R. Dyson and F. S. Oliveira. Flexibility, Robustness, and Real Options. In "Supporting Strategy: Frameworks, Methods and Models," Frances O'Brien and Robert Dyson (Ed.), pp. 343-366, Wiley, Chichester, 2007.

Flexibility, Robustness and Real Options

Robert G. Dyson and Fernando S. Oliveira

13.1. Introduction

The importance of ***flexibility*** in the strategic development process goes back to the formative days of strategic planning. One of its earliest manifestations was in the guise of ***contingency planning***. For example Argenti (1974) in his book 'Systematic Corporate Planning' defines a contingency plan as 'a component of a corporate plan designed as a response to an event E that is thought to be highly improbable (but possible) but of such importance that it must be allowed for in the plan'. Such plans are often in place in the event of say fire, computer system failure, bird flue or terrorist attack, but more generally contingency plans can be associated with any flexibility in the planning process aimed at dealing with the uncertainties of the future. This flexibility can often be captured in the form of a ***decision tree*** which is discussed in chapter 10.

Gupta and Rosenhead (1968) and Rosenhead (2001) formalized a version of flexibility and ***robustness*** as key aspects of the strategic development process and this approach is discussed in the following section. More recently the concept of ***real options*** has been developed as method of introducing flexibility into strategic decision making. In option theory a call option is the ability to pay a small sum of money now which allows a share to be bought (or not) at some specified time in the future at a pre-determined price. Option theory involves evaluating the price of the option. In real options the focus is on a real asset or strategic initiative (or option) rather than a share and the analysis involves valuing flexibility in strategic decision making. Real options are treated in later sections of the chapter.

In this chapter we compare the use of robustness analysis, decision trees and the real options approach as different ways of representing flexibility in strategic decision making: we analyse the advantages and disadvantages of the methods and we identify possible complementarities in these approaches. Finally, we apply the methods to an example in the electricity industry.

13.2. Robustness Analysis and Flexibility

Rosenhead (2001, p188) defines robustness analysis as a particular perspective on embedding flexibility in the planning process in situations where 'an individual, group or organization need to make commitments now under conditions of uncertainty, and where these decisions will be followed at intervals by other commitments'. With a robustness perspective the focus will be on the alternative immediate commitments which can be made, which will be compared in terms of the range of possible future commitments with which they appear to be compatible. The approach is to analyse which initial commitments will keep open the greatest number of desirable future end states given that the uncertainty of the future is defined by a discrete set of possible futures (or scenarios in our terms). The approach is illustrated in figure 13.1.

Figure 13.1 about here

At node 1 in figure 13.1 there is a choice of three decisions/strategic initiatives which may or may not be mutually exclusive. At a second stage there are further choices at nodes 2, 3 and 4, and at a third stage there are choices at nodes 5 – 9. The choices at the third stage lead to end states 10 – 20. In an uncertain world the value of the end states will vary. In the example the uncertainty is assumed to be captured by two scenarios and each end state is either desirable or undesirable under a particular scenario. (The method can of course be extended to further scenarios and additional values for the end states rather than just desirable and undesirable). For illustration, the choice (1,2) may be to launch a new product, (1,3) may be to enter a new market, whilst (1,4) may be to diversify through an acquisition. As the future unfolds further choices become available at the second and third stages. Under the first scenario, say a sustained global boom, further expansionary strategies will be considered. Under the second scenario, say a move to more local production due to the risk and high cost of global travel, a different set of alternatives will emerge. The end states might represent a particular product (or market) configuration.

The immediate commitment involves the first stage decisions (1,2), (1,3) and (1,4). Robustness analysis involves determining which initial choices keep the greatest number of desirable end states in play. In the example, if we plot the pathways from (1,2) we can see that end states 10 and 11 are possible. For (1,3) 10 – 16 and 18 are possible whilst from (1,4) 14, 16, 17, 19 and 20 are possible. The robustness of a first stage decision given a particular scenario is defined by equation 13.1.

$$\text{Robustness} = \frac{\text{Number of desirable end states reachable}}{\text{Total number of desirable end states}} \qquad (13.1)$$

Under the first scenario there are 6 desirable end states and decision (1,2) can lead to two of them i.e. 11 and 12, and thus has a robustness score of 2/6 i.e. 1/3. (1,3) can lead to 5 desirable end states and has a score of 5/6 and so on for each first stage decision under each scenario. The robustness matrix is as shown in table 13.1. If we assume that either scenario is plausible then decision (1,3) appears attractive as it keeps the greatest number of options (end states) open in scenario 1 and is relatively robust under scenario 2. However it does not give access to end state 17 which may be highly desirable under either scenario. However Rosenhead does not propose that the robustness scores are followed slavishly, but rather that the analysis should 'initiate a process of reflection and research, aimed at clarifying participants' understanding of the nature of the predicament that confronts them'.

Table 13.1 about here

In terms of the strategic development process model (chapter 1, figure 1.7) the robustness approach highlights the importance of building flexibility into the strategy creation process, only taking decisions when they are necessary (i.e. not taking possible future decisions until the future has begun to unfold), and in general of keeping your options open as long as possible. In robustness analysis flexibility is regarded as the ability to delay a commitment, i.e., you delay the final state to which you are going to commit your firm by the end of the planning horizon by keeping your options open.

13.3. Real Options, Valuation and Flexibility

Real Options is another tool devised to introduce flexibility as a major concept in strategic planning and project valuation. In one of the first academic papers on this topic MacDonald and Siegle (1986) studied the optimal time of investment in an irreversible project, taking into account that the firm has the possibility of delaying the project. (They showed that the correct calculation of the timing to invest in a project should take into consideration the comparison of the value of investing today with the value of investing at all possible times in the future.) Moreover, Pindyck (1991) also emphasises the importance of flexibility and its value in strategic planning. He showed that the possibility of delaying an investment, giving the firm an opportunity to wait for new information before taking the final decision of commit to the project (this is similar to the statisticians' concept of expected value of perfect information), and the presence of uncertainty and irreversibility (in certain decisions), increase the value of flexibility (as a firm can decide to change the course of a project after receiving more information about the stochastic variables influencing the value of the project). Dixit (1992) has also shown that the flexibility inherent in a given project has a positive value: this is supported by his observation that firms invest in projects with a return rate three to four times the cost of capital, i.e., firms only invest if the price rises well above the long run average cost (on the other hand, firms with operating losses stay in business for a long time). This shows that the flexibility inherent in the option to enter or leave a market may significantly increase the rate of return provided by an investment.

As another example of the use of options to increase flexibility we have the work of Abel and Eberly (1996) who analysed the use of real options to model investment problems under the existence of reversibility (i.e. in cases in which there is an increased flexibility). They presented costless-reversible and irreversible investment as the opposite ends of a wide spectrum that includes costly reversible investment (although a firm may resell the assets acquired during the investment, the resale prices may be below replacement costs). Following Bertola and Caballero (1994), they showed that under uncertainty, and in the presence of costly reversibility, there is a range of inaction under which the company will not invest: leading to the interesting insight that consideration of flexibility can actually lead to inaction, in certain circumstances.

The main conclusion from all these analyses is that flexibility increases the value of the firm. In this case, the value of the firm which, following Trigeorgis (1998) we call Strategic *NPV* equals the sum of the Static *NPV* (without taking in consideration the existence of options) and the value of the options.

Moreover, in the real options approach flexibility is regarded as the ability to delay, change, or abandon a commitment due to the reception of new information that changes the way the firm perceives the problem. The re-commitment will happen during the planning process. The firm commits itself sequentially, step-by-step as the future unfolds, assuming that it always chooses the best possible options.

