.00	3	.	4	1	15.0	3	.	.	.
12	20.0	4	2	4	4	1	1.00	2	0.33	4	1	15.0	4	5	5	20.0
13	20.0	5	1	2	3	3	.	1	.	4	1	10.0	3	.	4	7.5
14	20.0	2	2	2	5	4	.	2	.	4	5	4.0	4	4	4	4.0
15	30.0	4	1	2	2	2	.	2	.	3	2	.	4	2	4	3.0
16	25.0	.	0	3	3	.	.	.	.	.	.	.	.	.	.	.
17	.	3	.	.	.	.	.	.	.	.	2	12.0	5	8	.	.
18	.	3	1	2	2	4	.	4	.	.	2	.	4	4	4	15.0
19	.	4	0	5	3	1	.	2	0.25	2	2	10.0	5	1	4	10.0
20	25.0	3	0	2	4	3	.	1	0.60	4	1	25.0	5	1	5	1.0
21	25.0	5	1	3	3	2	.	2	.	4	1	20.0	5	9	4	8.0
22	20.0	4	1	2	2	2	.	2	.	4	2	15.0	4	5	4	10.0
23	30.0	5	0	4	3	4	.	4	0.18	2	2	10.0	4	2	4	.
24	30.0	.	4	2	3	4	2.00	2	.	.	4	7.0	3	.	4	12.0
25	25.0	1	2	5	2	4	1.25	2	0.45	2	1	15.0	4	3	5	15.0

NO	AVG_L	DIFFI	FC_MC	FC_CO	FC_PC	RED_U	TEST	SD30	SD	X_UNC	PL_H8	PL_HO	DE_T3	DE_T	FU5	FU
26	.	.	0	5	5	.	.	.	.	.	1	.	.	.	.	.
27	15.0	4	1	4	5	2	.	4	.	4	.	.	3	.	4	10.0
28	20.0	2	5	2	3	4	2.00	3	.	4	2	15.0	4	5	4	10.0
29	25.0	1	3	5	3	4	1.50	4	0.20	4	1	.	3	.	5	20.0
30	.	4	1	3	3	.	.	1	.	3	2	20.0	5	2	5	10.0
31	.	1	0	3	3	.	.	.	.	3	1	17.5	2	.	4	25.0
32	15.0	4	1	0	3	4	1.50	2	.	4	2	.	2	.	4	15.0
33	20.0	.	.	.	.	3	1.00	2	0.33	4	3	.	.	.	.	.
34	.	4	1	5	1	5	.	.	.	3	.	.	.	.	3	.
35	30.0	.	2	1	3	4	2.00	1	.	.	1	15.0	4	2	5	10.0
36	15.0	.	.	.	.	5	1.50	2	.	4	1	15.0	2	.	4	.
37	10.0	5	0	3	4	3	.	2	.	4	1	15.0	3	.	4	10.0
38	8.0	4	.	.	.	3	0.50	3	.	4	.	.	5	6	5	15.0
39	.	.	1	2	3	.	.	.	.	.	2	.	4	.	4	9.0
40	15.0	4	0	3	3	4	.	2	.	5	1	15.0	2	.	4	12.5
41	7.5	5	1	1	3	5	0.30	3	.	4	2	.	4	8	4	7.0
42	.	4	0	1	3	4	1.00	4	0.20	4	2	10.0	3	.	.	.
43	12.0	4	2	1	2	5	1.00	3	.	3	1	10.0	.	.	4	.
44	15.0	2	0	0	2	4	.	4	0.25	4	1	12.5	4	5	.	.
45	3.0	4	3	3	5	4	0.20	4	0.15	4	5	4.0	4	1	4	3.0
46	.	4	1	2	5	2	.	.	.	5	3	.	2	.	3	.
47	15.0	1	2	3	4	2	0.17	3	.	.	5	4.5	2	1	4	2.5
48	10.0	.	.	.	.	4	0.17	3	.	.	5	5.0	2	.	.	.
49	10.0	4	2	2	1	2	.	3	.	3	.	2.0	.	.	.	.
50	.	2	3	3	5	3	.	5	.	.	4	.	.	.	.	.