13.3.1. Types of Real Options

Overall the literature has developed the following main types of real options, which are aimed at increasing the flexibility and value associated with different types of strategic decisions within a firm and these should be considered in the strategy creation process. Following Trigeorgis (1998, p. 2), we have, at least the following options:

a) Option to invest in the future (at cost I). The firm holds an option to buy valuable land or resources (which turn out to have a value V). In this case, I represents the exercise price of the real option. The value of the option to invest would be equal to *max* (*V*-*I*, 0), resembling the value of a financial call option.

b) Option to abandon. If the market conditions get worse than expected management has the option to abandon indefinitely the project then valued *V*, receiving the resale value (*A*) of the assets owned. In this case the value of the option is equal to *max*(*A*-*V*, 0), resembling the value of a financial put option.

c) Time-to-build option, the investment is divided into different stages creating the option to abandon the project if the new information is unfavourable to future developments. This represents a compound option in which at each stage *s* the firm compares the required investment (*Is*) with the value of the subsequent stages (*Vs*). The value of the option, at any given stage, will be *max*(*Is* -*Vs*, 0), resembling a financial put option.

d) Option to expand. If market conditions are more favourable than expected the firm may expand or secure more resources. In the case of the option to expand, if the current value of the project is *V*, after expansion would equal *Ve* and the required investment is *Ie*, then the value of the option to expand would be *max*(*Ve*-*V*-*Ie*, 0), resembling a financial call option.

e) Option to shut down. If the market conditions are worse than expected the firm may temporarily shut down, restarting when the market recovers. Let, *Vd* represent the value of the project after shutting down. Then, the value of this option would be equal to *max*(*Vd*-*V*, 0), resembling a financial put option.

f) Option to restart. If market conditions improve the firm may restart production. In this case the firm aims to receive the production revenue *V* by paying the variable costs of production *Iv*. The value of this option is equal to *max*(*V-Iv,* 0), resembling a financial call option.

g) Option to switch. If the prices or demand change, the management may have the option to change the input (or output) mix. For example, an electricity generation firm owning several generation technologies (for example combined cycle gas turbines and pumped storage) may use one plant or the other at different times depending on the time of the day. At night, when prices are lower it shuts-down the natural gas turbine and uses electricity to pump-up the water to the pumped storage reservoir. During the day, at the average demand hours it runs the natural gas turbine and does not run the pumped storage plant. At the peak times of price (or if there is a fast increase in price) it runs both the natural gas turbine and the pumped storage turbine. This example shows that the management of a simple portfolio of electricity generation plants there are several interacting options, such as shut down and restart, and that these options lead to a change in the mix of fuel input used to generate electricity.

h) Growth options. An early investment may be seen as the start of a chain of interrelated projects giving access to future growth opportunities - multiple interacting options. As we will illustrate in the example presented in section 13.5, a firm may make an initial decision to enter a market as a way to open the door to other investments and opportunities.

In order to tackle realistic problems, the real options community has also analysed the issue of adapting the basic theoretical framework to solve real problems. For example: Cortazar, Schwartz and Salinas (1998) presented an application of real options to the valuation of environmental investments. Bollen (1999) developed an option valuation framework that explicitly incorporated a product life cycle. Huchzermeier and Loch

(2001) applied real options theory to evaluate flexibility in R&D projects. Smith and McCardle (1999) apply real options to the analysis of project development in the gas and oil industry.

13.3.2. Risk Neutral Valuation

There are several different methods to compute the value of an option, based on partial differential equations (this is the method used in the Black-Scholes formula, Black and Scholes (1973)), based on dynamic programming (this is the base of the binomial model we will follow in this presentation) or based on simulation (this method follows the Monte-Carlo approach in which the same model is repeated over and over again and the option value is the average in all the runs of the model).

The risk-neutral approach developed by Cox et al. (1976) is central to all these methods. This approach is based on the observation that in a perfectly rational world there are no arbitrage opportunities[1]. In this case, the authors observed that it is possible to build a portfolio (combining the option and the underlying asset on which the option is written) that earns a risk free rate of return. In this case, the value of this portfolio, and of the option, is independent of the preferences for risk.

As an example illustrating the existence of a riskless portfolio, consider an option to sell a combined cycle gas turbine (CCGT) for a price I, which can be exercised one year from now. This CCGT will have a value V_1 one year from now, which will depend on the expected spark spread (i.e., the difference between the electricity price and the fuel price).

In order to build a risk free portfolio, if the firm owns a CCGT plant, it buys a put option (to sell this plant one year from now), and writes a call option (giving a buyer the right to buy the plant one year from now)[2]. The value of this portfolio, one year from now, is described in table 13.2.

Table 13.2 about here

Therefore, this analysis shows that this portfolio has no risk; it is always equal to *I*. ***Consequently, in order to evaluate such an option we use as discount factor the risk free interest rate, r***. Furthermore, the present value of the portfolio is equal to the cost of buying it today as, otherwise, there would be arbitrage opportunities), as represented in equation 13.2 (in which *P* is the cost of buying a put option, *C* is the value received by the call option and V_0 represents the current value of the CCGT plant).

$$P - C + V_0 = \frac{I}{(1+r)}. \tag{13.2}$$

There are other ways to use real options to reduce risk. For example, electricity generation firms tend not only to own part of generation assets (instead of owning their totality) but also to sell long-term contracts on the value of the generation of a given plant, during a given period. This type of contract can be modelled using real options, in order to compute the value of the extra-flexibility that the firm benefits from. Moreover, this extra flexibility carries no risk, as we shall see.

In this case, we assume that a firm writes a call option on a given generation asset (selling to another firm the right to buy that asset at a price *I*) which is combined with an investment in such an asset in order to produce a risk free portfolio. (This is an important analysis as it shows how a firm can use real options to invest with no risk.)

Assume that the firm writes a call option on a CCGT plant (with value *C*), to be exercised in a year, with an exercise price *I*, and that the current value of the CCGT plant is V_0. Moreover, assume that the CCGT's value, one year from now (V_1), can only assume two possible values: high (V_H) and low (V_L). How much should the firm charge for the call option? What percentage of the CCGT's capital should the firm buy?

The value of the portfolio composed by the written call option and the ownership of a plant is described in table 13.3. From the analysis of this figure we can see that this portfolio is ***not*** risk free as, in general, V_L can be different from I.

Table 13.3 about here

In order to compute the risk free portfolio we need to compute the ***hedge ratio (h)***:

$$h = \frac{V_H - I}{V_H - V_L} . \qquad (13.3)$$

Then, in order to compute the risk free portfolio we buy the h part of the capital of a CCGT plant, see table 13.4. By re-arranging equation 13.3 it is easy to show that I-(1-h) $V_H = hV_L$ and therefore, we have a risk free portfolio.

Table 13.4 about here

We are now able to answer the first question: how much to charge for the call option? As the value of the portfolio is risk free, then to buy an h part of the CCGT plant and to write a call on the value of a CCGT plant has a current value (in the absence of arbitrage opportunities) equal to the present value of the portfolio, computed using a risk free interest rate *r*, represented in equation 13.4.

$$. \ h \times V_0 - C = \frac{hV_L}{1+r} \tag{13.4}$$

Therefore, we can conclude that, when we have a complete market, all the cash-flows should be discounted at the risk-free interest rate, as this represents the correct valuation from the perspective of a risk-neutral agent.

13.3.3. The Value of Risk

A second question we need to answer is: how do we price a risk? In the development of a strategic project, management aims to achieve a rate of return as high as possible, by assuming a given level of risk. Therefore, inherent to any strategic move there is a level of risk and a sequence of cash flows that need to be priced, in order to decide if the project should be pursued of not.

Traditionally the value of a project would be computed using the weighted average cost of capital (e.g., Brealey and Meyers, 1991, Chapters 2 and 3). This cost of capital would reflect the risk of the project (or of the firm as a whole). This discount rate (the weighted average cost of capital) could then be used within a decision tree (as presented in Chapter 10) to discount the cash flows and compute the value of the project. However, the problem with this discount rate is that it is *subjective,* dependent on the specificities of the firm, and it does not respect the principle of non-arbitrage.

The real options theory answers this question by respecting the non-arbitrage principle and using risk neutral valuation. A very interesting discussion on the use of decision trees to model real options can be found in Smith and Nau (1995), Brandão et al. (2005) and Smith (1995).

From our analysis in the previous section we know that all the cash flows should be discounted using the risk free rate of return. Therefore, in order to understand how the "market" values risk (and to compute the value of a project) real options theory uses two possible methods:

a) It builds a portfolio of assets whose cash flows replicate the ones of the project the firm is developing. Then the value of the project is equal to the value of the replicating portfolio.

b) It computes the probabilities (called "risk neutral") associated with the transitions between states such that the present value of the discount cash-flows equals the current value of the replicating portfolio. These risk neutral probabilities are used to compute the value of the project, replacing the *subjective probabilities* used in the decision trees (as presented in Chapter 10).

a) The replicating portfolio method

The firm needs to compute the value *V* of a strategic project whose value is assumed to follow a geometric Brownian motion (see Hull (1993), section 9.6 for a detailed explanation on modelling geometric Brownian motion with binomial lattices). In order to compute the value of this project we choose a traded stock with current price *S* and a risk-free security (that pays an interest rate *r*). Given the volatility and rate of return of this stock, it is known that at any given time the stock price will move up to *Su* or down to *Sd*. (Where *u* is greater than 1 and $d = \frac{1}{u}$).

In order to replicate the cash flow of the project we need to determine how much to invest in the stock (B_1) and in the bond (B_0). Equations 13.5 and 13.6 represent the value of the portfolio when the value of the stock goes up or down, respectively.

$$B_0(1+r)+B_1Su \quad (13.5)$$

$$B_0(1+r)+B_1Sd \quad (13.6)$$

As we know the value of the project in the two states up (V_h) and down (V_l) of the replicating portfolio, then the quantities we need to invest in the stock (B_1) and bond (B_0) can now be determined by solving the system of equations 13.7, in which B_0 and B_1 are the variables.

$$B_0(1+r)+B_1Su = V_h \quad (13.7)$$

$$B_0(1+r)+B_1Sd = V_l$$

Finally, using the no-arbitrage argument, the current price of the replicating portfolio is equal to the value of the project, as presented in equation 13.8.

$$V = B_1S + B_0 \quad (13.8)$$

b) The Risk Neutral Probabilities method

At each stochastic node in the decision tree we replace the *subjective probabilities* of transition between states by the risk neutral probabilities. Given the value V of the replicating portfolio, computed at any node of the tree, we can solve equation 13.9 in order to find p (the risk neutral probability of moving up). These probabilities will be the same in each node of the tree (for as long as the process generating the cash flows is stable) and therefore, we do not need to compute the replicating portfolio for each node.

$$B_1 S + B_0 = \frac{pV_h + (1-p)V_l}{1+r} \qquad (13.9)$$

By replacing equations 13.7 in equation 13.9 and solving in order to find *p* we get the formula to compute the risk neutral probabilities at any node, represented by equation 13.10, when we only have one source of uncertainty.

$$p = \frac{1+r-d}{u-d} \qquad (13.10)$$

13.4. Comparing Robustness Analysis, Decision Trees and Real Options

So far we have described how robustness analysis, decision trees and real options theory can be used to incorporate flexibility into the decision process. We can now compare these approaches, identifying the merits of each one of them (see table 13.5).

Table 13.5 about here

The main advantage of robustness analysis is its simplicity and the very low level of information required in order to introduce flexibility into the problem. Another of its strengths is to assume that all the forecasts are wrong and therefore the classification of the possible states is prone to error. (This is the main idea behind robustness, as if the classifications can be wrong the firm should leave accessible as many desirable states as possible so that at the end of the planning period some of them are still reachable.) Hence, the robustness concept goes beyond the maximum expected value criterion to analyse the benefits of a given decision. (A decision is good if it has a good possibility of leading the firm to a desirable (satisfactory expected value) state, independently of the expected value associated with the initial decision.) Most importantly, this analysis serves as a very good tool to chart some of the possible future states of the world after a few interacting decisions, enabling a qualitative discussion of the strategic moves available to the firm.

The main disadvantages of using robustness analysis arise from the sources of its strength, i.e. the low information required and the qualitative nature of the analysis. It is designed for a discussion about the firm's strategy at a given point in time and uncertainty is only incorporated through end state scenarios (although the analysis can be reviewed at each stage of the process).

Another weakness of this method is the lack of quantitative awareness as it is not able to answer the following question: which decision should the company take in the last stage of the decision process when no state is desirable or there is more than one desirable state. For these reasons, robustness analysis by itself is not able to provide all the information required by the decision maker when developing a strategy. However, it is designed to contribute to the strategic development process by making flexibility a focus of the discussion.

The main advantage of the decision tree and real options approaches is the introduction of flexibility into decision making by computing conditional strategies. I.e., in the strategic development process the strategies designed by the firm are already conditioned on the set of possible paths of the environment. In this case, a firm is not certain that it is able to achieve a given state (even though it assumes that it can compute the value of that state) and, therefore, in order to introduce flexibility into its strategy a firm computes policies that are conditional on the future development of the world. Moreover, the decision trees and real options approaches attempt to compute the value of each option that the firm has available, and in this way are able to compute the value of flexibility (i.e., the increase in the firm's value due to the options available at any given time). Most importantly, the decision trees and real options theory provide a framework to think about flexibility. By using these approaches firms can look for possible options within a given strategic decision, states in which the course of action can be changed and, in this way, the value of the firm increased. Additionally, the real options approach has a very important advantage over traditional decision trees: the use of risk neutral valuation, which values the project taking into account its market value by computing risk neutral probabilities and the replicating portfolio.

The main disadvantages of real options is its reliance on quantitative data and on the existence of a portfolio capable of replicating the cash flows associated with a given strategic decision, which can be very difficult to compute. The main disadvantages of the decision trees are the quantitative approach, as these data can be hard to obtain, and the dependence on the subjective perceptions of the firm.

Overall, robustness analysis on one hand, and decision trees and the real options theory on the other, look at flexibility in very different, and complementary, ways. Whereas robustness analysis sees flexibility as the possibility of choosing amongst the highest number of possible desirable states (after a sequence of strategic decisions), real options theory (and decision trees analysis) sees flexibility as the possibility of changing the course of action at each step of the way. In a sense we could argue that whereas the robustness approach only focuses on the long-term performance of the firm, real options theory and decision trees are able to connect short-term decisions to long-term performance.

For all these reasons, there is a major advantage of robustness analysis (when compared with decision trees and real options) that makes it an important tool for the strategic development process. The robustness approach commits the firm to a set of strategic decisions that leads to a full set of desirable states (without committing the firm to any of them), so in a sense it keeps flexibility by avoiding pursuing a given set of decisions. On the other hand, real options theory (and decision trees) can advise the undertaking of a given project just because there is a possible sequence of actions that are highly profitable (with a certain probability). Therefore, the firm commits itself to a given set of conditionally optimal strategic decisions. *As a consequence, the optimal policy computed by using real options (or decision trees)* ***may not be robust****, as it may be over reliant on one desirable state*.

Next, we exemplify the use of the robustness analysis, decision trees, and the real options approaches, using an example from the electricity market.

13.5. An Example from the Electricity Market

The aim of this exercise is to exemplify the use of robustness analysis and the real option approach in the context of the electricity market, illustrating the advantages and limitations of the methods.

We analyse the case of a firm that is planning to enter the UK electricity market. The firm is considering buying existing plant (a CCGT or a Coal plant) or investing in new plant (a CCGT or a Coal plant). The market entry is highly risky, as there are two main sources of uncertainty: electricity prices (that are dependent on the other firms' behaviour, on regulation and on demand) and fuel prices in general.

After analysing the current market the firm concluded that the cost of investing in a 1GW CCGT plant is about £380 (million) and in a 1 GW Coal plant is £200 (Million). It also concluded that the cost of buying existing or building new capacity is the same. For this reason, and to speed up the process, the firm is considering buying a CCGT or a Coal plant, in a first stage. Then, after two years of experience in the market, they would invest in new capacity (again in a 1GW CCCT or Coal plant). The planning horizon for this project is 10 years.

The main source of uncertainty is the long term electricity price. The firm believes that this price is mainly dependent on regulatory action and investment. As the government is due to publish (within 2 years) an important document defining its policy for the electricity sector during the next 20 years, the firm expects to have a much better idea of this price after the government publishes this document.

Another important source of uncertainty is the fuel cost and, more specifically, the gas price. This price is a function of the internal supplies from the North Sea (that are expected to decrease) and of the access to importations from mainland Europe. Another important source of uncertainty is the access to the supplies from Russia and from Arabic countries, which influence the long-term gas prices in the world. The firm believes that within 10 years these main uncertainties will also be reduced as the connections to Europe and Russia will be better.

The current risk-free interest rate (r) is 5% and the weighted average cost of capital (k), for this firm, is 15%. The two sources of uncertainty are modelled using a binomial tree (high, low) for both electricity and gas prices. The firm believes that the probability of having high gas prices in the future is about 70% and high electricity prices have a probability of 40%. By combining these uncertainties the company analyses several different combinations of acquisitions, investment, and uncertainties, computing the expected cash-flow for each one of them.

Let us first analyse this problem using a decision tree, see figure 13.2.

Figure 13.2 about here

In the decision tree the represent decision nodes, the represent stochastic nodes. All the monetary values are in £ million and probabilities in percentage.

The decision tree starts with a decision point in which the firm decides between investing in a CCGT plant, in a Coal plant or delay (and possibly abandon) the investment. The first stochastic node represents the uncertainty regarding electricity prices (the firm believes that prices will be high with a 40% probability and that they are not dependent on its investment strategy). In the third stage, the firm decides between investing in a CCGT plant, in a Coal plant or not investment at all. In the final stage the uncertainty regarding the gas prices is realised. The firm believes that prices will be high with a 70% probability and that they are independent from its investment strategy. The payoffs associated to each strategy are the present value of the payoffs during the project, using a discount rate of 15%.