NO	AVG_L	DIFFI	FC_MC	FC_CO	FC_PC	RED_U	TEST	SD30	SD	X_UNC	PL_H8	PL_HO	DE_T3	DE_T	FU5	FU
51	12.0	4	2	2	4	3	0.50	2	.	3	3	.	.	.	4	4.0
52	11.0	2	1	1	5	4	0.25	3	.	4	5	2.5	2	.	4	3.0
53	20.0	2	3	1	2	.	.	5	0.10	4	4	4.0	3	2	5	3.0
54	20.0	2	2	2	4	.	.	5	.	2	3	.	2	2	4	4.0
55	.	.	2	2	3	.	.	4	.	4	.	.	2	.	4	.
56	15.0	4	2	2	5	4	1.00	2	.	2	1	10.0	4	3	5	10.0
57	20.0	4	.	1	3	3	.	3	.	2	.	.	3	.	4	.
58	20.0	.	5	1	1	.	2.50	.	.	.	.	.	.	.	.	.
59	.	.	0	1	2	.	1.00	.	.	.	.	.	.	.	4	10.0
60	25.0	3	1	0	2	4	1.00	3	.	1	2	.	.	.	4	10.0
61	15.0	4	1	1	3	1	.	2	.	4	2	.	2	.	2	.
62	20.0	.	.	.	.	4	.	.	.	4	2	10.0	2	.	.	11.0
63	.	4	1	1	2	2	0.50	2	.	.	2	9.0	4	3	4	.
64	20.0	2	1	1	2	.	.	3	.	5	.	.	4	4	2	.
65	.	3	1	1	2	4	0.25	2	.	4	2	10.0	3	.	4	10.0
66	.	2	0	0	0	4	1.50	3	.	4	2	.	4	.	4	10.0
67	30.0	3	0	0	1	4	1.00	2	.	4	1	10.0	.	.	4	10.0
68	.	.	1	1	1	.	.	4	.	.	4	3.0	4	2	4	10.0
69	.	.	1	1	3	.	.	4	.	1	1	.	4	1	4	15.0
70	.	.	5	5	5	.	.	4	.	.	2	10.0	.	.	4	.
71	.	4	0	2	3	4	2.00	.	.	3	4	6.0	4	2	5	20.0
72	.	.	2	2	5	3	.	.	.	.	.	.	4	2	4	10.0
73	.	4	.	.	.	4	1.00	4	0.15	.	.	.	3	.	4	14.0
74	25.0	.	2	2	3	.	.	4	0.15	3	5	5.0	4	3	.	.
75	20.0	.	2	2	2	4	.	4	0.10	3	4	.	.	.	3	.

NO	AVG_L	DIFFI	FC_MC	FC_CO	FC_PC	RED_U	TEST	SD30	SD	X_UNC	PL_H8	PL_HO	DE_T3	DE_T	FU5	FU
76	.	3	2	1	1	4	2.00	.	.	.	4	4.0	4	2	4	.
77	25.0	3	1	1	2	3	.	2	.	1	.	.	2	.	5	17.5
78	20.0	2	0	0	0	5	1.00	.	.	2	4	5.0	4	2	4	20.0
79	10.0	.	1	0	0	4	1.50	3	.	.	4	4.0	4	2	4	3.0
80	5.0	4	0	0	1	5	2.00	3	.	4	2	10.0	1	.	3	.
81	.	3	2	1	1	2	2.00	4	0.10	2	4	.	3	.	4	15.0
82	.	2	3	1	2	.	.	4	.	2	4	.	4	1	4	10.0