In the first decision node the firm can buy a CCGT or a Coal plant, or it may delay or abandon option. The optimal decision (signalled with True) is to delay the project until the uncertainty related to the government document is resolved. The expected value of the project, after the government publishes the document, is £76 million, see figure 13.3. The value of the delay or abandon decision is computed using the formula *max* $(0, (0.6*0+0.4*208)/1.05^2)$ in which zero represents the value of the decision to abandon, and $(0.6*0+0.4*208)/1.05^2$ represents the value of delaying the project for two years. In the delay option the firm receives the expected value of the optimal action when electricity prices are low (which is to abandon the project) and when the electricity prices are high (which is to buy and invest in a Coal plant, with a present value of £208 million).

Figure 13.3 about here

In this case the value of the option to delay the project is equal to £40 million, which is equal to the different between £76 and £36 million (the value of the project if the firm decides to buy a Coal plant).

It should finally be noticed that in the second stage there is an option to abandon the investment project (although keeping the plant already bought). This option has no value if the electricity prices are high, but it can have a substantial value when prices are low, by reducing losses. This option has a value of £70 million if the firm buys a CCGT plant and a value of £61 million if the firm buys a Coal plant.

We can now analyse the project using real options. As shown by Brandão et al. (2005) these real options can be modelled as decision trees in which all the cash flows are discounted at the risk free interest rate and the probabilities used at the stochastic nodes are risk neutral. In this case, the project is valued as if it would be traded in the market.

As presented in section 13.3, in order to proceed with the risk neutral valuation we first need to identify a portfolio of traded assets capable of replicating the project cash flows at each one of the possible states. Then we can compute the risk neutral probabilities (which replace the subjective probabilities of the company) and discount all the cash-flows at the risk free interest rate. In order to build this portfolio we use a risk-free security which provides an interest rate of 5% a year, and British Energy (BE)'s stock price. (It should be noted that BE's stock price and our investment are negatively correlated, as BE owns mainly Nuclear plants, but for as long as this correlation is strong this asset can be used to compute the value of the project).

The current value of BE's stock price is 730 pence. In order to model its evolution in the next 10 years (our planning horizon) we use a two step (the first step for the first two years, and the second step for the last 8 years) binomial tree that assumes that BE's stock prices follow a geometric Brownian motion (as suggested in section 13.3).

As the sources of uncertainty are different (and electricity prices are more important) the firm expects that in the case of high electricity prices the value of BE will increase by 50% within two years, and that in the case of high gas prices the value of BE will increase by about 3 times in the last eight years of the project (at a rate of about 15% a year). The binary tree in figure 13.4 models the evolution of BE's stock price. This model differs slightly from the classical geometrical Brownian motion as we consider that uncertainty changes over time (as we know that we have two different sources of uncertainty), and therefore, instead of using a binomial lattice we use a binomial tree.

Figure 13.4 about here

In this case the computation of the risk-neutral probabilities needs to be done step-by-step, from the last nodes to the first node. Moreover, we need to compute two different risk-neutral probabilities, one for each of the stages (two years and ten years). (If we were using the replicating portfolio approach we would need to compute a different portfolio for each stochastic node in the decision tree.)

We are now in a position to compute the risk neutral probabilities by using formula 13.9 (note that we *cannot* use formula 13.10, as the process followed by BE's model is *not* a classical geometric Brownian motion). The risk neutral probabilities for the first two years are computed by the formula $730 = \frac{1095p + 487(1-p)}{(1+0.05)^2} \Leftrightarrow p = 0.523$. In the case of the last eight years the risk neutral probabilities can be computed either by analysing the upper or the lower branches. If using the upper branches we get $1095 = \frac{3285p + 365(1-p)}{(1+0.05)^8} \Leftrightarrow p = 0.429$ and if using the lower branches we would get the same value $487 = \frac{1460p + 162(1-p)}{(1+0.05)^8} \Leftrightarrow p = 0.429$.

This represents a first important output of this analysis. We can compare how the firm's subjective probabilities compare with the market based probabilities. Regarding the evolution of Gas prices it seems that the firm is conservative. Whereas the firm expects Gas prices to go up with a 70% probability, the market based probability is only 42.9%. Regarding the electricity price again the firm is conservative as it attributes a probability of 40% to high prices, whereas the market based probability is 52.3%.

We can now replace the subjective probabilities by the risk neutral probabilities and recalculate the value of the project using the cash flows discounted by using the risk free interest rate. These calculations are represented in the real options tree in figure 13.5.

Figure 13.5 about here

The first new result to notice is that to delay is not the optimal decision any longer. The value of the delay or abandon decision is calculated by the formula *max*(0, $(0.477*226+0.523*1557)/1.05^2$) in which zero represents the value of the decision to abandon, and £836 (million) = $(0.477*226+0.523*1557)/1.05^2$ represents the value of delaying the project for two years, see figure 13.6. However, this time the best policy is to invest, therefore the delay option has no value.

Figure 13.6 about here

The optimal policy is to buy a CCGT plant, and two years from now if the electricity prices are high we will invest in another CCGT plant (with an overall net present value of £1557 million), if the electricity prices are low we invest in a Coal plant (with an overall net present value of £226 million). Therefore, the value of this project is £914 million, which is the weighted average of these two investments. Finally, the option to abandon the investment project has no value under risk neutral valuation.

Under robustness analysis the initial decisions and second stage decisions are similar to the previous approaches but the uncertainty is captured through scenarios at the end state. The robustness structuring of the problem is shown in figure 13.7. This follows

Figure 13.7 about here

the approach of the earlier example but (following Rosenhead (2001), page 196) the end states under the scenarios are taken to have four possible outcomes, desirable, acceptable, undesirable and catastrophic. Scenario 1 relates to the situation of a high cost of gas coupled with high electricity prices. Under this scenario investing in two CCGTs is acceptable but two coal fired generators is more desirable due to the lower cost base. Not investing at all would be a poor choice. Scenario 2 assumes a high cost of gas due to shortages but a low electricity price due to a range of alternative methods of generation including perhaps coal, nuclear and sustainable sources. Under this scenario a decision to have invested in two CCGTs would have been catastrophic. Scenario 3 assumes a low cost of gas and high electricity prices and here investing in CCGTs would have been the best option with not investing being unacceptable. Scenario 4 assumes low gas and electricity prices and here a single CCGT might have been the most desirable strategy.

The robustness analysis of the situation involves constructing a robustness matrix but can also include a debility (unhealthy) matrix to allow for the poor choices as shown in table 13.6. In the robustness matrix we can calculate that there are a total of five

Table 13.6 about here

good end states (four acceptable and one desirable). Three of these are accessible from decision (1, 2), three from decision (1, 3) and two from decision (1, 4). We can similarly compute the other elements of the matrix. The debility matrix focuses on the poor choices (undesirable and catastrophic) and there is only one of these under scenario 1, three under scenario 2, one under scenario 3 and none under scenario 4. Decision (1, 2) leads to the greatest number of poor strategies in scenario 2.

From the robustness matrix we can see that (1, 3) dominates the other two decisions keeping the greatest number of options open. It also dominates the other two in the debility matrix given that here low scores are preferred. Robustness analysis would point us in that direction therefore. Option (1, 2) perhaps leads to the most desirable outcome under the most favourable circumstances but performs poorly under scenario 2. This is the option preferred by the real options approach and this perhaps suggests that robustness analysis might lead to safer choices but not to the extent of doing nothing.

13.6. Conclusions and Future Research Directions

Robustness analysis and real options (using decision trees) can be used to model flexibility and uncertainty in strategic development. They treat flexibility differently. Robustness maintains strategic flexibility by leaving as many options open as possible, whereas the real options theory aims to introduce uncertainty into strategic development by introducing decision points (during the execution of a strategy) that can change the decision path.

Uncertainty represents the main reason why firms need to be flexible when developing strategic plans. The robustness approach models uncertainty by postulating that as the value of any strategic plan leads to an uncertain payoff a firm should keep as many options as possible open so that it can change its commitment to any given plan at any time. The decision trees approach to model uncertainty is to introduce stochastic nodes in which *nature* influences the value of the project, by using subjective probabilities to model the likelihood of certain events. The real options theory uses this same approach introducing the market valuation – through the computation of risk neutral (objective) probabilities.