NO	SIN_P	D_ORG	ADD_D	STR_P	INV_F	INV_INF	IN_F_INF	EX_B
1	4	2	1	4	5	3	4.2	1
2	4	1	2	4	4	4	4.0	2
3	4	2	2	.	4	3	3.6	2
4	4	2	4	4	4	.	4.0	3
5	1	2	1	5	.	.	.	4
6	2	3	4	5	3	3	3.0	3
7	1	3	2	5	2	2	2.0	4
8	4	2	2	4	5	.	5.0	1
9	5	1	4	5	3	4	3.4	3
10	4	2	4	4	4	4	4.0	1
11	5	1	2	5	3	4	3.4	1
12	5	1	.	.	4	4	4.0	3
13	5	1	4	5	5	.	5.0	3
14	4	4	4	5	4	4	4.0	4
15	4	2	5	4	4	3	3.6	2
16	.	.	.	.	4	3	3.6	2
17	.	.	.	.	2	3	2.4	1
18	.	3	.	5	3	5	3.8	4
19	4	2	1	5	4	5	4.4	1
20	5	1	1	5	5	4	4.6	1
21	4	2	4	5	5	5	5.0	1
22	2	4	4	4	3	3	3.0	1
23	4	4	5	4	4	3	3.6	4
24	3	3	.	.	2	2	2.0	2
25	4	2	4	5	4	.	4.0	3

NO	SIN_P	D_ORG	ADD_D	STR_P	INV_F	INV_INF	IN_F_INF	EX_B
26	.	4	.	.	5	5	5.0	4
27	.	.	3	5	5	.	5.0	3
28	4	2	2	.	3	3	3.0	4
29	.	.	.	.	3	3	3.0	4
30	4	3	4	4	3	2	2.6	1
31	4	4	.	5	4	3	3.6	3
32	3	4	2	4	3	4	3.4	2
33	.	.	.	.	5	4	4.6	4
34	4	2	4	3	3	5	3.8	.
35	4	3	4	4	2	2	2.0	2
36	1	2	2	5	4	4	4.0	3
37	3	2	.	5	4	.	4.0	4
38	4	3	3	4	4	2	3.2	1
39	4	1	.	.	5	4	4.6	3
40	4	2	4	4	4	4	4.0	2
41	5	1	.	5	4	4	4.0	3
42	4	4	4	5	2	4	2.8	4
43	.	.	4	5	2	3	2.4	2
44	3	2	4	5	4	.	4.0	3
45	1	4	4	5	3	3	3.0	1
46	.	.	.	.	4	3	3.6	4
47	5	4	2	5	4	4	4.0	2
48	5	2	3	4	3	5	3.8	3
49	.	5	.	5	3	3	3.0	1
50	.	5	.	5	4	.	4.0	3

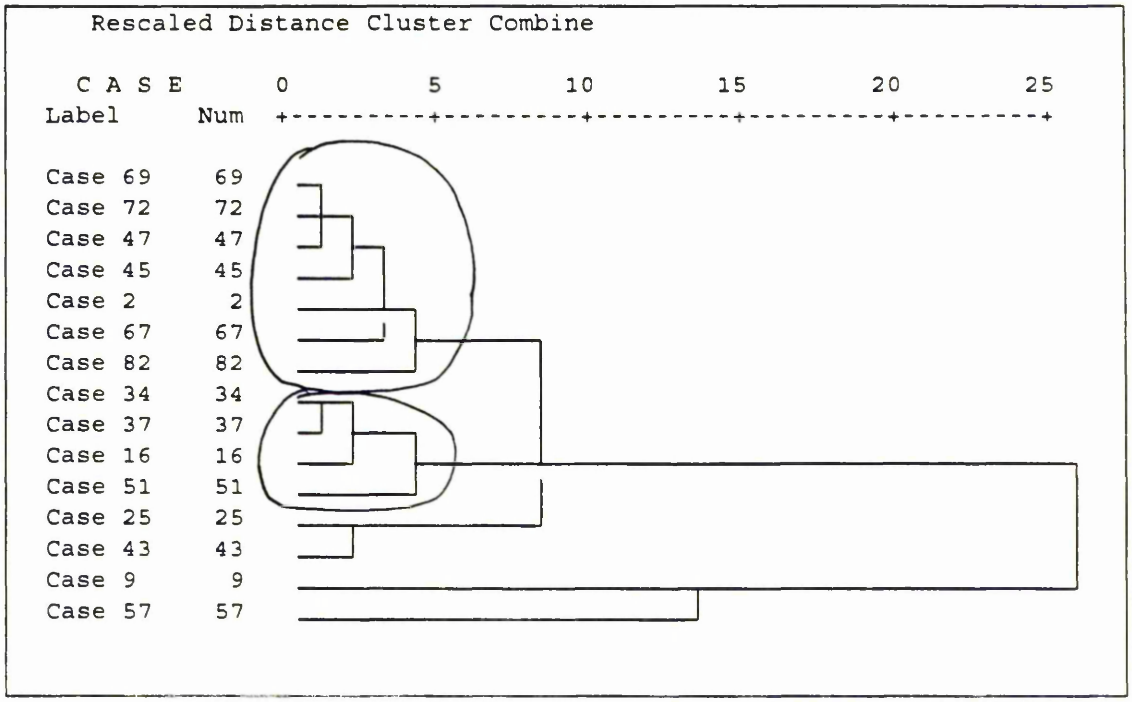
NO	SIN_P	D_ORG	ADD_D	STR_P	INV_F	INV_INF	IN_F_INF	EX_B
51	3	5	5	4	3	3	3.0	4
52	4	2	4	4	3	3	3.0	2
53	4	5	5	5	2	3	2.4	3
54	4	4	.	5	3	4	3.4	4
55	.	.	.	.	3	2	2.6	2
56	4	2	4	4	4	2	3.2	2
57	3	2	3	4	.	.	.	3
58	.	.	.	.	0	4	1.6	2
59	4	.	.	5	3	.	1.8	4
60	.	.	.	.	3	5	3.8	1
61	5	4	2	4	2	3	2.4	4
62	4	.	.	.	3	5	3.8	3
63	4	3	.	4	4	.	4.0	2
64	.	4	2	4	3	2	2.6	4
65	4	3	2	4	3	3	3.0	1
66	1	4	4	4	5	4	4.6	3
67	2	4	3	4	4	3	3.6	2
68	3	.	.	3	4	4	4.0	3
69	4	1	.	4	3	3	3.0	2
70	4	.	.	.	3	3	3.0	3
71	.	3	.	5	5	5	5.0	4
72	.	4	.	4	5	5	5.0	3
73	4	2	4	4	3	5	3.8	1
74	.	.	.	.	.	.	.	4
75	4	2	3	4	4	0	2.4	2

NO	SIN_P	D_ORG	ADD_D	STR_P	INV_F	INV_INF	IN_F_INF	EX_B
76	2	4	.	4	4	5	4.4	2
77	3	3	4	4	2	2	2.0	3
78	2	.	.	4	4	4	4.0	1
79	.	2	5	4	2	4	2.8	2
80	4	2	4	4	3	.	1.8	1
81	2	2	.	4	3	5	3.8	.
82	3	.	4	4	4	3	3.6	1