Overall, we have shown that these methods of modelling flexibility in strategic decision making are complementary. The decision trees approach is subjective, requires a large data set, and represents the perceptions of the firm. The real options model aims to develop market based models of strategic flexibility. As shown in the example, if the firm’s and the market’s perceptions are very different these two methods may lead to different decisions. The robustness analysis is subjective as well, it is a qualitative approach, and has the main advantage of not committing the firm to an uncertain strategic path. As shown in the electricity markets example, the robustness approach can lead to investment strategies that disregard the most profitable strategy (as it may lead to a less flexible strategic decision path) in order to keep the strategic plan with the highest number of attractive alternative plans, leading to a different strategy than the one that would be chosen by using real options.

The future direction of research in the topic of flexibility needs to be driven by both theoretical and practical concerns. We think that the robustness approach can be further developed by considering interacting decision makers and by introducing risk aversion into the decision maker's problem. Moreover, the incorporation of models of learning, by which firms can iteratively change the interactions between the different decisions, can be important.

In the real options approach some examples that explicitly model the interactions between decision makers have been already analysed. For example, Smit and Ankum (1993) modelled corporate investment in a duopolistic industry showing that under competition there is a lower tendency to postpone projects. Grenadier (1996) also modelled the interaction in a duopoly (in the real estate industry) showing, under the assumption of perfect rationality. Kulatilaka and Perotti (1998) have also studied the interaction between the two companies as a one-shot first-entrance game (a model of strategic growth options in a duopoly) strongly emphasizing the value of the initial investment as the acquisition of opportunities relative to competitors (they view strategic investment in conditions of uncertainty as a commitment to a more aggressive future strategy). However, only small examples have been analysed, and so far there is no theory developed for the analysis of oligopolistic and complex industries. Another important issue is the modelling of interactions between the different strategic decisions considered and being implemented by a firm.

Endnotes

---

[1] We say that there are arbitrage opportunities if it is possible to make an instantaneous profit with no risk. For example, assume that the exchange rate between the US dollar and the British Pound is 1 GBP = 1.88079 USD and the exchange rate between the US dollar and the Euro is 1 EUR = 1.281 USD. Then, if there are no arbitrage opportunities the exchange rate between the British Pound and the Euro will be 1 GBP = 1.46822

EUR. Otherwise, a trader can make a profit without risk just by buying and selling currencies.

[2] These options can be traded over the counter in which the firm finds a buyer and a seller interested in the contract. For example, any company interested in developing a similar portfolio would assume the buyer or seller role. By exchanging these option contracts the two firms would be able to remove risk from their investment, as shown next. In this case, these contracts are tailored for the specific use planned for it. One important limitation of this analysis is that in practice it is difficult to find an option contract that completely hedges risk. The theory of real options assumes that the market is complete and that it is always possible to find all the assets required to build a risk free portfolio.

References

Abel, A. B. and Eberly, J. C. (1996), ‘Optimal investment with costly reversibility’, *The Review of Economic Studies* 63 (4): 581 – 593.

Argenti, J. (1974), ‘Systematic Corporate Planning’, Nelson, England.

Brandão, L. E., Dyer, J. S. and Hahn, W. J. (2005), ‘Using binomial trees to solve real-option valuation problems’, *Decision Analysis* 2 (2): 69-88.

Bertola, G. and Caballero, R. (1994), ‘Irreversibility and aggregate investment’, *Review of Economic Studies* 61: 223 – 246.

Black, F. and Scholes, M. (1973), ‘The pricing of options and corporate liabilities’, *Journal of Political Economy* 81 (3): 637-654.

Bollen, N. P. B. (1999), ‘Real options and product life cycles’, *Management Science* 45 (5): 670 – 684.

Brealey, R. A. and Myers, S. C. (1991), ‘Principles of Corporate Finance’, 4th ed., McGraw-Hill.

Cortazar, G., Schwartz, E. S., and Salinas, M. (1998), ‘Evaluating environmental investments: a real options approach’, *Management Science*, 44 (8): 1059 – 1070.

Cox, J., Ross, S., and Rubinstein, M. (1979), ‘Option pricing: a simplified approach’, *Journal o Financial Economics* 7 (September): 229-263.

Dixit, A. (1992), ‘Investment and hysteresis’, *The Journal of Economic Perspectives*, 6 (1): 107 – 132.

Grenadier, S. R. (1996), ‘The strategic exercise of options: development cascades and overbuilding in real estate markets’, *Journal of Finance*, 51 (5): 1653 – 1679.

Gupta, S. K. and Rosenhead, J. (1968), ‘Robustness in sequential investment decisions’, *Management Science* 15: 18-29.

Huchzermeier, A. and Loch, C. H. (2001), ‘Project management under risk: using the real options approach to evaluate flexibility in R&D’, *Management Science* 47 (1): 85 – 101.

Hull, J. (1993), ‘Options, Futures, and Other Derivative Securities’, Second Edition. Prentice-Hall International, Inc.

Kulatilaka, N. and Perotti, E. C. (1998), ‘Strategic growth options’, *Management Science* 44 (8): 1021 – 1031.

McDonald, R. and Siegel, D. (1986), ‘The value of waiting to invest’, *Quarterly Journal of Economics* 101 (4): 707 – 728.

Pindyck, R. 1991, ‘Irreversibility, uncertainty, and investment’, *Journal of Economic Literature* 29 (3): pp. 1110 – 1148.

Rosenhead, J. (2001), Robustness analysis: keeping your options open. In Rosenhead J. and Mingers J., ‘Rational Analysis for a Problematic World Revisited’, Wiley, England.

Smit, H. T. J. and Ankun, L. A. (1993), ‘A real options and game-theoretic approach to corporate investment strategy under competition’, *Financial Management*, Autumn: 241 – 250.

Smith, J. E., and Nau, R. F. (1995), 'Valuing risky projects: option pricing theory and decision analysis', *Management Science* 41 (5): 795-816.

Smith, J. E., and McCardle, K. F. (1999), 'Options in the real world: lessons learned in evaluating oil and gas investments', *Operations Research* 47 (1): 1-15.

Smith, J. E. (2005), 'Alternative approaches for solving real-options problems', Comment on Brandão et al. 2005, *Decision Analysis* 2 (2): 89-102.

Trigeorgis, L. (1998), 'Real Options, Managerial Flexibility and Strategy in Resource Allocation', Third Edition, The MIT Press.

Trigeorgis, L. (1998), 'Real options and interactions with financial flexibility', *Financial Management* 22 (3).

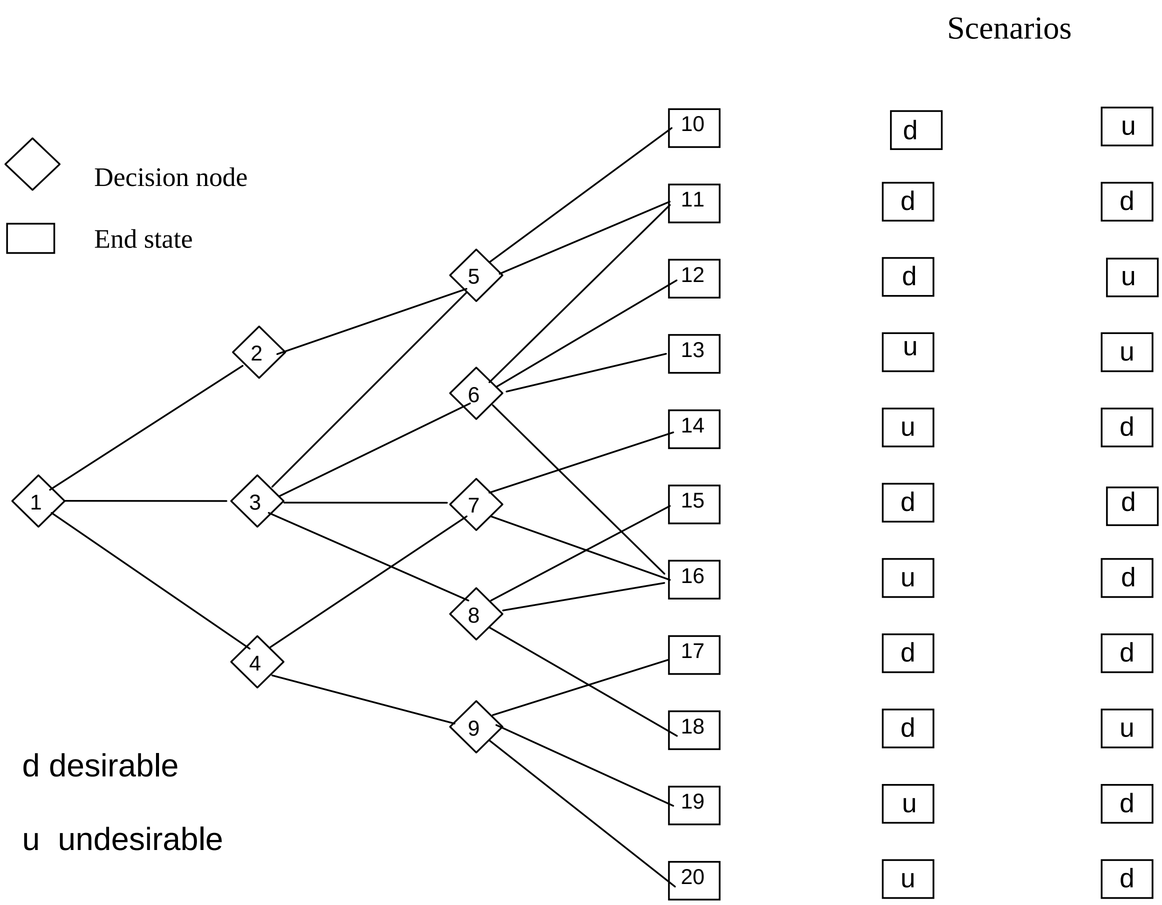

Figure 13.1 A Multi-Stage Decision Process

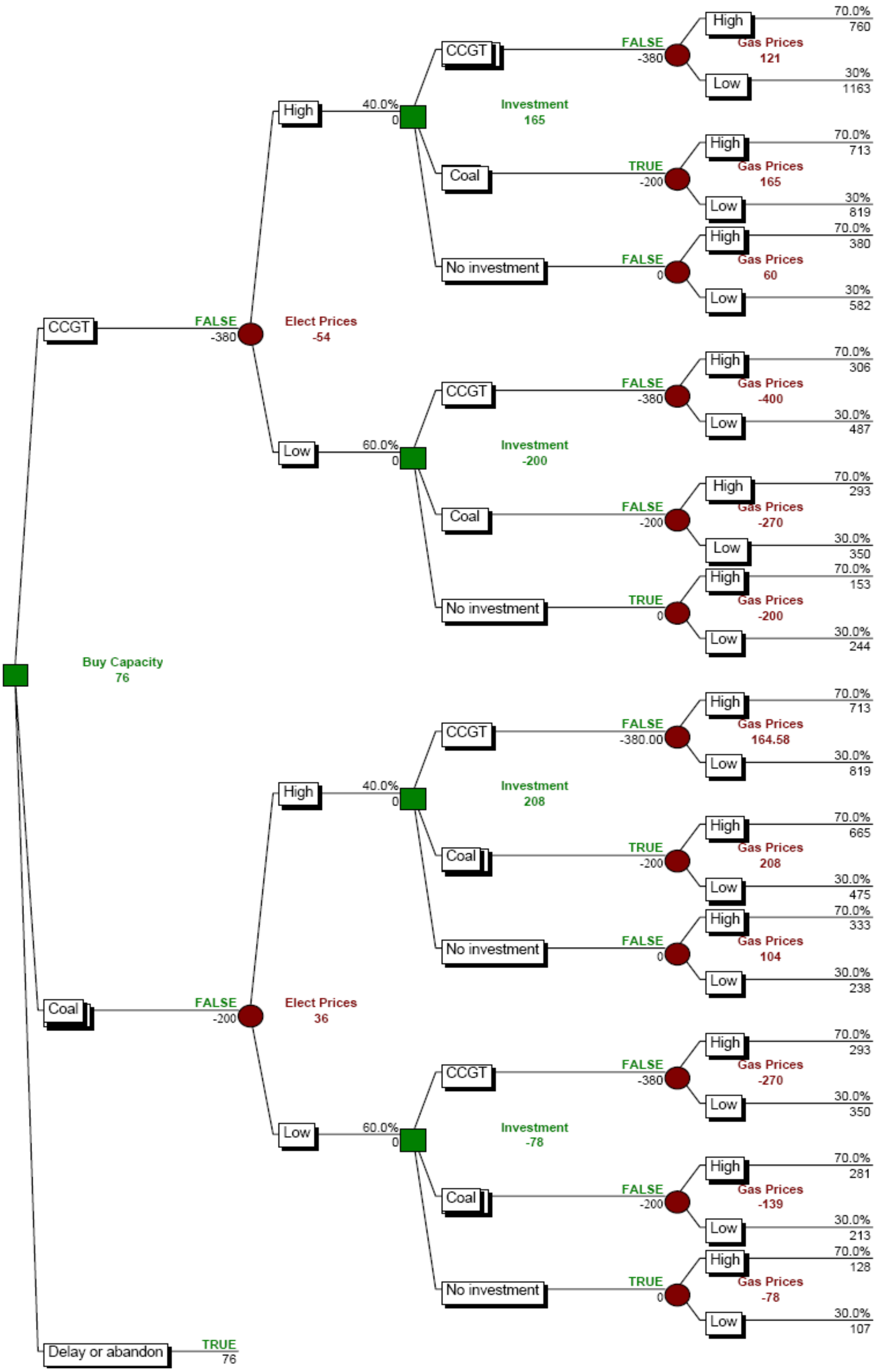

Figure 13.2: Classical Decision Tree

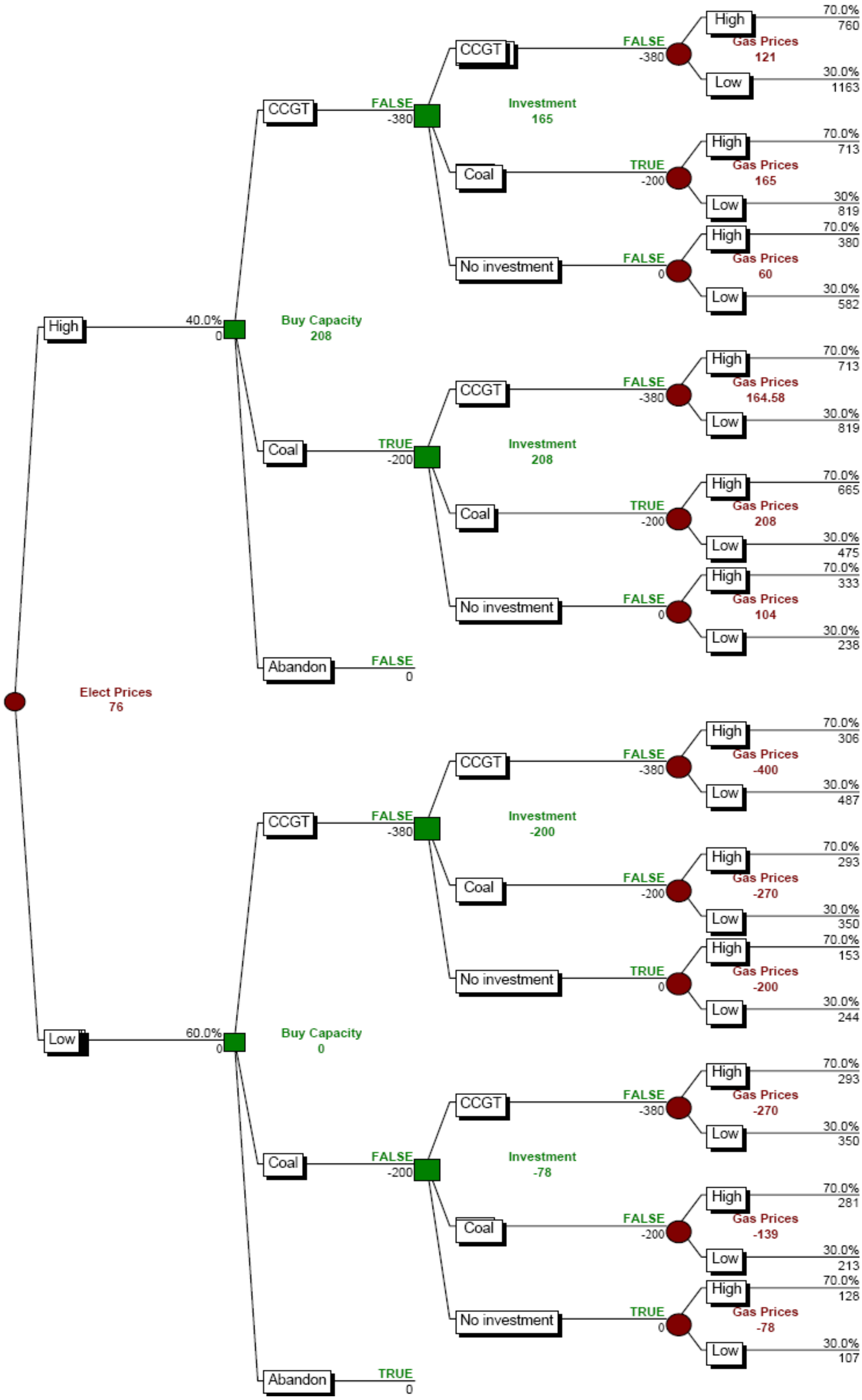

Figure 13.3: The Decision to Delay or Abandon in the Classical Decision Tree

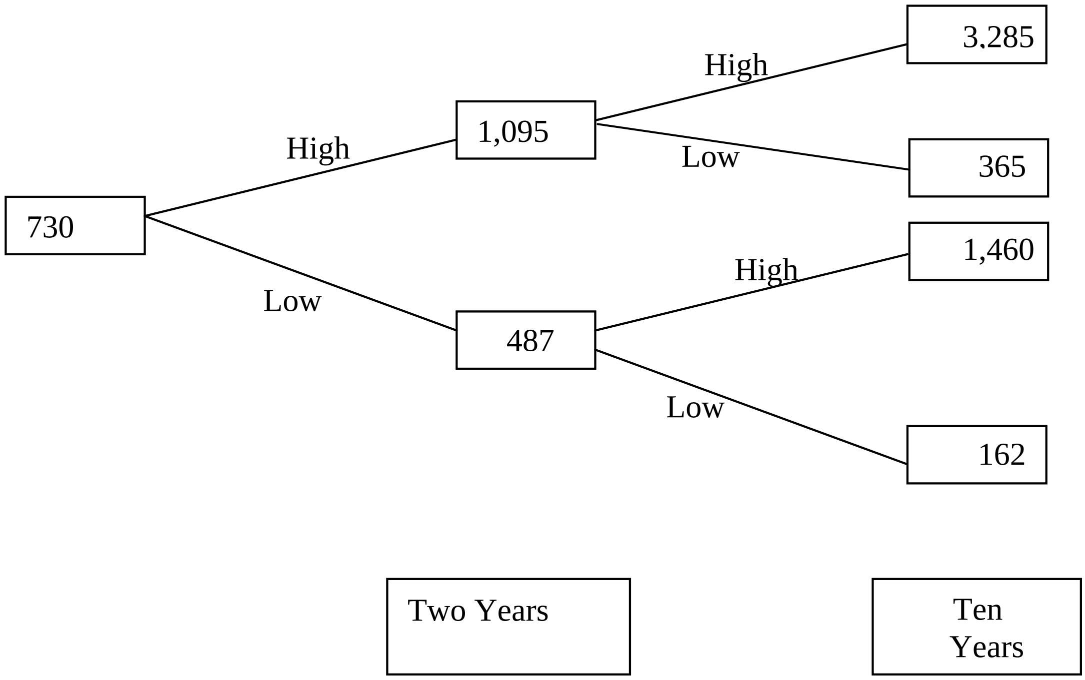

Figure 13.4: Binary tree to model the evolution of BE's stock price as a function of gas prices (in pence)

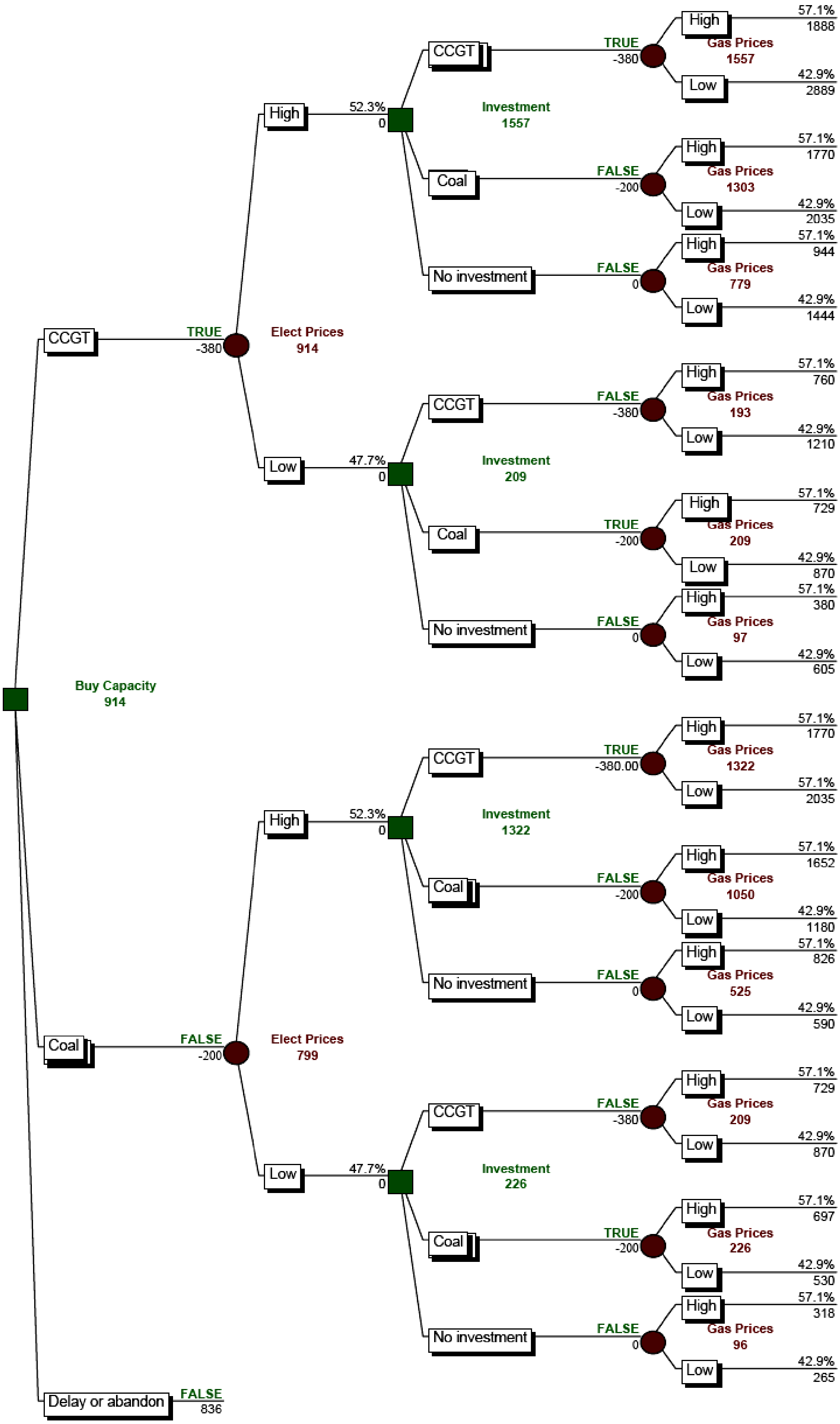

Figure 13.5: The Real Options Tree

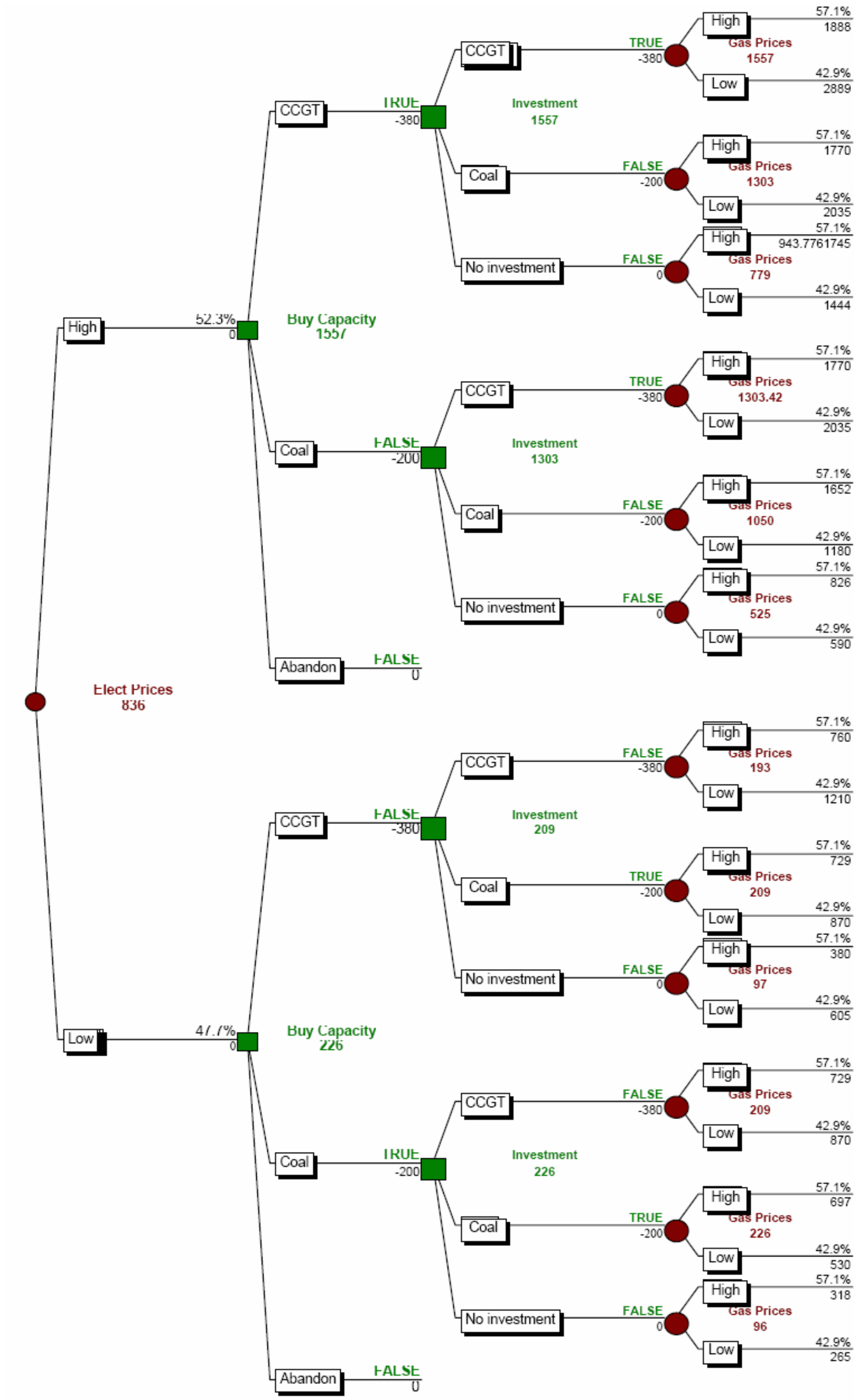

Figure 13.6: The Decision to Delay or Abandon in the Real Options Tree

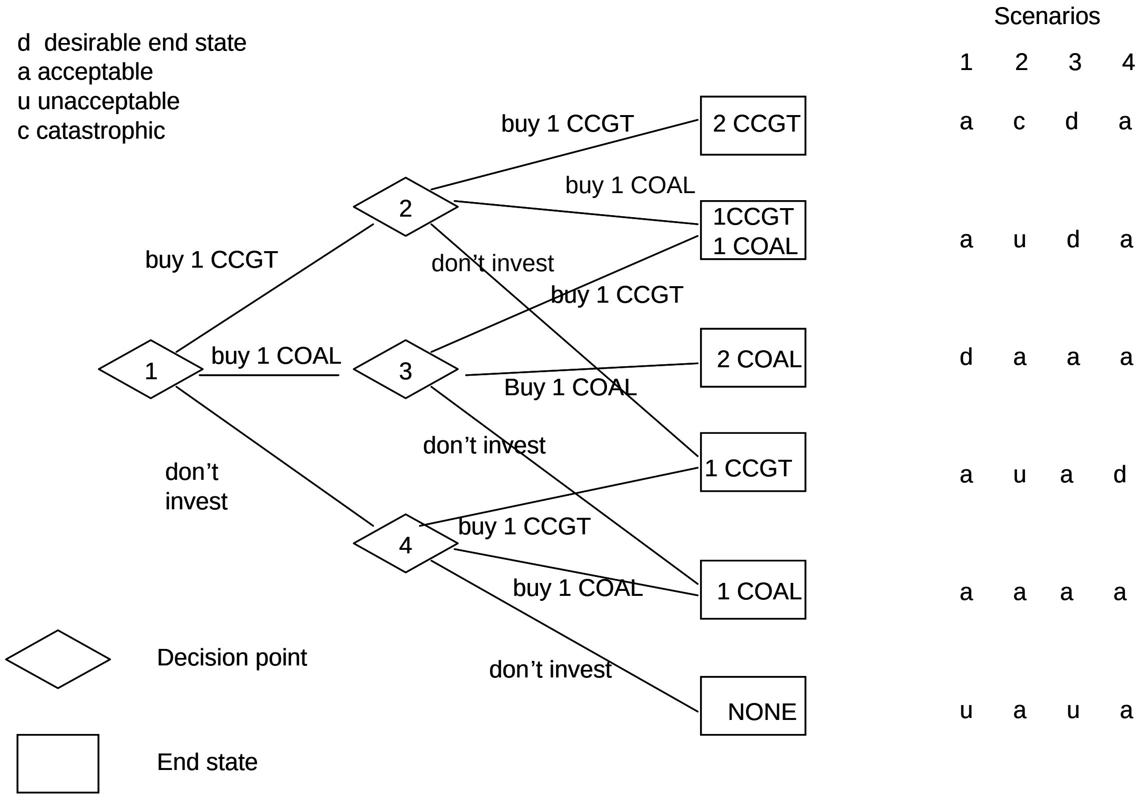

Figure 13.7 Two stage Planning Problem

		Scenario	
		1	2
	(1,2)	2/6	1/7
Decision	(1,3)	5/6	4/7
	(1,4)	1/6	5/7

Table 13.1 Robustness Matrix

Value of the:	V_1	
	$V_1 < I$	$V_1 \geq I$
CCGT Plant	V_1	V_1
Put option	I-V_1	0
Call option	0	-(V_1- I)
Portfolio	I	I

Table 13.2. An example illustrating the formation of a riskless hedge.

Value of the:	*High Value*	*Low Value*	Range
CCGT	V_H	V_L	V_H-V_L
Call option, with exercise price I	V_H-I	*0*	V_H-I
$V_1 – C$	I	V_L	I- V_L

Table 13.3. Value of a Portfolio with a CCGT and a written Call option

Value of the:	*High Value*	*Low Value*	Range
CCGT	hV_H	hV_L	h(V_H-V_L)
Call option, with exercise price I	V_H-I	*0*	V_H-I
$V_1 – C$	I-(1-h) V_H	hV_L	*0*

Table 13.4. A Risk Free Portfolio with a CCGT and a written Call option

Criterion	Robustness Analysis	Decision Trees	Real options
Flexibility	- It is realised by leaving as many open options as possible.	- Decisions are made step-by-step. - As the decision process proceeds a firm is able to change the plan of actions. - Every plan of actions is conditional on the future realisations associated with the stochastic variables.	- Decisions are made step-by-step. - As the decision process proceeds a firm is able to change the plan of actions. - Every plan of actions is conditional on the future realisations associated with the stochastic variables.
Uncertainty	- There is no uncertainty regarding the intermediate states reached for a given set of decisions. - There is uncertainty regarding the value of each one of the states after these are reached.	- There is uncertainty regarding the states reached by a given sequence of actions. - Uncertainty is *subjective*.	- There is uncertainty regarding the states reached by a given sequence of actions. - Uncertainty is *objective* and determined by the market.
Information required	- Easy to obtain - Qualitative - Subjective.	- Difficult to obtain - Quantitative - Subjective.	- Difficult to obtain - Quantitative - Objective
Risk profile	- Not analysed.	- Risk is subjective - Firms maximise the expected utility.	- The risk is priced by the market - Firms are risk neutral.
Valuation	- Only through the desirability or otherwise of the end states.	- Central topic - Valuation is subjective and it is dependent on the perceptions of the firm developing the project.	- Central topic - Valuation is objective and it is determined by the market.

Table 13.5 Comparing the Robustness analysis and the Real Options approach

Robustness Matrix (end states d and a)   Debility Matrix (end states u and c)

Scenario   Scenario

Decision	1	2	3	4	1	2	3	4
(1,2)	3/5	0	3/5	3/6	0	2/3	0	0
(1,3)	3/5	2/4	3/5	3/6	0	1/3	0	0
(1,4)	2/5	2/4	2/5	3/6	1/1	1/3	1/1	0

Table 13.6 Option Evaluation