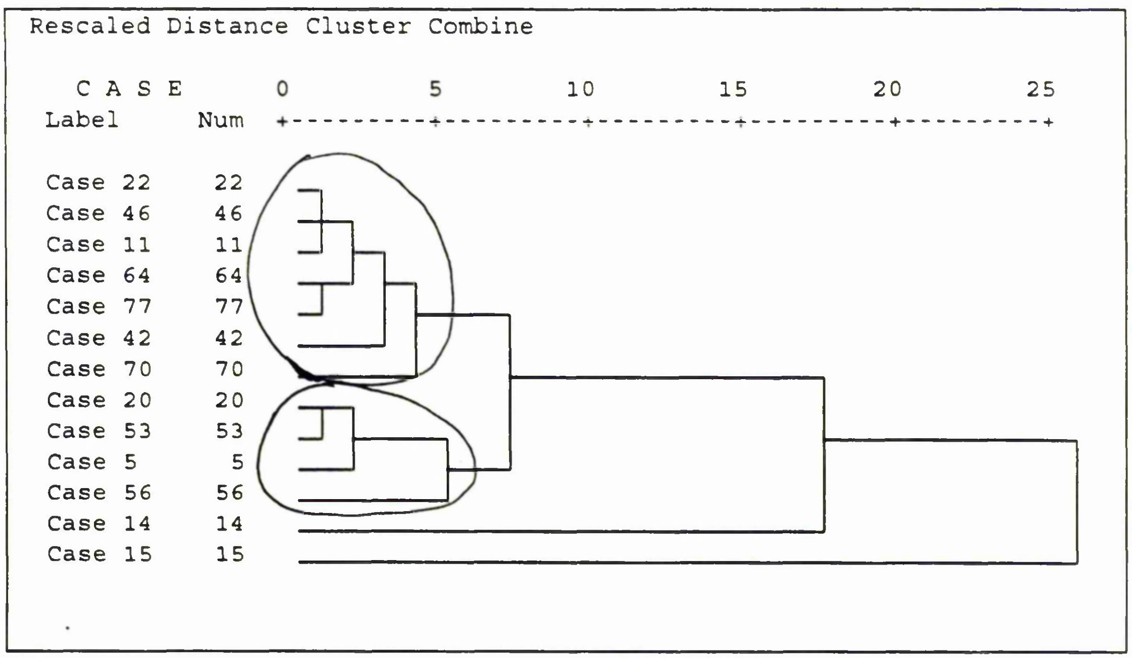
List of outliers in the case study- and questionnaire responses

	Respondent	Type of outlier		Valuation
		Outlier (>= 1.5 box lengths)	Extreme (>= 3 box-lengths)	
Outliers in case study valuations				
A1	68, 70		x	-10.5
	21	x		2.5
A2	6		x	10.5
A4	45	x		15
A5	58	x		3.5
A6	72	x		20.5
	68	x		25.5
	69		x	27.5
B2	10	x		.5
	70	x		1.5
	32	x		11.5
	45		x	17.5
	28		x	21
B3	45		x	22.5
B5	23	x		13
C1	59	x		15.5
Outliers in questionnaire responses				
Avg life	50, 71	x		40
	82	x		50
	65		x	100
	76		x	125
Sd	13	x		0.7
Fu	8	x		27.5
	7,23,70	x		30

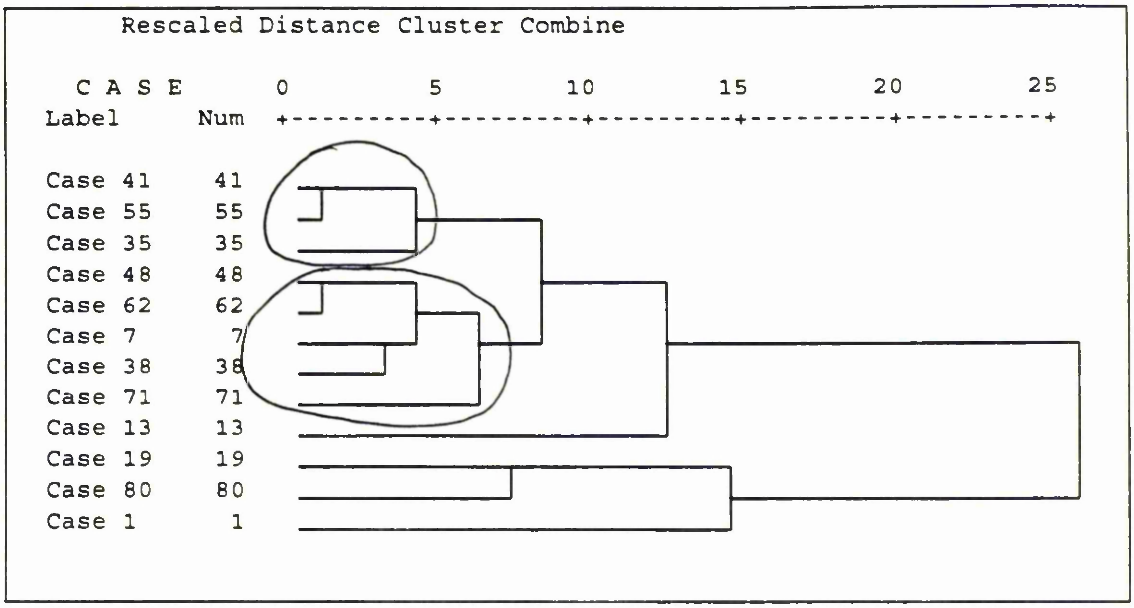
Case studies A1 to A3:



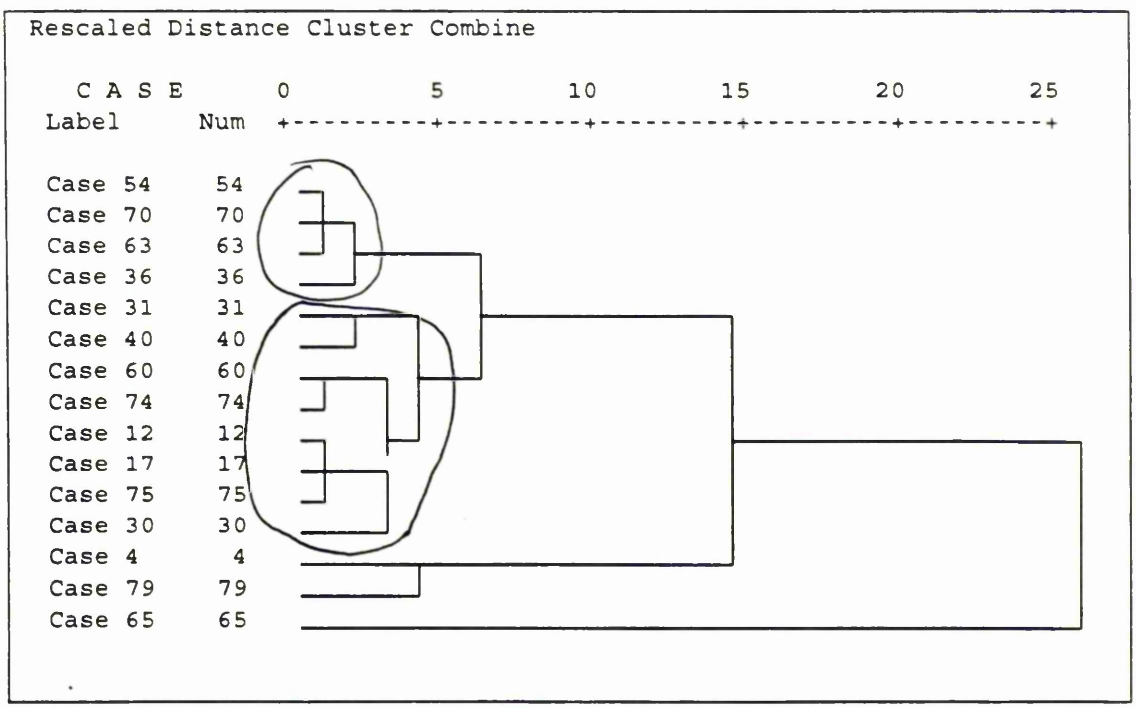
Case studies A4 to A6:



Case studies A7 to B2:



Case studies B3 to B5:



Case studies C1 to C2: