"The application of a real options valuation methodology to a coal mining project in New South Wales, Australia"

By

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STATEMENT OF ORIGINALITY

This dissertation contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and to my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Shaun Leary
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Abstract
This study uses a real options approach to value an operating coal mine in the Hunter Valley, New South Wales, Australia. It then compares the results with a traditional discounted cash flow (DCF) analysis, finding that not only is the methodology presented viable, but the relative simplicity of its implementation using binomial lattices makes it a realistic and feasible alternative to traditional DCF analysis.

A review of the current literature revealed two schools thought with reference to mining valuations. They were traditional valuations derived from Net Present Value (NPV), and values derived from real options analysis (RO). Valuation methodologies within the RO literature were not consistent and were found to fall within five categories, the Classic, Subjective, Market Asset Disclaimer (MAD), Revised Classic and Integrated approaches. This study uses the MAD approach, arguing that it provides a method to capture project specific and market related risks as well as being easily implemented using simple binomial lattices.

The study found that the RO approach presented a feasible and mathematically viable alternative to the traditional NPV methodology showing that a constructed portfolio using firms that undertake similar projects to those of the case study will capture both project specific (private) and market related (public) risks. Furthermore it was found that the RO analysis yielded results that were in the vicinity of 25% greater than the traditional NPV values. This was found to be in line with the literature. It is also argued that real options such as the option to expand, the option to contract, the option to wait and the option to
abandon cannot simply be added to calculate an overall RO value since there are issues of additivity that need to be considered and require more research.

This study makes a contribution to the business literature by being the first study to address the applicability of real options valuations to the coal mining industry.

**Introduction**

One of this study’s primary aims is to present an alternative valuation model for financially modelling coal mines. The study does this by evaluating a currently operating coal mine and then comparing the results derived from a traditional DCF/NPV analysis with those from an alternative Real Options Valuation. It then asks the question, does the typical NPV analysis adequately capture all the value associated with the coal mining project, and if not, does the Real Options approach more adequately capture the value associated with coal mining?

In mining finance, Discounted Cash Flow (DCF) models are the basis for most project evaluations, with the conventional view that the Net Present Value (NPV) of a project is the measure of value the project will add to the firm. This premise is increasingly being challenged in the financial literature with the most viable option being the Real Options Analysis (ROA) methodology.

The ROA technique has evolved from the seminal work of Black and Scholes (1973) in financial options to present thinking, where the same principles are applied to real assets
like natural resource projects. Brennan and Schwartz (1985) presented a seminal paper linking financial options thinking to a mining project and from this point on there has been an explosion of study in regards to its applicability to natural resource projects.

Despite the theoretical appeal of ROA, current studies (Remer, Stokdyk et al. 1993; Truong, Partington et al. 2008) show that most companies still use traditional DCF/NPV methods. This study argues that there are several reasons for this, including the complicated mathematical themes often presented in the literature and secondly a lack of understanding of the shortcomings of the NPV methodology. One motivation for this study is to address this mathematical complexity and lack of NPV understanding by presenting a simple intuitive real options model. The mathematical complexity is purposely kept simple to make the method more initiative and accessible to the practitioner involved in evaluations of mining projects.

The dissertation is structured in the following manner. Firstly Chapter 1, a literature review, is presented detailing the evolution of financial evaluations for natural resource projects. It reviews the development of alternative approaches to traditional DCF/NPV valuations including ROA and Hotelling's method. It establishes the ROA as the main alternative to traditional DCF/NPV methods.

After the Literature Review, Chapter 2 presents a specific methodology for valuing a coal mining project using ROA and comparing the value derived from this method to a traditional DCF/NPV analysis. This Chapter presents the method for a traditional DCF/NPV valuation detailing many of the assumptions and drawbacks that have led to it being questioned in the
literature. The five competing real options approaches are also presented. Namely, the classic approach, the subjective approach, the Market Asset Disclaimer (MAD) approach, the revised classic approach and the integrated approach (Borison 2005a). This Chapter establishes that the MAD approach is the most appropriate for this study.

Chapter 3 presents the results of a Case Study evaluation using the methods presented in Chapter 2. It builds a cash flow model based on a mining model derived from first principles. This cash flow model is included in MS Excel format in Appendix 1. The cash flow model presented accounts for the lumpy nature of cash flows in mining projects, an approach that is not previously seen in the literature. Previous literature studies using ROA to value mining projects almost always exclusively present cash flow models based on some form of probabilistic determination. This it is argued is simplistic and is not in line with industry practice where detailed Life Of Mine (LOM) models are always constructed to reflect the current estimated mining schedule. A significant contribution of this study is to show how this industry practice of constructing "lumpy" cash flow models can be reconciled with the approach that is taken in the academic literature. The study does this by arguing that that ROA using the method detailed in Chapter 2 can be "bolted" on to the back end of traditional DCF/ NPV analysis derived from the "lumpy" cash flow model. This approach will make it intuitive and more likely to be accepted by management who can still refer to the established DCF/NPV in any decision making process. Empirically this is presented as;

\[
\text{Expanded NPV} = \text{Traditional NPV} + \text{Real Options Value}
\]
The options that are considered in this case study are the option to abandon the mine, the option to expand production, the option to contract production and the option to wait. These options are well established within the literature and are shown to add 20% additional value to the Case Study. This finding is in line with the literature which typically finds similar increases in value associated with the operating options available to mine management.

**Chapter 4** presents a discussion section centred on the viability of applying the method to corporate valuations within the mining industry. The practicality and its likelihood for corporate acceptance are discussed as well as some of the ethical questions surrounding a valuation methodology that increases the value of projects in the vicinity of 20% are also considered.

The strategic benefits of thinking in real options terms are also discussed. This new thinking paradigm can position the company to strike when market conditions are favourable or recognise potential investments even when traditional methods argue for rejection. Not only does this present project level benefits but on a firm wide basis it could influence mergers and acquisitions activity. By being a first mover it is argued that a firm embracing real options theory is likely to unlock value that is not recognised by its competitors.
The final component of this study is the conclusion. It argues that the study makes a significant contribution to the business literature by presenting a method in line with existing literature but building on it by presenting a methodology that is simple to use and understand and applying it to a real world coal mining operation. It uses current mining valuation practices to construct the underlying asset, the NPV, which is not contentious despite issues surrounding its derivation. The portfolio of coal assets used to derive parameters used in the ROA is more contentious. This study argues however, that its use is more valid than current subjective practices used in the literature and that its application could be applied to other commodities such as iron ore and gold for example.
Chapter 1: Literature review

Introduction
Mineral project valuations are a contentious issue. Various authors argue the merits of differing approaches (Brennan and Schwartz 1985; Miller and Upton 1985a; Smith and McCardle 1998; Zarkos, Morgan et al. 2007; Martinez 2011; Maybee 2011; Nishihara and Shibata 2011) mostly from within a positivistic view (Mackenzie and Knipe 2006). This review aims to introduce the main valuation methodologies, trace their evolution and evaluate the strengths and weaknesses in each argument. It aims to do so whilst giving some thought to whether different conclusions could be reached if studies were considered in contexts other than a Positivist view (Mackenzie and Knipe 2006).

Competing mineral project evaluation methodologies
The main contenders competing for acceptance within the mineral valuation literature are shown below and are grouped into three categories.

1. Traditional Valuation Methods such as Discounted Cash Flows (DCF) used to calculate project Net Present Value (NPV) (Sharpe 1964; Myers and Turnbull 1977),
2. Hotelling’s Principle (Hotelling 1931; Levhari and Liviatan 1977; Cairns and Davis 1998a),
3. Real Options (Tourinho 1979; Brennan and Schwartz 1985; Paddock, Siegel et al. 1988; Sick, R.A. Jarrow et al. 1995; Trigeorgis 1996; Cortazar, Schwartz et al. 1998; Mathews 2009; Won 2009),
Traditional Valuation Methods

Traditional mineral project valuation methodologies argue for conformism to mainstream financial theories namely efficient market hypothesis (EMH), modern portfolio theory (MPT) and the Capital Asset Model (CAPM). A brief review of the existing traditional capital budgeting literature in the context of alternative methods is presented here with the reader directed to Bodie, Ariff et al (2007) for a full description of mainstream capital budgeting methods.

A review of recent literature shows that capital budgeting within modern Australian and International firms (Remer, Stokdyk et al. 1993; Truong, Partington et al. 2008) largely utilises the traditional Discounted Cash Flow (DCF) approach to estimate a Net Present Value (NPV). These studies show 94% of Australian companies use NPV as their primary capital budgeting and project evaluation tool which was also in line with international findings. This was an increase on earlier studies (Copeland and Antikarov 2001) that found 19% in 1959 to 87% in 1978 demonstrating that the DCF methodology and NPV evaluations techniques are not only the choice of industry when evaluating projects but its popularity appears to be growing. Copeland and Antikarov (2001), argue that this growth in popularity is probably technology driven with the advent of personal computers.

The use of traditional capital budgeting in valuing mining projects is contentious within the mineral economics literature (Brennan and Schwartz 1985; Guzman 1991; Jacoby and Laughton 1992; Guerrero 2007). Brennan and Schwartz (1985) in a seminal paper on the evaluation of natural resource investments criticise the application of a single period
discount rate arguing that the price uncertainty in natural resources is vitally important with swings of between 25-40% common. They argue that the application of a single project discount rate is inappropriate since variances such as price fluctuations and other forms of risk associated with the project are likely to cause errors. They also criticise the traditional approaches lack of ability to deal with management's ability to react to changing market conditions.

Guzman (1991), is also critical of the application of traditional methods to resource projects. Firstly, he argues that the assumptions of perfect, frictionless capital markets where borrowing and lending is unrestricted at the risk free rate with investors being risk averse, utility maximising and sharing uniform expectations, is unrealistic. He further asks, that if these expectations for the CAPM to hold are unrealistic, then does the CAPM remain valid if these underlying assumptions are relaxed? Bodie, et al, (2007) also argue that these simplifications are problematic. Investors cannot access risk free funds at the same rate for example, and that it is unrealistic to expect that all investors plan for a single holding period. They extend the argument of Guzman (1991), in that they also argue that the CAPM is only applicable to a universe of publically traded financial assets such as stocks and bonds. Beta is only relevant therefore, to assets traded within this universe. The application of the CAPM to value individual mining projects that exist outside this investment universe is then argued to be problematic since the market portfolio of stocks cannot be considered as a proxy for the market portfolio of mining projects.
Both Guzman (1991) and Bodie, et al., (2007) argue that the assumption that investors plan for a single holding period is also flawed. The CAPM they argue is a single holding period model and if it is extended to projects with multiple periods such as those in mining projects then its use is argued to be flawed.

**Hotelling's method**
Hotelling (1931), was the first to explicitly recognise that mineral projects and the economics of exhaustible resources presented challenges that were not adequately addressed using accepted economic principles. He argued that static equilibrium economics did not account for the finite resource base of mining based economics and that under the existing school of thought the mining firm would be driven to extract resources at an infinite rate. He argued this was illogical, because there must be a point where production would exceed demand and prices would therefore fall. His argument centres on the fact that an equilibrium point would be found between production and demand and maximise profits. This argument is best expressed in his own words:

“If a mine-owner produces too rapidly, he will depress the price, perhaps to zero. If he produces too slowly, his profits, though larger, may be postponed farther into the future than the rate of interest warrants. Where is his golden mean?” (Hotelling 1931). Hence he was the first to ask the question - what constituted the optimum extraction rate to maximise profit? In asking such a question he was assuming that the mining firm was driven to act as a profit maximising entity, a concept that was later supported by (Friedman 1953) but one that has since been challenged within the context of the Agency Theory debate (Jensen and Meckling 1976; Cragg and Greenbaum 2002; Heath 2009) and the validity of
von Neumann and Morgenstern’s (1953) Expected Utility Theory (EUT) assertion that investors behave in a rational and efficient manner.

Hotelling’s law states that the mineral resource is fixed, and extraction takes place so that the value of the resource is maximised subject to the fixed stock constraint and constant demand for the mineral and a constant rate of interest. Net prices are then argued to rise at the discount rate under these assumptions producing the Hotelling r% rule (Davis 1996). Since its derivation many authors have attempted to either prove or disprove the validity of Hotelling’s principle by either extending the base model or reviewing actual data with that is predicted by the theory (Levhari and Liviatan 1977; Pindyck 1980; Miller and Upton 1985a; Miller and Upton 1985b; Halvorsen and Smith 1991; McDonald 1994; Adelman and Watkins 1995; Slade and Thille 1997; Davis and Cairns 1998; Davis and Moore 1998; Cairns and Davis 1998b).

The first work attempting to extend Hotelling’s work looked at the case of incomplete exhaustion of the resource (Levhari and Liviatan 1977) which contrasts to Hotelling’s assumption of complete exhaustion of the resource. The authors present a method to describe the full marginal cost of extraction. One of the main criticisms by Levhari and Liviatan is that Hotelling assumes that the output of a mining project is continued until the resource is completely exhausted. This they argue is unrealistic as a mine would choose to shut down if costs become high enough to make the mine uneconomic despite the fact that there may still be reserves remaining.
Whereas Levhari and Liviatan challenge the notion of complete exhaustion, Pindyck (1980) addresses the question of uncertainty with natural resources. He argues that with constant extraction costs and risk neutral firms, neither demand nor reserve uncertainty affects the price dynamics and Hotellings rule will still apply. He further argues that when extraction costs are a function of the level of reserves, demand uncertainty still has no effect on the expected behavior of price, although reserve uncertainty will affect price.

Miller and Upton (1985a) build on Hotelling’s proposition in a paper titled "A Test of the Hotelling Valuation Principle". In it they argue that the unit price of an exhaustible natural resource, less the marginal cost of extracting it, will tend to rise over time at a rate equal to the return on comparable assets (Hotelling 1931) by relaxing the assumption that the resource needs to be extracted to exhaustion they derive what they term as Hotelling Valuation Principle (HVP) which is shown in Equation 1.

\[
V_0 = (p_0 - c_0) \sum_{t=0}^{n} q_t = (p_0 - c_0)R_0
\]

**Equation 1** The Hotelling Valuation Principle (Miller and Upton 1985a)

Where: \(V_0\) = the present value of the in ground reserves

\(P_0\) = Current spot price of commodity or mineral
Equation 1 states that the present value of a unit of reserves in the ground is equal to the market value of that commodity less the cost of extracting it. They then attempt to review the validity of the Hotelling Valuation Principle (HVP) by reviewing predicted values with historical data. They argue that under Hotelling’s theory an upward trend in net prices which would entice current miners to optimise resource extraction and conserve the rest for future consumption should be observed. However, they found that throughout the 1970’s there was a downward trend in resource prices for many minerals which conflicts with predicted HVP values. To account for this they argue that these falling prices need to be considered in the context of earlier work (Pindyck 1980) that showed that discovery of new resources could in effect drive prices down as more resources become available for exploitation. This fall in price results from resources being depleted less quickly than they are being found. These phases in reduced prices it is argued are temporary by the nature of the finite resource and that the exhaustibility underlying the HVP would reassert itself.

Miller and Upton (1985a) further argue that measuring the difference in interest rate and growth rate as required by the HVP has serious deficiencies and proposed using a method whereby the value of the reserves in any currently operating mineral deposit depend on current period prices and extraction costs, regardless of when the reserves are extracted.
(Equation 1). With this in mind they investigated the relationship between the market value of reserves for petroleum producing firms and current output prices net of extraction costs and found them to be in line with expectations predicted by the HVP (Equation 1). A comparison was made to a DCF analysis using a 10% discount rate on the same data. The HVP was found to be more statistically significant and they then use these findings to argue the HVP is a better predictor of project value than traditional DCF. A further study in the same year by the same authors (Miller and Upton 1985b) aimed at reinforcing the findings of this earlier paper, did not, however, prove as fruitful. The initial paper reviewed data from 1979-1981 and strongly support the HVP as previously asserted. The second paper however, presents a series of follow-up tests using time-series cross-section data covering the period August 1981 to December 1983. Because the variance of petroleum prices in this period was substantially less than in the earlier period, the follow-up sample proved generally non informative and began casting some doubt over the validity of the method.

In light of the doubt cast by Miller and Upton’s follow up study, Halvorsen and Smith (1991) reviewed actual data for the Canadian metal mining industry from 1954 to 1974. From this study they reject the HVP arguing that observed price trends were not in line with the HVP. Other authors also recognise that the HVP seems to exaggerate the actual value of in ground resources (McDonald 1994; Adelman and Watkins 1995). McDonald argues that these results are to be expected given the nature of oil well production and extraction rates in the US, whereas, Adelman and Watkins recognise and discount the HVP as a viable valuation technique because of its inability to accurately reflect actual data. Slade and Thille (1997) attempt to provide a better fit of the model with actual data by building risk into the
HVP by integrating it with CAPM but also find that HVP was not a good predictor of resource value even with CAPM build in.

Contrasting with the findings outlined above, several authors subsequently argue that Hotelling’s or adaptations of the rule holds (Cairns 1998; Davis and Cairns 1998; Davis and Moore 1998; Cairns and Davis 1998a; Cairns and Davis 1998b). In these studies it is argued that capacity constriants, option value, and uncertainty impact on the HVP and need to be built into the Hotelling Valuation. In their first paper Cairns and Davis(1998a) argue that with some modifications, to account for operating constraints and price uncertainty, the HVP rule should still hold and will account for the emperical results previously reported in petroleum plays. In their second paper (Cairns and Davis 1998b) use the same techniques applied above for hard rock mines and find that the method overestimated the value of by up to 70% when comparing predicted prices to actual data. This was improved by utilizing an adapted formula that considered capacity constraints and price drifts over time as well as traditional HVP variables of price, cost and reserve data, but is still significantly different from actual prices.

This review of the Hotelling principle shows a method that has been continually evolving and despite its intuative appeal and ease of use does not appear to be accepted within the general mineral valuation literature. Evidence of its non-appeal to academics and practioners as a viable methodology can be found in an absence of a developed literature post the year 2000.
Whilst Hotelling’s valuation principle appeared to be losing momentum during the mid 1980’s another school of thought was developing in the mineral economics literature that was based around the options valuations theory made popular in the financial literature (Black and Scholes 1973; Merton 1973). In the financial literature Black and Scholes (1973), proposed in a seminal paper that an option on stock is implicitly priced if the stock is traded, and developed a mathematical solution to valuing options. The model was further extended (Merton 1973) to incorporate the pricing of American style options and then, in a review of the currently developing options literature, the concept that valuations built on the Black and Scholes method could be applied to other asset classes apart from stocks was discussed (Smith 1976). Smith argued the technique could be used in valuing the equity of a levered firm, a dual purpose fund, corporate policy and the risk structure of interest rates on corporate debt. However, it is clear in this paper that the link between Black and Scholes valuation methodology and the valuation of real assets like mineral projects had not yet been made with most thinking still focused on financial instruments.

**Real Options Evaluations**
Tourinho (1979) presented a PhD that appears to be the first significant attempt at utilising the Black and Scholes methodology to value natural resource projects, arguing that the resource should be viewed as an asset and the reserve an option to extract the economically viable portion of that resource asset. This attempt at using the Black and Scholes method was not without problems with the author arguing that the owner would never want to extract the reserve if their was no time limit on extraction. A concept that was in line Black
and Scholes theory that stated that call options on non-dividend paying stocks are never exercised early. He also found that as uncertainty increased with a mineral project the value of the reserve increased a fact also recognised in the price of the commodity being mined. The concept was then extended to petroleum leases (Paddock 1982) and commodity-linked bonds (Schwartz 1982). It was clear from these early studies that although with promise there were still significant theoretical issues surrounding the application of the methodologies application to non financial assets.

At the same time that the HVP was losing momentum and options theory applied to real assets was in its infancy the traditional DCF methodology appears to have been gaining in popularity within both the general financial community and also the resource sector. In a study of project evaluation techniques used in industry from the largest “Fortune 500” companies (Remer, Stokdyk et al. 1993) it was found that the popularity of DCF and NPV had increased in usage from 52% in 1978 to 97% in 1991, a fact that supported in a subsequent study (Graham and Harvey 2001; Truong, Partington et al. 2008) that not only describe the prevalence of NPV as the dominant valuation methodology but also makes comment on the application of the methodology, arguing that that more than half of the respondents to their survey would use their firm’s overall discount rate to evaluate a project in an overseas market, even though the project likely has different risk attributes than the overall firm. Truong, Partington et al. (2008) make similar findings in Australia. This indicates that practitioners might not apply the CAPM or NPV rule correctly or that the NPV method may have been inappropriate.
As a response to some of the questions that were being asked of the accepted NPV methodology a seminal paper in the field of mineral economics was presented by Brennan and Schwartz (1985) in which they present a compelling case for the adoption of the Black and Scholes (1973) principles to the problem of valuing mineral projects and argue against the use of NPV/DCF in resources sector. The main arguments presented by Brennan and Schwartz (1985) were that current DCF valuation methodologies used a simple derivation of Fischer (1907) model under uncertainty inappropriately. The discount rate derivation they argue is crude and inappropriate since it is derived from a single period asset pricing theory (CAPM) and often misussed a notion supported by Graham and Harvey (2001). Other arguments forwarded by the authors were a neglect of the stochastic nature of commodity prices, and also a neglect of managements ability to react to these price variations. They also consider the observed possibility that a project may be closed down or abandoned if the commodity price falls to low and that it would not continue on a ruinous path as dictated under a traditional NPV approach if it was unprofitable.

Brennan and Schwartz’s methodology also recognised the limitations of the DCF model which requires a stochastic understanding of the cash flow stream. This it is argued by Brennan and Schwartz is problematic since it is hard to model commodity price behavior. To get around these problems they build on the work of Black and Scholes (1973) and present the first paper that addresses the concept of contingent claims. In their paper they argue for a self-financing portfolio whose cash flows replicate those which are to be valued, that is they argue for a portfolio of assets that mimics the behavior of a resource project. In formulatinhg their proposition they concluded that assets whose cash flows depended on
unknown prices and the optimal policy for managing them could be determined by constructing replicating self-financing portfolios. This they argued could be achieved by trading in futures contracts.

An explosion of literature occurred after Brennan and Schwartz presented their seminal paper with various authors extending the model whilst others attempted to apply it to different commodities. One of the first studies to embrace Brennan and Schwartz’s model investigated an option pricing approach to evaluating petroleum projects (Ekern 1988), setting the tone for numerous future papers that deal with the valuation of petroleum projects. Ekern’s objective was the application of the methodology rather than an advancement of its theoretical base. The author argues that the techniques reliance on market based input data and yields improved estimates of the expected cash flows whilst also avoiding the need to generate a discount rate and as such was a better model than traditional DCF. One significant criticism of this study is that it assumes that the hedging probability can be derived by using a replicating portfolio, requiring the assumption of complete markets (Smith and Nau 1995).

In the same year as Ekern (1988), another study (Paddock, Siegel et al. 1988) looked at valuing a petroleum lease but was much more critical of the traditional NPV approach as an alternative, highlighting five significant issues with traditional DCF analysis versus the real options approach in valuing the petroleum leases. Their five concerns were:
1. Exploration and development timing was not consistent between different party's analysis of the same petroleum leases with these timings typically arbitrary and subject to error. This problem led to valuations that are divergent between companies, the government, and the capital markets they argued.

2. Different entities they argued have different assessments of future statistical distributions, and thus expected paths, of hydrocarbon prices, none of which need conform to the aggregate expectations held by capital markets. This also leads to divergent valuations.

3. Discount rate selection is often subjective and prone to error despite the fact that using the correct discount rate is crucial and the DCF is very sensitive to any rate chosen.

4. The DCF calculations, particularly Monte Carlo applications, are very complex and costly.

5. Assessments of geological and cost distributions can vary, perhaps widely, across companies and the government. This also causes large discrepancies among respective valuations.

As an alternative to the DCF approach these authors (Paddock, Siegel et al. 1988) argue for a petroleum lease representing a set of nested options that could be valued using the approach previously proposed (Brennan and Schwartz 1985) and identified the following options:

- *Option to explore analogous to call option,*
• **Option to develop** - the leaseholder has the option to pay the development costs and install productive capacity. Therefore, ownership of an undeveloped reserve is an option to obtain developed reserves by paying the development cost.

• **Option to extract** - Once the leaseholder has exercised its development option, he owns developed reserves. He then has the option to extract the hydrocarbons if he chooses.

A model aimed at determining the value of financial and real asset value contingent on the price of oil was presented soon after (Gibson and Schwartz 1990) relying on the spot price of oil and its instantaneous yield. The authors applied the model to valuing a barrel of oil deliverable in one to ten years time but made the point that the model offered the opportunity to develop what they called a replicating portfolio that could be used to value oil field projects. Jacoby and Laughton (1992) built on the work by Gibson and Schwartz (1990) by attempting to illustrate the practicle application of the methodology to operating offshore oil field developments in the North Sea, arguing that current DCF analysis was innapropriate mainly because of the risky nature of future cash flows across multiple periods and the innapropriate use of corporate discount rates. They argued that by constructing a portfolio of oil futures they can create a trading strategy in portfolios of the underlying assets which will replicate the cash-flows of the real asset, and as such its value. The project is argued to be a portfolio of claims to individual cash-flows. Cash-flows can be valued individually by period, and then summed to provide the value of the project. This interest within the Petroleum and Oil was also highlighed by a study undertaken by the Shell company at the time who argued that the method offered significant potential (Kemna
Kemna argued that the Shell company believed that although superior to DCF the ability to “sell” the method to management was problematic because of its complexity.

The application of Real Options (RO) to a Copper project (Mardones 1993) was done using the same method proposed by Jacoby and Laughton (1992) but using copper rather than oil futures to set up a contingent portfolio. The authors argued that the RO method was more precise than the traditional methods because it treated risk more rigorously and accounted for management flexibility in responding to varying copper market prices. The recognition of management flexibility was also picked up by Trigeorgis (1993a) who argued for greater value when multiple options were available and considered in the valuation. This multiple option interaction was not considered by previous authors (Jacoby and Laughton 1992; Mardones 1993) who had valued individual options one at a time and then summed them. Trigeorgis (1993a) argues that this is problematic and further develops the concept in a subsequent paper where he discusses the non additive nature of options where he also discusses the role of financial flexibility as a source of value in addition to operating flexibility.

A significant criticism of the RO approach (Brennan and Schwartz 1985; Trigeorgis 1986; Ekern 1988; Paddock, Siegel et al. 1988) to valuing resource projects (Jacoby and Laughton 1992; Mardones 1993) was the reliance of the method on the construction of a portfolio of replicating assets that spanned the life of a project. This issue was addressed by Smith and Nau (1995) who argue that in order to construct a replicating portfolio the assumption of a complete market needs to be made. The complete market assumption argues that a portfolio of assets can be constructed which perfectly replicates the payoffs of a project (Smith and Nau 1995). This assumption the authors argue is unrealistic in the case of many
real world projects outside of the financial asset world. Rather than completely discounting the notion of option analysis, however, they present a model within the context of partially complete markets where risks are divided into market and private uncertainties. Private uncertainties are firm specific and cannot be hedged by financial instruments, however, market uncertainties can be hedged. The authors then argue for an integrated approach that takes into account these private and market uncertainties. They conclude that decision analysis and options pricing are fully compatible and a combination can be used in an incomplete market setting.

Another significant problem often cited with the NPV model is the inability of the methodology to value the ability of management to actively make decisions that impact on a project performance (Mardones 1993; Davis 1996; Copeland and Antikarov 2001; Copeland and Antikarov 2005; Cairns and Davis 2007; Cobb and Charnes 2007). Mardones (1993), for example, argues that managerial flexibility adds value to a project but this gain is rarely considered since the NPV method cannot capture it. Operating flexibility he argues to cut costs or exploit increased commodity prices operates as an option and as such can be valued additional to the traditional NPV methodology.

\[
\text{RO value} = \text{NPV Value} + \text{Option premium}
\]

A conceptual equation detailing the RO value of a mining project (Davis 1996).

The option premium component of is best described as the ability of management to learn and react to project variables like price.
In financial option pricing theory, the value of an option depends firstly on the volatility of the underlying asset (Black and Scholes 1973; Ross, Westerfield et al. 1996). The more volatile the asset the more valuable the option should be. In a mining context this argument is extended to be the more volatile a mineral commodity price the more valuable the option to manage should be. The current volatility of world commodity markets means that this often ignored value component is actually very valuable and needs to be considered. Mardones (1993) makes an attempt to quantify the option premium and found that the option premium accounted for a 2.4% increase in value of a Chilean Copper mine whilst Cavender (1992) found a 16.6% premium for a gold mine in the US. In the case of the coal industry there is no literature available describing the application of RO to project valuations. This is significant because if the experience of Cavender (1992) and Mardones (1993) can be extrapolated to the coal industry then coal projects will typically be undervalued.

Another characteristic of financial options is that options that are at or near the money have more value than those that are well out of the money and unlikely to ever be exercised (Davis 1996). In the case of a mining project Davis argues that this means that marginal mining operations should, where the exercise option is at or near the money, have a higher option value than a more stable mining operation that is unlikely to have any options exercised. An opportunity to test this hypothesis could currently be made by comparing mining operation values across commodities. Large bulk mining operations such as coal and Iron Ore it is argued should have potentially lower option premiums since they are often much longer lived often with mine lives over twenty years and with relatively stable prices
in real terms. Projects with typically lower mine lives and relatively high price fluctuations such as gold and nickel should have a much higher option premium due to the relatively shorter mine lives and price volatility.

In his discussion on whether option premiums in mineral asset pricing is important, Davis (1996) discusses the main issues related to RO valuations being related to the comprehensiveness of the managerial flexibility modelled, and methodological issues. Davis (1996) sees the most significant issue that RO neglects as being associated with the exclusive option that companies hold over future projects. This he argues is the managerial ability to generate additional positive NPV assets through the skills and resources held by the firm. A coal mine in the Hunter Valley holding mining leases holds for example, the exclusive right but not obligation to develop these projects using their resources. These options should be valued but appear to be ignored within the literature.

Building on the theme previously presented by Davis derived from independent skills and resources held by the firm, it is argued here that the strategic or competitive advantage of a firm over its competitors also needs to be considered. Within the literature there only appeared to be one acknowledgement of this potential source of value and is provided by Del Sol and Ghemawat (1998) who argue that the most significant problem associated with traditional DCF analysis is that it is commonly applied without regard for strategic competition. They argue for a three pronged framework that needs to be considered for any DCF analysis which focuses on competitive dynamics, sustainability and the option to
revise the initial investment plan. It is argued here, that although presented as a problem associated with traditional DCF analysis these issues are also common to RO valuations. The way that this problem would manifest itself in the RO valuation methodology would be where there is an option to suspend or wait to invest in a project based on price for example. However, as Del Sol and Ghemawat (1999) point out in their analysis of DCF, waiting to invest could allow a competitor to exercise the option to proceed before management acts. Therefore it is argued that the RO model fails to recognise that competition for a limited number of business opportunities can make waiting to invest just as risky as investing immediately which could in fact be eroding value. One potential source of further research in this area could be to investigate the application of RO in the context of strategic considerations.

Another potential problem with RO valuations is the simplicity by which uncertainty has been modelled. The risk associated with mineral projects is often more than just lost production for example. An environmental catastrophe has significantly more downside than a competitor taking a strategic stake in project as discussed previously. In this instance the RO methodology is probably overestimating the value of the project since this risk is not valued; however, this is an argument that could also be levelled at the NPV method.

A methodological issue discussed by Davis (1996) deals with the fact that the RO methodology assumes that management will always exercise their option at the optimum time. However, as previously discussed in relation to strategy this is probably not the case.
In the real world, it is most likely that strategic considerations are taken into account by rational managers and as such projects would be likely to open or close in response to factors such as competitor actions rather than solely on factors such as commodity price alone.

A review of the literature revealed a limited number of instances where RO valuation methodologies were applied to discrete projects. One example is that presented by Lemelin, Sabour et al. (2006) who discuss the application in valuing Mine 2 at Raglan. This mine they argue consists of numerous mineralised zones that can produce numerous payable metals and as such complicates the options available to management. They overcame this complexity by applying a least squares Monte Carlo methodology to the RO valuation which is the first time this has been done in the literature. This is an important case study in that it provides an example of how a commonly used Monte Carlo Method is applied to derive a RO model and is a deviation away from previous complex mathematical models. As part of their analysis they also performed traditional NPV analysis on the same deposits for the same periods. They found that the NPV underestimated the value of the mine in relation to the RO methodology by 14% a variance that they attributed to the managerial flexibility. This is consistent with the findings of other workers like Mardones (1993).

Another significant aspect of the study valuing Mine 2 at Raglan is their commentary on how they believe that the complexity of options pricing has traditionally been a deterrent
for many would be practitioners despite the acknowledged potential benefits that could be gained. They argue that the method that they forward can provide a practical valuation tool that can enhance RO for mining companies. It is the purpose of this study to also present a practical tool that can easily be implemented in an operational context.

One criticism of Lemelin, Sabour et al.’s (2006) paper is that they do not discuss the problems associated with RO valuations in general and if their method acts to reduce or counteract any of these problems. One potential area they could have discussed in relation to issues with RO valuations has to do with the previously discussed problem of RO valuations only being able to deal adequately with a few discrete options because of the complexity of the mathematics involved. However, since the Monte Carlo methodology they employ is based more on being able to run simulations with considerable computing power, perhaps some of these limitations may have been overcome. This is potentially an area of further study if this technique is applied elsewhere.

Another potential criticism of this study is the fact that they make no real attempt to validate the transfer of their findings across to other commodities. The reader is left to consider if it is valid to transfer their finding to other commodities such as coal. This criticism is one that cannot just be levelled at this study as this omission was consistent across the literature.
Another study was done by Mardones (1993) who studied a Chilean Copper mine. His findings were consistent with those of Lemelin, Sabour *et al.* (2006) in that he argues that NPV analysis performed on the project for the same period also produced lower value than that of the corresponding RO valuations. McCarthy and Monkhouse (2002) took a different approach in their study of a closed copper mine. They investigated the merit of using the methodology as a decision tool rather than a valuation tool in making the decision as to whether or not the mine should be closed or opened. They found that the RO method was in line with management intuition to keep the mine closed but at odds with the NPV method that argued the mine should be reopened in a year. These findings are at odds with the rest of the literature that found the NPV methodology usually undervalued projects.

The lack of case studies, despite the well-developed theoretical literature, highlight the need for further practical research to be performed in this area. Within the coal industry for example, there is significant scope to value mining projects using the RO methodology. This review agrees with the position taken by various authors who discuss complete and incomplete markets (Smith and Nau 1995; Smith and McCardle 1998; Smith and McCardle 1999; Smith and Detlof von 2004) and who argue for options style analysis to overcome the inherent weaknesses in evaluating long lived mining projects using the popular DCF approach.

All of the literature surveyed in this study predominantly undertook analysis from a positivist viewpoint with most studies adopting a quantitative modelling approach.
This study will align itself with a functionalist (Hassard 1991), postivist/postpostivist (Mackenzie and Knipe 2006) approach that looks objectively at a set of quantitative models derived from a mining operation with no consideration for the political or social interactions both within and external to the case study. The study does, however, recognise the potential impact that viewing the data from different perspectives could have, as demonstrated by Hassard (1991) pointing to the fact that this area could prove fruitful as an area for further research in the controversy surrounding alternative valuation methodologies (Brennan and Schwartz 1985).

As identified by numerous authors the currently accepted NPV method tends to undervalue mineral projects by not valuing managerial flexibility and decision making. A method that more accurately values coal mines and coal mining companies will potentially be attractive to management since it should more accurately reflect the true value of the project ignoring any external motivations as previously discussed. This research project would also addresses the shortcoming of the existing literature on mineral valuations in that most discussion is centred around metals projects with no evidence currently forwarded to suggest that the techniques can be applied to other commodities like the coal industry. As well as comparing valuations derived from different methodologies like RO and NPV this study will make comparisons to the findings from other commodities and discuss the validity of transferring the results to other mineral groups such as iron ore for example.
The RO approach is argued to be a viable alternative to the historical valuation methodologies such as the Hotelling Principle and the widely used NPV method in mineral project valuations. The NPV methodology is shown to significantly undervalue projects a shortcoming that the RO method attempts to overcome. This paper acknowledges the merit in the RO approach and proposes that a research project that values coal mines in the Hunter Valley would be of significant benefit to the coal mining industry as it could provide evidence that valuations using this approach are a viable option for project valuation of coal mining projects.
Chapter 2 – Methodology

Introduction
The chief aim of this chapter is to present an alternative valuation methodology, Real
Options (RO), to the traditional capital budgeting techniques used in the coal industry. This
study will value an operating mine using only publically available information using
conventional DCF/NPV methods and ROA using two accepted methods the Binomial Lattice
and the Black and Scholes closed form numerical solution methodologies. The results
derived from using the alternative method can then be compared with results derived using
conventional valuation methods.

The previous literature review showed that the evaluation of natural resource projects is
controversial with various authors presenting methodologies to deal with risky cash flows
associated with mining projects (Brennan and Schwartz 1985; McDonald and Siegel 1986;
Trigeorgis 1986; Guzman 1991; Jacoby and Laughton 1992; Smith and Nau 1995; Smith and
McCardle 1998; Cairns and Davis 1998a; Dias 2004; Trigeorgis 2005; Guj and Garzon 2007;
Fan and Zhu 2010). Standard capital budgeting processes these authors argue bias against
long-lived investments such as mines and do not account for other intangible aspects such
as business strategy or managerial flexibility (Tourinho 1979; Trigeorgis 1993b). In an
attempt to ascertain the validity of traditional valuation methods and the ability of an
alternative approach to valuation of these projects, this project asks several key questions,
namely;

1. Do conventional valuation models undervalue coal projects?
2. Can RO analysis be practically applied to Open-Cut coal mining projects?
3. How valid is it to apply the results from this study to other mining projects?

Whilst the Literature Review presented in Chapter 1 shows a strong theoretical base for the
application of alternative valuation methodologies for mining projects, the link binding this
theory to coal mining practice is not well developed, a fact that has led to a gap in the
literature base and to which this project attempts to address. To address this gap a case
study methodology is adopted whereby a mining operation in the Hunter Valley is analysed
using publically available information.

The Case Study approach adopted in this research aims to utilise a detailed and intensive
analysis of a single mine and compare it to the results from other RO studies within the
mining valuation literature. This single case approach has limitations as discussed by
Bryman and Bell (2007). One limitation they discuss applicable to this study concerns the
external validity and generalisation of the case study research findings. They argue that it is
important to recognise that it is not possible to make sweeping generalisations from
findings of a single case study. They argue a case study is a sample of one and it is not valid
to draw conclusions from such a small sample size. The authors do however, make the
point that generalisations can be made on a theoretical base, whereby propositions can be
explored through the generation of concepts attained in the development of detailed case
study analysis. Lemelin, Sabour et al (2006) for example, in their evaluation of Real options
at the Raglan Mine 2 in Canada use the case study approach to generate concepts and
propositions that they argue could apply to similar mining projects. They do not, however,
make the proposition that based on their findings that their methodology is valid at all
mines. Rather they make the point that their methodology demonstrates how Real Options Analysis can be efficiently used to deal with management responses to uncertain future outcomes. This study will adopt a similar approach and attempt to develop concepts and explore potential generalisations that are presented in the case studies and explore the potential for application to other mining projects. As such the purpose of the case study approach in this study is to demonstrate the feasibility, viability and advantages of using the RO approach in a coal mining valuation problem.

**Traditional Financial Valuations**

NPV, IRR and Payback Period are the most popular evaluation techniques used in capital budgeting within Australia (Truong, Partington et al. 2008). Discounting is done using a weighted average cost of capital (WACC) (Ross, Westerfield et al. 1996) which is assumed constant for the life of the project and is usually based on target weights for debt and equity. In Australia The CAPM is the most popular asset pricing model (Truong, Partington et al. 2008) which is in line with the British (Arnold and Hatzopoulos 2000) and American (Graham and Harvey 2001) evidence. This reliance on traditional valuation methods by business is significant because it means any results obtained using alternative methods will be contentious. Hence a detailed understanding of the traditional and alternative cases will need to be made in order to argue the strengths and weaknesses of the differing techniques.
Traditional Capital Budgeting
A traditional capital budgeting process is composed of calculating the expected cash flows of a project discounted at an appropriate cost of capital. Studies of Australian (Truong, Partington et al. 2008), British (Arnold and Hatzopoulos 2000) and American firms (Graham and Harvey 2001) confirm this assertion. Typically within the corporate finance (Bodie, Ariff et al. 2007) and Mineral Economics literature (Brennan and Schwartz 1985; Guj and Garzon 2007) this is done using the Capital Asset Pricing Model (CAPM). This study will construct a cash flow model of the case study, discounting the cash flows with a calculated Weighted Average Cost Of Capital (WACC) for the owner of the mine, Xstrata PLC.

Mine Cash Flow Modelling
This study attempts to build on work presented in the literature (Shafiee, Topal et al. 2009 a; Shafiee, Topal et al. 2009 b) that describes how costs can effectively be built into the valuation models of mining projects. This study will construct a detailed cash flow model, the process of which is described below.

In order to construct a meaningful cash flow model of a mining project, a mine plan is firstly constructed which details the physical quantities mined in a given time period. It is not the purpose of this study to undertake a detailed analysis of the mine planning process, however, since the mine plan drives the cost profile of a mining operation an overview of the mine planning process is warranted. For a more detailed discussion of mine planning the reader is referred to (Hustrulid and Kuchta 2006).
The first step in constructing a detailed mine plan is to define the resource using raw geological data derived from drilling and detailed geological modelling. Using production rates from the available equipment, simulations of various extraction plans are undertaken using specialised mine planning software \(^1\). Outputs from the simulations are physical quantities, qualities of coal, equipment usage, labour and infrastructure requirements. The mine plan presented can then be costed along functional criteria. Typically, an open cut coal mine is costed in broad terms in the following groupings:

- Land clearing
- Topsoil removal
- Drilling
- Blasting
- Load haul and dump
- Benefaction
- Rail to port
- Ship loading

The mine cost model developed in this case study will be grouped in these main cost centres.

Guzman (1991) and Guj and Garzon (2007) make the point that most mining projects are long lived, often for periods of ten years or more and as such they could be expected to

\(^1\)Runge’s XPAC Open Cut Design software module is a simple, easy-to-use, design and reserving system for open cut coal deposits, and open cut deposit where the geology has been modelled with grids. For a more detailed discussion concerning it function and capability go to; http://www.runge.com/files/XPAC%20Open%20Cut%20Fact%20Sheet%20_AUST_LOW%20RES.pdf
experience many fluctuations in the real costs relating to mining, however, like much of the literature (Sabol 1999; Dimitrakopoulos and Abdel Sabour 2007), they focus on the stochastic nature of commodity prices but ignore the probabilistic nature of costs. This study accounts for the probabilistic nature of future costs by implementing a Geometric Brownian Motion (GBM) model for input items like fuel, labour, tyres, explosives and replacement mining equipment. Appendix 1 provides the full cash flow model in MS Excel for the Case Study utilising GBM to estimate future costs.

Geometric Brownian Motion (GBM)
GBM is an accepted methodology used within the mining valuation literature to model future commodity prices (Brennan and Schwartz 1985; Schwartz 1997; Cortazar and Schwartz 1998; Cortazar, Schwartz et al. 2001; Gonzalo Cortazar and Reyes 2001). There is however, little evidence within the literature to account for the expected variability of costs during the life of mining projects. This study will assume a log normal distribution of costs, enabling GBM modelling of costs similar to price modelling which is well documented in the literature (Nigel 2010). In general terms the cost change process described by GBM is described by a drift effect (non-random) and a volatility effect (random). Mathematically this is shown in Equation 2.

$$\Delta S = \mu S \Delta t + \sigma S \varepsilon \sqrt{\Delta t}$$

Equation 2 Geometric Brownian Motion

Where $S$ = Current cost
\[ \mu S \Delta t \] = Mean or Drift

\[ \sigma S \epsilon \sqrt{\Delta t} \] = Standard Deviation

In order to simulate future costs using GBM, Equation 2 shows that three key pieces of information are required, the current cost, the expected drift of costs and the standard deviation of costs (see the Brownian Motion tab in Appendix 1 for the Excel Implementation of the model). The drift and standard deviation parameters will be calculated from historical values derived from the Australian Bureau of Statistics (ABS), Materials Used in Coal Mining Price Index \(^2\) which measures the price changes in raw input prices in the ongoing mining process. This study considers this index as a good proxy for the costs associated with mining and is in line with industry practice.

**Capital Asset Pricing Model (CAPM)**

The corporate finance literature typically proposes a model for capital budgeting in an uncertain environment that provides an expected return for an asset for a given amount of risk (Sharpe 1964; Lintner 1965; Ross, Westerfield et al. 1996). The CAPM argues that the appropriate discount rate that should be used to discount expected future risky cash flows, as seen in Equation 3, is calculated as presented in Equation 4, and accounts for an asset sensitivity to non-diversifiaible risk represented by Beta.

---

\[ NPV = \sum_{t=1}^{T} \frac{E(C_t)}{(1+r)^t} \]

**Equation 3 Net Present Value of future cash flows**

Where

\( E(C_t) = \) the expected cash flow at time \( t \)

\( r = \) the risk adjusted discount rate

\[ E(r) = r_f + \beta[E(r_m) - r_f] \]

**Equation 4 Capital Asset Pricing Model**

Where

\( E(r) = \) the expected rate of return

\( r_f = \) risk free rate

\( \beta = \) Beta

\( E(r_m) = \) Expected return on the market portfolio

\[ \beta_i = \frac{\text{Cov}(R_i, R_m)}{\sigma^2(R_m)} \]

**Equation 5 Beta of an asset**

Where

\( \beta_i = \) Beta

\( \text{Cov}(R_i, R_m) = \) the covariance of the asset \( R_i \) and the market \( R_m \)

\( \sigma^2(R_m) = \) the variance of the market.
The main characteristics of the CAPM as described by Equations 4 and 5 are that the appropriate discount rate is composed of two parts, a riskless component ($r_f$) and a risky component ($\beta[E(r_m) - r_f]$). From Equation 4 it is also apparent that the higher the expected risk adjusted component the higher the expected return from the investment. $\beta$ is a relative measure of volatility of the asset in question in relation to the market portfolio (see equation 5) and as such a beta of 1 implies average market risk. A beta below 1 is less than market risk and above 1 is above market risk.

Another characteristic of the CAPM model described in Equation 4 is that it plots as a straight line (Figure 1), where $r_f$ is the y intercept and $\beta$ is the slope of the line. This line is known as the security market line (SML) (Ross, Westerfield et al. 1996). Assets that plot above this line are undervalued since their return is higher than predicted under CAPM, conversely assets that plot below the line are overvalued since their return is lower than expected for a given level of risk.
Figure 1 The Security Market Line postulating a linear relationship between the returns from an individual asset $r_i$ and returns from the market $r_m$ (Trigeorgis 1996).

CAPM provides the return that any asset must return to compensate for its risk. It argues that any project that lies above the SML will add value to the company. Alternatively any project that plots below the SML falls short of the required return to add value to the company and any project plotting on the SML is marginal. This study will use the FTSE 100 and ASX200 as proxies for the London and Australian stock markets respectively and value the case study mine using CAPM derived from publically available information. This approach is the generally accepted method within the financial literature, however it is acknowledged, that there is also debate as to whether these proxies are true representations of the market portfolio (Roll 1977; Lewellen and Nagel 2006).

Implicit in using CAPM in this study is that the following assumptions are accepted when using CAPM to value an asset (Trigeorgis 1996).

- Investors are rational and have the rational aim of maximising utility
• All portfolios are efficiently diversified
• Investors have the same expectations of expected values, variances and covariance’s
• Investors can borrow or lend at the risk free rate
• There are no costs associated with transactions
• Markets are efficient
• Assets are able to be traded at will
• Investors are price takers

The required rate of return described by the return derived from the CAPM is known as the cost of equity capital, however the capital structure of most companies is such that they also have a component of their capital makeup as debt. The cost of debt for companies is generally well known and is achieved by a company’s credit worthiness. The cost of capital for a firm is therefore a combination of both its cost of equity and its cost of debt. This is expressed as:

$$WACC = \frac{S}{S+B} \times r_s + \frac{B}{S+B} \times r_B \times (1 - T_c)$$

**Equation 6** The Weighted Average Cost of Capital Source (Ross, Westerfield et al. 1996)

Where

\[
WACC = \text{Weighted Average Cost of Capital} \\
S = \text{Equity Capital} \\
B = \text{Debt} \\
r_s = \text{Required return on equity}
\]
For NPV calculations it is the WACC as described in Equation 6 that is used as the discount rate most typically (Truong, Partington et al. 2008). This WACC uses the CAPM to derive the cost of equity and derives its cost of debt from its borrowing rate. Truong, Partington et al (2008) in a study of Australian companies found that CAPM was the most widely used model which is consistent with earlier international studies (Gitman and Forrester 1977; Gitman and Mercurio 1982; Graham and Harvey 2001; Jagannathan and Meier 2002; Taheri, Irannajad et al. 2009) who found similar results in North American firms. Because of its industry acceptance the WACC is used in this study as the appropriate discount factor for future cash flows when constructing an NPV based on Equation 3.

Despite this acceptance of CAPM by mainstream businesses there are several arguments against its use in long lived resource projects. The first argument against CAPM is the use of a discount rate derived from the CAPM, is that the model itself is a single period model (Ross, Westerfield et al. 1996; Trigeorgis 1996; Bodie, Ariff et al. 2007). The single period model assumes that the beta and risk free rate used when calculating the WACC are constant for the total NPV analysis, however, since most mining projects are multi period projects with associated multi period cash flows this becomes problematic since it has been shown that beta and the risk free rate actually vary over time (Trigeorgis 1996). The single period nature of CAPM does not therefore make any allowance for shifting parameters such as Beta or the Risk free rate over time.
Ross, Westerfield et al.(1996) discusses the notion of a non-static beta in the context of the volatility of the underlying industry and the potential to reduce the volatility of beta by using an industry beta rather than an individual company beta because of the large random variation associated with volatile industries. They argue that a portfolio of companies from a similar industry would be a better reflection of the riskiness of a single company because it would reduce the variance associated with random events in the more volatile industries like mining. In the case of a coal company like Xstrata Coal, the beta it would use in a CAPM calculation would be an industry average across a portfolio of coal mining companies. A problem with this approach, however, is that many mining companies are diversified across different commodities and pure coal mining are limited in their number. It would not be valid for example to use BHP in such a portfolio and only pure coal mining companies could be used if an industry coal beta was being derived. To address this issue some authors have suggested a predicted beta rather than one based on historical data only (Rosenberg and Guy 1976). This study argues for and constructs a portfolio from ASX listed pure open cut coal mining companies who will be exposed to the same public and private risks (Smith and Nau 1995) as those experienced in the case study, the merits of which are developed further later in the study.

Another significant issue often cited with traditional NPV is that there is no accounting for managerial flexibility during the course of the project (Smith and Nau 1995; Davis 1996; Trigeorgis 1996; Cortazar and Casassus 1998; Laughton 1998; Paulis and Sick 1999; Smith and McCardle 1999; Slade 2001; Samis 2001; Yeo and Qiu 2003; Borison 2005; Sabour and
Poulin 2006; Guerrero 2007; Guj and Garzon 2007). This is considered a major problem with valuing mining projects using traditional capital budgeting techniques since no mining manager would continue down an operating path that is ruinous or suboptimal. In reality, risks and uncertainty are a significant component of the mining process and as such the stochastic nature of the mining process seems to be at odds with the static deterministic nature of conventional valuation methods.

**Options Analysis**
Real Options analysis of mining assets (Brennan and Schwartz 1985; Ken 2007; Shafiee, Topal et al. 2009 a; Martinez 2011) represents a fundamental paradigm shift in the evaluation of mining assets but addresses the problems previously discussed with traditional methods. The analysis and methodology of real operating options is a significant departure from the conventional DCF/NPV methods given that it takes into account the uncertainty associated with cash flows derived from future mining activities.

Financial Options valuation methodologies are widely accepted (Hull 2008) and it is within this accepted methodological frameworks that the probabilistic nature of coal mining can be evaluated more thoroughly than with the conventional methods. This section of the Methodology Chapter will introduce the valuation methodology of financial options and then discuss how this methodology can be transferred to real asset like coal mines.
Financial Options
Derivatives such as options and futures contracts are securities which derive their price from another security. These derivatives are also called contingent claims because their payoff is contingent on the price of another security (Bodie, Ariff et al. 2007; Hull 2008). The holder of an option has the right but not the obligation to do something and pays the option premium to purchase this option. For example, an option contract may allow its owner to have the right but not the obligation to purchase 10,000 shares of Xstrata PLC shares at a price of $10 per share within three months of the date of the contract. If the shares go to $12 the owner may exercise the option and make a profit equal to $12 less $10, that is, $2. Exercising the option means the option will be taken up, however, if the price of the underlying share was less than $10 the buyer would simply purchase the shares in the market for less, so the owner would not exercise the option. Because there is no requirement for the option holder to exercise it, they effectively have a floor on their losses meaning the holder of the option cannot make a loss with the option contract apart from the cost of the option contract itself.

The contracted price of the option is called the strike price and the length of the option is called the option maturity. If the share price is greater than the strike price the option is said to be in the money, and if it is below the asset price it is out of the money. An option that gives the owner the right to buy a share at a particular strike price is a call option, whereas the option to sell at a particular price is a put option. An owner of an option is said to hold a long position and the writer is said to have a short position. For every long position there needs to be a corresponding short position.
Another fundamental of options finance is the timing of when the option can be exercised. According to Hull (2008) there are two main types of options, European and American. An American option can be exercised any time prior to its expiration period whereas; a European option can only be exercised at its expiration date.

Having already established that the option provides the right but not the obligation to buy or sell an asset depending on whether the owner has a long or short position and given the strike price of the option, the holder can have some certainty over the outcome of the transaction. The option holder will know the payoff if they elect to execute the option. Hull (2008) provides a detailed discussion on the payoff characteristics of options and the various strategies that can be employed to ensure certain payoffs. The payoffs for positions held are shown in Equations 7 to Equation 10.

Long Call: \( \text{Payoff} = \max (S-K, 0) \) \hspace{1cm} \text{Equation 7}

Short Call: \( \text{Payoff} = -\max(S-K, 0) \) \hspace{1cm} \text{Equation 8}

Long Put: \( \text{Payoff} = \max(K-S, 0) \) \hspace{1cm} \text{Equation 9}

Short Put: \( \text{Payoff} = -\max(K-S, 0) \) \hspace{1cm} \text{Equation 10}

Where: \( K = \) Strike price

\( S = \) Asset price
Figure 2, adapted from Hull (2008) graphically shows various option positions. The payoff of the option is the value of the option at maturity of the position held. Before this maturity position is reached, the option has value even if it out of the money (e.g. for a long call $K<S$, long put $K>S$) because there is still time for the underlying asset to increase in price and the payoff to increase. It is now apparent that time and underlying asset price are drivers of option price, however, there are other factors that drive the price of options.

There are five key variables that impact the price of the option (Trigeorgis 1996; Hull 2008). These are:

1. Price of the underlying asset ($S$)
2. The Strike Price ($K$)
3. Time to maturity ($T$)
4. Volatility ($\sigma$)
5. Risk free rate ($r$)
Figure 2 Payoff from different option positions as the asset price (S) increases. (a) Long call option, (b) Short call option, (c) Long put option, (d) short put option. S represents the underlying asset price and K is the strike price. After Hull (2008) pg 190.

The underlying strike price (contracted purchase price) impacts the payoff of the option because as the value of the strike price increases the payoff from the option decreases. Volatility also plays a significant role in the value of the option and is described by the standard deviation of the price changes of the underlying asset. The volatility used in pricing the option is the anticipated volatility until maturity of the option and is typically derived from either historical prices or implied from the current market price of the option. The higher the volatility the higher the option price. Restated this means the higher the uncertainty surrounding the price of an asset the higher the value of the option. The reason
for this increase in value with uncertainty is because as the risk of the underlying asset increases the holder of the option puts a floor on their loses meaning they are exposed to less risk (Crundwell 2008).

Hull (2008) presents a discussion on the sensitivity of the price of options to change in the underlying parameters of the security being valued. Collectively these measures are called the Greeks and can be used to describe risk sensitivity, measures and hedge parameters. Common Greeks include;

- Delta, which measures the rate of change of option value with respect to changes in the underlying asset's price.
- Vega, which measures the price relative to the volatility of the underlying asset.
- Theta, which measures sensitivity relative to time.
- Rho, which measures sensitivity to the interest rate.

Other Greeks include Gamma, Vanna, Vomma, Charm, Veta, Vera

Real Options
Real options apply the theory of financial options to physical (real) assets. There are, however, key differences that need to be considered (Mun 2006) in any analysis. Real options for example, are generally long lived, whereas, financial options are short lived, typically three months or less. The underlying asset of a financial asset is the stock price, whereas, it is a company project in real options that is exposed to a multitude of project and market specific risks (Smith and Nau 1995). Finally financial options are traded in well

3 See Hull (2008), Ch 15 for a more detailed description of the Greeks.
established derivatives markets, whereas, real options are not traded at all. Table 1 shows a comparison between financial and real options.

Table 1 A comparison of Financial and Real Options after (Lazo, Pacheco et al. 2009)

<table>
<thead>
<tr>
<th>Financial Option</th>
<th>Real Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option Exercise price</td>
<td>Project investment cost</td>
</tr>
<tr>
<td>Underlying asset: Stock</td>
<td>Project</td>
</tr>
<tr>
<td>Stock Return</td>
<td>Project return</td>
</tr>
<tr>
<td>Stock price volatility</td>
<td>Project value volatility</td>
</tr>
<tr>
<td>Stock dividend flow</td>
<td>Project net cash flow</td>
</tr>
<tr>
<td>Time to expiration of financial option</td>
<td>Time to expiration of investment opportunity</td>
</tr>
<tr>
<td>Risk free interest rate</td>
<td>Risk-free interest rate</td>
</tr>
</tbody>
</table>

In terms of NPV the options approach adds a premium to the conventionally derived NPV using traditional DCF (Davis 1996). This is expressed as:

\[ NPV_{RO} = NPV_{DCF} + \text{Option value} \]  \[\text{Equation 11}\]

Other authors describe this option value as the value of flexibility (Mun 2002; Crundwell 2008) arguing that it is the strategic value of management's ability to change the course of operation from the initial course described using a conventional NPV.
Throughout the mineral valuation literature there are many examples of real options.

Within an open cut mining context this study argues the main options available to management are;

1. The option to delay
2. The option to expand
3. The option to contract
4. The option to shutdown
5. The option to switch

**The option to delay (Wait)**
The option to wait provides management with the right but not the obligation to make the investment in the next period. Under this scenario management will only invest if the value of the project in the next period is higher than the investment required to exercise the option (Trigeorgis 1996). This is analogous to a long call option position with a positive payoff when $S-K > 0$.

The option to wait is particularly relevant to the mining industry as it accurately describes exploration projects. In the situation where an area has been drilled and a resource defined, management has the option to either develop or wait. The option is exercised when they begin mining. Conventional NPV theory argues that if a project has a positive NPV it should be undertaken by the firm since it creates value thereby maximise the worth
of the firm (Bodie, Ariff et al. 2007), however experience shows it is often management’s decision not to exercise their option to develop the project despite having a positive NPV.

The option to wait scenario explains why positive NPV projects are not always immediately exercised. Management will often argue for an uncertain future and a desire to see how the business environment will develop in the future before committing to a project, even with a positive NPV. This is especially relevant to commodity driven projects like coal mines with highly volatile markets and long investment horizons. Rather than exercising the option deferring the project and keeping the call option open has value. This deferral has more value when the uncertainty is high and is in line with the previous assertion in the financial options discussion that options have greater value with higher uncertainty.

**The option to Expand**

Once a project has been established, management has the flexibility to expand production by a certain percentage if desired. This operating option is analogous to a call option and has a positive payoff when \( S-K > 0 \). In this instance the cost associated with the expansion can be viewed as the option premium. This option is usually exercised if the market conditions turn out favourable.

Within the mining context this is a relevant option that describes management’s flexibility to ramp up production.
The Option To Contract
If business conditions turn out to be unfavourable for a project, management can exercise their option to contract. This option allows them to reduce their loses in an unfavourable environment and is analogous to a put option. It's exercise price is described in Equation 9 with any costs associated with the reduction in production representing the strike price. It's payoff is positive when K-S>0.

In a mining context this option describes management's ability to reduce the scale of production. It may represent for example, reducing production by 30%, and would be exercised if the price of the commodity being mined dropped below some threshold value.

The option to Shut Down
Trigeorgis (1996) and Lazo et al. (2009) discuss two types of shut down options. The first type of shut down option describes where the project is abandoned for the salvage value of plant and equipment. In this situation they are abandoning the project because both fixed and operating costs are greater than the revenue of the project. The second shutdown option is a temporary one and describes the option where production is temporarily shut down at any period during the projects life. Lazo et al. (2009) discuss how this option is exercised when management decide that revenues are not sufficient to cover variable operating costs during this period. In this manner the flexibility to operate, (or not), is seen as a call option to acquire that periods revenue by paying the variable costs of operating as the exercise price. In a mining context production could be ceased with the mine put on care and maintenance, having only to pay any costs associated with care and maintenance activities.
**The Option to Switch**

The option to switch describes management’s ability to switch between products allowing the maximum value in terms of its current use of resources or of its best alternative. The option is therefore viewed as the current use value plus a put option on its value with an exercise price equal to the alternative. In a mining environment this option would add value if there was an option to switch production between products like thermal or semi soft coal or lump or fines for iron ore. The exercise price would be equal to a put option on any cost associated with the switch, for example greater benefaction costs.

**The Valuation of Financial Options**

The general concept enabling the valuation of options is that a portfolio can be constructed consisting of buying shares of an asset and borrowing against these shares at the riskless rate so as to exactly replicate the return of the options, independent of the price of the stock (Trigeorgis 2005). Since the option and the equivalent portfolio provide the same future returns if levered correctly, to avoid risk-free arbitrage, the option and the portfolio must sell for the same price. This assumption of no arbitrage allows the option price to be determined by constructing the equivalent replicating portfolio and understanding is price.

There are several methods available to value options and within each of these methods there are different sub methods to calculate the value (Black and Scholes 1973; Merton 1973; Brennan and Schwartz 1977; Cox, Ross et al. 1979; Trigeorgis 1996; Hull 2008). Partial differential equation methods involve mathematical solutions with the most famous being
that presented by Black and Scholes (1973). These solutions can become complex when multiple sources of uncertainty relating to the underlying asset are encountered. To overcome some of the mathematical complexity lattices can be used. This study will use lattices and the Black and Scholes method to value options. For an in depth discussion of financial options the reader is directed to Hull (2008).

All valuation methodologies rely on the following two assumptions;

1. Arbitrage free markets.
2. Risk neutral probabilities.

Arbitrage free markets assume that the law of one price (Lamont and Thaler 2003). This law argues that assets with the same cash flows must have the same price otherwise an arbitrage opportunity would exist where assets could be bought or sold in one market and traded in another for a risk free profit (Fama and French 1992). Risk neutral valuation operates under the assumption arbitrage free markets and argues that an investor will not care whether they hold the derivative or asset since their payoff will be the same and as such any cash flows need only be discounted using the risk free rate.

Lattice valuations
There are several different types of lattices described in the literature for valuing options including binomial, trinomial and quadrinomial lattices. This study will use the binomial lattice in which the original value of the asset either goes up or down. It is an accepted

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method of option valuation in the literature (Smith and Nau 1995; Jin-feng, Yan et al. 2010) because of its simplicity (Smith and McCardle 1998). Other types of lattices include trinomial and quadrinomial lattices in which there can be multiple sources of up or down movements. The downside to these trinomial and quadrinomial alternative lattices is their complexity.

According to Hull (2008), binomial lattices can be used to solve option values using two methods. The first method utilises risk neutral probabilities whilst the second method uses a market replicating portfolio approach. The binomial lattice methodology utilising risk neutral probabilities involves adjusting the cash flows throughout the lattice with risk-neutral probabilities and discounting them at the risk free rate. This is the method used in this study.

Hull (2008) argues that Binomial trees are the best method for valuing American Style options in a risk neutral world. This dissertation will apply the Binomial Lattice methodology to value options and will follow the conventions described by Hull (2008). He argues that in a small interval of time (δt) a stock price will move up by a proportional amount u or down by a proportional amount d. This is represented graphically in Figure 3.
If the current price of an asset $S_0$ is known then the value of all time states can be calculated using the binomial lattice shown in Figure 4 below. At time 1 there are two possible outcomes $S_0u$ and $S_0d$, at time 2 there are three possible outcomes $S_0u^2$, $S_0$ and $S_0d^2$ and so forth for each time period.

Figure 3 Source Hull (2008)

Figure 4 A Binomial tree for an asset. Source (Crundwell 2008)
Because the value of the options are known at the end of the tree the value of preceding options can be calculated by discounting at the risk free rate under the risk neutral assumption.

The value $S$ at Time 0, is assumed to be the conventional NPV. This it is assumed is the value of the project without deviation. The riskiness of this NPV is then accounted for in $t = 1$ in Figure 5 by applying the up ($u$) factor from Equation 12 and the down ($d$) factor from Equation 13.

$$u = e^{\sqrt{dt}}$$

**Equation 12.** The risk neutral up factor.

$$d = \frac{1}{u} = e^{-\sqrt{dt}}$$

**Equation 13.** The risk neutral down factor

$$p = \frac{a - d}{u - d}$$

**Equation 14** The risk neutral probability

$$a = e^{rst}$$

**Equation 15** The risk neutral growth factor

In the case where $S = 100$, $u = 1.4$ and $d = 0.6$ the value at $S_u$ would be 140 and $S_d$ would be 60. Each subsequent node is calculated until all the nodes have an associated risk neutral cash flow. Once the terminal cash flows have been calculated, in this case at $t=5$, then it can
be assumed that the option must be exercised. At this point the strike price (K) is accounted for as previously discussed. In the case of a long call position at \( S_u^5 \) in Figure 5 the payoff (value) of the call option would be \( \text{Max} (S_u^5 - K, 0) \). Each terminal node is calculated in the same fashion. Once all the terminal nodes are calculated the option values are rolled back using the process of backwards induction (Hull, 2008). Because a risk neutral world is assumed the process involves discounting the option payoff at the risk free rate. This is done using;

\[
 f = e^{-r \Delta t} (pf_u + (1-p)f_d) \quad \text{Equation 16}
\]

Where:
- \( f \) = Option value at time \( t \)
- \( p \) = risk neutral probability factor (Equation 14)
- \( r \) = the risk free rate
- \( f_u \) = Option value at \( t+1 \) in the up state
- \( f_d \) = Option value at \( t+1 \) in the down state

In words this is simply the weighted average discounted option values from the next period. The method starts at maturity and rolls all points back until the time 0 option value is calculated.
Figure 5 Calculation of option values at terminal nodes for a long call option. Source (Crundwell 2008).

The discrete time steps used in this study will be one year but it is recognised that the lattice is only an approximation that converges on the solution provided by the partial differential equations (Chance 2008) developed by Black and Scholes (1973). Crundwell (2008) makes the point that as the time interval is reduced then the binomial approximation should converge on the partial differential equation solution. Hence it is argued that the binomial method provides an adequate solution to valuing the option.

The Black and Scholes Method of Valuing Options

According to Hull (2008) the Black and Scholes Model assumes that the underlying asset follows the Geometric Brownian Motion model previously discussed for the cost model
(Appendix 1). The formulae they derived for pricing European call and puts are presented below.

\[ \text{Call}(S, t) = N(d_1)S - N(d_2)Ke^{-r(T-t)} \]

**Equation 17.** The Value of call option using the Black and Scholes methodology

Where:

\[
d_1 = \frac{\ln S + \left( r + \frac{\sigma^2}{2} \right)(T-t)}{\sigma \sqrt{T-t}}
\]

\[
d_2 = \frac{\ln S + \left( r - \frac{\sigma^2}{2} \right)(T-t)}{\sigma \sqrt{T-t}} = d_1 \sigma \sqrt{T-t}
\]

The price of the corresponding put option based on parity arguments is

\[ \text{Put}(S, t) = Ke^{-r(T-t)} - S + \text{Call}(S, t) = N(-d_2)Ke^{-r(T-t)} - N(-d_1)S \]

**Equation 18.** The Value of put option using the Black and Scholes methodology

In both Equation 17 and 18 above:

- \( N(d_1) \) = The cumulative distribution function of a normal distribution.
- \( T-t \) = Time to maturity
- \( S \) = Current price of the asset
The up and down movements depicted in the lattice method previously described approximate the randomness of the share price movements which is assumed to follow a random walk profile as described by GBM. The benefit of this type of valuation is its simplicity in implementation once the input parameters have been derived. Its downside however, is its lack of intuition and the "black box" type of feeling it can produce in management. It is calculated in this study as a check against the binomial methodology.

The transfer of financial options theory to mine valuations

The most fundamental concepts behind the real options methodology of valuation are the assumption of arbitrage free, and complete markets (Trigeorgis 1986; Smith and Nau 1995; Samis, Davis et al. 2005). The assumption of arbitrage free markets argues that two different assets with the same cash flows must have the same price (Trigeorgis 1996; Hull 2008). In the case of real options the assumption is made where a portfolio is constructed that replicates the cash flows of the asset under consideration. Once the portfolio is constructed and weighted correctly, its value is assumed to be the same as the asset being valued (Smith and Nau 1995; Trigeorgis 1996; Borison 2005a). A rational investor it is argued would be indifferent between the cash flows generated by the portfolio or the project. Hence the risk free rate can be used to discount future cash flows back to present.

The assumption of complete markets argues for a securities market that is sufficiently complete so that a replicating portfolio can be built whose cash flows are perfectly
correlated with the asset being valued. However, this fundamental assumption, although used within most of the academic literature (Trigeorgis 1996; Trigeorgis 2005; Mun 2006; Zhang and Zou 2008; Mathews 2009) is often questioned and has led to competing methodologies for using real options (Borison 2005a; Borison 2005b).

Borison (2005a) in a review of the existing real options methodologies argues for five broad classifications of methods when using real options. These methodologies are;

1. The Classic approach
2. The Subjective approach
3. Marketed Asset Disclaimer (MAD) Approach
4. The Revised Classic Approach
5. The integrated Approach

The Classic Approach
The Classic approach uses a method that is a direct application of the theory of financial options assuming that real asset cash flows can be directly replicated with a portfolio derived from a complete market spanning and replicating the volatility and returns of the real world asset. The underlying value of the asset is argued to be the same as the constructed portfolio. For a specified maturity and strike price, the value of operating options can be calculated using either the closed form solution (Black and Scholes 1973) or the Binomial Lattice Method (Cox, Ross et al. 1979). The project volatility and expected
growth rate are therefore assumed to be the same as the portfolio. Historical parameters are estimated from the trading history of the portfolio and applied to either the closed form or binomial lattice valuation solution for the expected future risky cash flows.

The classic approach assumes that it is possible to construct a replicating portfolio and that this portfolio follows an expected return path described by GBM. This according to Borison (2005a) allows the use of the closed form and binomial lattice solutions and is extensively used throughout the literature in valuing resource projects using real options (Tourinho 1979; Paddock 1982; Brennan and Schwartz 1985; Dixit and Pindyck 1995; Davis 1996; Trigeorgis 1996; Copeland and Antikarov 2001; Lautier 2003; Shafiee, Topal et al. 2009 a; Jin-feng, Yan et al. 2010).

The Subjective Approach
The subjective approach is based on the same arguments of a replicating portfolio and no arbitrage opportunities. Borison (2005a) argues that under a subjective approach the assumptions of a complete market and liquidity of the market are more relaxed. The main difference between the classic and subjective approach lies in the mechanics of deriving the parameters used in the valuation. Borison (2005a) shows that typically the underlying asset and its volatility are subjectively estimated and provides an example where the volatility and expected return for an oil and gas project are estimated from industry experience rather than numerical analysis. This method has merit since it incorporates a degree of management experience into the valuation, however as Borison (2005a) argues, often no attempt is made to justify these subjective assessments as an appropriate proxy for market
traded values. Typically projects that argue for the underlying commodity replacing the replicating portfolio would be said to be using the subjective approach to RO valuation.

**The Marketed Asset Disclaimer (MAD)**
The Marketed Asset Disclaimer (MAD) unlike the classic and subjective approach is not based on the premise of a traded replicating portfolio whose characteristic parameters can be built into a options solution. Whereas the subjective approach (Borison 2005a) is argued to take a step away from the traditional replicating portfolio approach it is still broadly in line with the traditional method, the MAD approach in contrast completely steps away from traditional options valuation by not requiring a replicating portfolio at all. Rather, the MAD approach uses the NPV of the underlying project itself as the twin security (Copeland, Koller et al. 2000). This Copeland, Koller et al. (2000) argue is assumed to be the best unbiased estimate of the market value of the option where it is also a traded asset. They support their method by arguing that they make no assumptions stronger than those used in traditional NPV calculations. The only market derived data used is the WACC.

The implementation of the MAD approach is made by assuming that the underlying asset, in this case the NPV, follows the standard GBM path, hence, they argue for the use of binomial lattices to value the uncertainty of the asset. This method makes the assumption that the calculated NPV is the value of the asset as if it were traded now. The NPV is calculated using the normal cash flow (DCF/NPV) methodology using an appropriate WACC as the discount rate. Subjective estimates for volatility and expected growth are formed and then used to
build a risk neutral binomial lattice (based on GBM) that is used to value the option under consideration.

There are two main arguments cited against the use of the MAD approach. Firstly Borison (2005a) questions whether it is valid to subjectively assess the NPV of the asset. Thus he ignores the fact that it may in fact be possible to construct a portfolio that replicates the payoffs of the asset. As a result market based information may be ignored potentially creating arbitrage opportunities and hence being at odds with the fundamental assumption of arbitrage free markets when valuing options.

The second problem with the MAD approach stems from the use of GBM and its applicability to the single asset that the NPV of the project represents. Borison (2005a) argues that whilst it is valid to apply the GBM assumption to market based assets this is not necessarily the case for a single asset that does not have a liquid market. In the case of a mining project for example the assessed value of the project could be influenced by project specific one off risks that are not part of the random fluctuation of asset value, a geotechnical failure or unforseen geological conditions for example. Therefore Borison asks, is it valid to be applying the assumption of GBM when constructing the valuation lattices?

The preceding three approaches can be broadly grouped together in that they consider that the whole project can be wrapped up in their respective methodology. Essentially this argues that all project risks are accounted for by following a random walk type of profile
described by GBM that is applied at the time of option valuation. Several authors argue against this assumption indicating that project risks must be broken down into market and project specific risks. Each type of risk is considered and valued differently. Within a mining context for example, the project could be divided into price risk of the commodity being mined (e.g. Coal, Iron Ore, Gold etc) and operational risk such as unknown geological conditions for example. This argument for the deconstruction of project risk has led to two additional competing methodologies for real options analysis, namely the revised classic approach (Dixit and Robert Pindyck 1996; Amram and Nalin 2000) and the Integrated Approach (Smith and Nau 1995).

The Revised Classic Approach
Under the revised classic approach projects dominated by market risks are valued using the classic approach and those dominated by private risks are valued using decision trees.

Dixit and Pindyck (1996) differentiated the risks involved in a project as being either market or project related and proposed a method of valuing real options whereby if a project is dominated by market risks it is valued using the classical approach previously described but if it is dominated by project specific risks it should be valued using decision tree analysis (DTA).

Under a DTA framework managerial subjective assessments are used to calculate the project value. This value represents the assets certainty equivalents based on
management’s utility function (Friedman and Savage 1948). A criticism levelled at studies using this method (Amram and Nalin 2000) is, how does the practitioner assign the project to either the market or project specific category, a significant issue given that most projects are a combination of both market and project specific risks.

A second argument against its usage is what discount rate should be used in the decision tree analysis when the project is categorised as dominated by project specific risks. To address these concerns Smith and Nau (1995) presented the Integrated Methodology whose aim is to value a project using real options by considering both the private and public risks in the valuation.

**The integrated approach**
The integrated approach considers projects as being a mix of both public and private risks. The approach argues for a valuation methodology that accounts for both of these forms of risk by making the fundamental assumption of a partially complete market (Smith and Nau 1995). It is based on the premise that private risks are valued using decision trees and public risks using classic real options methods. It addresses the all or nothing nature of the Revised Classic Approach by incorporating both private and public risks into the valuation as opposed to either or, but also uses the risk free rate as the discounting factor based. It does this on the premise of risk neutral valuation and an argument that shows the equivalence of the DTA and binomial lattice methods under certain conditions (Smith and Nau 1995; Smith and McCardle 1998; Smith and McCardle 1999).
A significant problem with the integrated approach is its complexity in implementation. For projects that are long lived the mechanics of the model become unwieldy. For example, Figure 6 shows a simple model for a wait, defer, decline decision for an oil field decision for a single period. It demonstrates the number of calculations required for a simple single period model. Most real world models are significantly more complex than that demonstrated and would become hard to manage practically with a model similar to that shown in Figure 6 at every decision node. An operating mine with the option to expand, contract, wait or abandon in every year over a long period, say twenty years, could potentially have many hundreds of sub models like the one shown in Figure 6 across the decision points in every period. This makes it a very hard model to work with and explain.

**Figure 6** Full decision tree for the Expanded Capital Budgeting Example. Source (Smith and Nau 1995).
<table>
<thead>
<tr>
<th>No.</th>
<th>Author</th>
<th>Title</th>
<th>Commodity</th>
<th>RO Approach</th>
<th>Numerical Method</th>
<th>Option Analysis Parameter Source</th>
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<tbody>
<tr>
<td>1</td>
<td>(Tourinho 1979)</td>
<td>The Valuation of Reserves of Natural Resources: An Option Pricing Approach</td>
<td>General</td>
<td>Classic</td>
<td>Equation</td>
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<td>(Brennan and Schwartz 1985)</td>
<td>Evaluating Natural Resource Investments</td>
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<td>Classic</td>
<td>Equation</td>
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<td>3</td>
<td>(Trigeorgis 1986)</td>
<td>Valuing Real Investment Opportunities: an Options Approach to Strategic Capital Budgeting: DBA Dissertation</td>
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<td>Classic</td>
<td>Equation</td>
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<td>4</td>
<td>(McDonald and Siegel 1986)</td>
<td>The Value of Waiting to Invest</td>
<td>Oil/General</td>
<td>Classic</td>
<td>Equation</td>
<td>Oil Price</td>
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<tr>
<td>5</td>
<td>(Ekern 1988)</td>
<td>An option pricing approach to evaluating petroleum projects</td>
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<td>Subjective</td>
<td>Binomial Lattice</td>
<td>Oil Price</td>
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<td>(Paddock, Siegel et al. 1988)</td>
<td>Option Valuation of Claims on Real Assets: The Case of Offshore Petroleum Leases</td>
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<td>Subjective</td>
<td>Equation</td>
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<td>Oil</td>
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<td>Subjective</td>
<td>Equation</td>
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<td>Subjective</td>
<td>Equation</td>
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<td>Equation</td>
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<td>Binomial Lattice and</td>
<td>Oil price for public risks</td>
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<td>(Moyen, Slade et al. 1996)</td>
<td>Valuing Risk and Flexibility: A Comparison of Methods.</td>
<td>Copper</td>
<td>Classic</td>
<td>Equation</td>
<td>LME Copper price</td>
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<td>(Trigeorgis 1996)</td>
<td>Real Options: Managerial Flexibility and Strategy in Resource Allocation</td>
<td>Text Book</td>
<td>Subjective</td>
<td>Lattice / Equation</td>
<td>Various</td>
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<td>Equation</td>
<td>Copper price</td>
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<td>Strategy</td>
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<td>24</td>
<td>(Cortazar and Casassus 1998)</td>
<td>Optimal timing of a mine expansion: implementing a real options model.</td>
<td>Copper</td>
<td>Subjective</td>
<td>Equation</td>
<td>Copper price</td>
</tr>
<tr>
<td>25</td>
<td>(Cortazar, Schwartz et al. 1998)</td>
<td>Optimal Investment and Production Decisions and the Value of the Firm.</td>
<td>Copper</td>
<td>Subjective</td>
<td>Equation</td>
<td>Copper price</td>
</tr>
<tr>
<td>27</td>
<td>(Davis 1998)</td>
<td>Estimating volatility and dividend yield when valuing real options to invest or abandon.</td>
<td>Oil</td>
<td>Subjective</td>
<td>Equation</td>
<td>Oil / Gold Price</td>
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<tr>
<td>28</td>
<td>(Kelly 1998)</td>
<td>A binomial lattice approach for valuing a mining property IPO</td>
<td>Gold</td>
<td>Subjective</td>
<td>Binomial Lattice</td>
<td>Gold price</td>
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<td>29</td>
<td>(Laughton 1998)</td>
<td>The potential for use of Modern Asset Pricing methods for upstream petroleum project evaluation.</td>
<td>Oil</td>
<td>Subjective</td>
<td>Equation</td>
<td>Oil Price</td>
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<tr>
<td>30</td>
<td>(Smith and McCardle 1998)</td>
<td>Valuing Oil Properties: Integrating Option Pricing and Decision Analysis Approaches.</td>
<td>Oil</td>
<td>Integrated</td>
<td>Equation / Decision tree</td>
<td>Oil Price</td>
</tr>
<tr>
<td>31</td>
<td>(Sunnevåg 1998)</td>
<td>An option pricing approach to exploration licensing strategy.</td>
<td>Oil</td>
<td>Subjective</td>
<td>Equation</td>
<td>Oil Price</td>
</tr>
<tr>
<td>32</td>
<td>(Burton, Moel et al. 1999)</td>
<td>Alternative Explanations for Managerial Flexibility: Economic and Sociological Analyses of Mine Closing Decisions</td>
<td>Gold/Copper</td>
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<td>33</td>
<td>(Galli, Armstrong et al. 1999)</td>
<td>Comparison of three methods for evaluating oil projects</td>
<td>Oil</td>
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<td>34</td>
<td>(Paulis and Sick 1999)</td>
<td>Analyzing a Real Option on a Petroleum Property. Real Options Theory meets practice.</td>
<td>Oil</td>
<td>Subjective</td>
<td>Equation</td>
<td>Spot commodity</td>
</tr>
<tr>
<td>35</td>
<td>(Sabour 1999)</td>
<td>Decision making with option pricing and dynamic programming: development and application</td>
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<td>MAD</td>
<td>Equation</td>
<td>Gold Price</td>
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<td>36</td>
<td>(Smith and McCardle 1999)</td>
<td>Options in the Real World: Lessons Learned in Evaluating Oil and Gas Investments.</td>
<td>Oil</td>
<td>Integrated</td>
<td>Equation / Decision tree</td>
<td>Oil Price</td>
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<tr>
<td>40</td>
<td>(Grenadier 2000)</td>
<td>OPTION EXERCISE GAMES: THE INTERSECTION OF REAL OPTIONS AND GAME THEORY.</td>
<td>Strategy</td>
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<td>41</td>
<td>(Bowman and Moskowitz 2001)</td>
<td>Real Options Analysis and Strategic Decision Making.</td>
<td>Strategy / Biotech</td>
<td>MAD</td>
<td>Equation</td>
<td>Annual return on similar biotechnology stocks</td>
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<tr>
<td>42</td>
<td>(Copeland and Antikarov 2001)</td>
<td>Real Options. A Practitioner's Guide.</td>
<td>Text Book</td>
<td>MAD</td>
<td>Lattice / Equation</td>
<td>CAPM NPV with subjective parameters based on Monte Carlo Simulation</td>
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<tr>
<td>43</td>
<td>(Cortazar, Schwartz et al. 2001)</td>
<td>Optimal exploration investments under price and geological-technical uncertainty: A real options model.</td>
<td>Oil/Copper</td>
<td>Revised Classic</td>
<td>Equation</td>
<td>Subjective Geological (Private) and Oil price (Public) risk incorporated into Brennan Schwartz (1985) type model</td>
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<tr>
<td>44</td>
<td>(Cottrell and Sick 2001)</td>
<td>FIRST-MOVER (DIS) ADVANTAGE AND REAL OPTIONS.</td>
<td>Strategy</td>
<td>NA</td>
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<td>45</td>
<td>(Slade 2001)</td>
<td>Valuing Managerial Flexibility: An Application of Real-Option Theory to Mining Investments.</td>
<td>Copper</td>
<td>Classic</td>
<td>Equation</td>
<td>Copper Price</td>
</tr>
<tr>
<td>Page</td>
<td>Title</td>
<td>Author(s)</td>
<td>Description</td>
<td>Sector</td>
<td>Methodology</td>
<td>Equation/Decision Tree</td>
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<tr>
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<td>46</td>
<td>Valuing a Multi-Zone Mine as a Real Asset Portfolio - A Modern Asset Pricing (Real Options) Approach</td>
<td>(Samis 2001)</td>
<td>Metals</td>
<td>Subjective</td>
<td>Equation / Decision Tree</td>
<td>Gold price, Geological uncertainty</td>
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<td>47</td>
<td>Resources, real options, and corporate strategy</td>
<td>(Bernardo and Chowdhry 2002)</td>
<td>Strategy</td>
<td>Classic</td>
<td>NA</td>
<td>NA</td>
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<td>48</td>
<td>TO OPEN OR NOT TO OPEN-OR WHAT TO DO WITH A CLOSED COPPER MINE</td>
<td>(McCarthy and Monkhouse 2002)</td>
<td>Copper</td>
<td>Classic</td>
<td>Trinomial lattice</td>
<td>Copper price</td>
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<td>50</td>
<td>Valuing exploration and production projects by means of option pricing theory</td>
<td>(Zettl 2002)</td>
<td>Oil</td>
<td>Subjective</td>
<td>Equation</td>
<td>Oil Price</td>
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<tr>
<td>51</td>
<td>Valuation of an oil field using real options and the information provided by term structures of commodity prices.</td>
<td>(Lautier 2003)</td>
<td>Oil</td>
<td>Classic</td>
<td>Equation</td>
<td>Oil Price</td>
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<tr>
<td>52</td>
<td>REAL OPTIONS: EXAMPLES AND PRINCIPLES OF VALUATION AND STRATEGY.</td>
<td>(Smit and Trigeorgis 2003)</td>
<td>Strategy</td>
<td>Subjective</td>
<td>Binomial Lattice / Decision Trees</td>
<td>Subjective parameters used for illustration of method</td>
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<td>53</td>
<td>Real Options Analysis: Where Are the Emperor's Clothes?</td>
<td>(Borison 2005)</td>
<td>General</td>
<td>NA</td>
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<td>NA</td>
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<td>54</td>
<td>Using Binomial Decision Trees to Solve Real-Option Valuation Problems.</td>
<td>(Brandão, Dyer et al. 2005)</td>
<td>Oil</td>
<td>Integrated</td>
<td>Equation / Decision tree</td>
<td>Oil Price</td>
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<tr>
<td>55</td>
<td>&quot;Realizing the Potential of Real Options: Does Theory Meet Practice</td>
<td>(Triantis 2005)</td>
<td>General</td>
<td>NA</td>
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<td>56</td>
<td>MAKING USE OF REAL OPTIONS SIMPLE: AN OVERVIEW AND APPLICATIONS IN FLEXIBLE/MODULAR DECISION MAKING</td>
<td>(Trigeorgis 2005)</td>
<td>General</td>
<td>Classic</td>
<td>Equation / Decision Tree</td>
<td>NA</td>
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<td>57</td>
<td>Valuing Real Options using Implied Binomial Trees and Commodity Futures Options.</td>
<td>(Arnold, Crack et al. 2006)</td>
<td>General</td>
<td>NA</td>
<td>Binomial Lattice</td>
<td>Spot commodity prices</td>
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<td>58</td>
<td>Project Valuation Using Real Options: A Practitioner Guide</td>
<td>(Kodukula and Papudesu 2006)</td>
<td>Text</td>
<td>Subjective</td>
<td>Binomial Lattice</td>
<td>Various case studies</td>
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<td>59</td>
<td>Valuing mine 2 at raglan using real options</td>
<td>(Lemelin, Sabour et al. 2006)</td>
<td>Copper Mine</td>
<td>Subjective</td>
<td>Equation</td>
<td>Gold, Nickel, Copper, Cobalt, Silver, Lead, Platinum, Palladium, Rhodium</td>
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<td>No.</td>
<td>Authors</td>
<td>Title</td>
<td>Subjective/General</td>
<td>Method</td>
<td>Equation</td>
<td>Parameters</td>
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<tr>
<td>60</td>
<td>Dimitrakopoulos and Abdel Sabour 2007</td>
<td>Evaluating mine plans under uncertainty: Can the real options make a difference?</td>
<td>General</td>
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<td></td>
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<td>62</td>
<td>Hall and Nicholls 2007</td>
<td>Valuation of mining projects using option pricing techniques.</td>
<td>General</td>
<td></td>
<td></td>
<td>Coal price</td>
</tr>
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<td>63</td>
<td>Zhang and Zou 2008</td>
<td>The three-factor model of evaluating mining rights of coal resources based on options</td>
<td>Coal</td>
<td></td>
<td>Equation</td>
<td>Coal price</td>
</tr>
<tr>
<td>64</td>
<td>Abid and Kaffel 2009</td>
<td>A methodology to evaluate an option to defer an oilfield development.</td>
<td>Oil</td>
<td></td>
<td>Equation</td>
<td>Oil Price</td>
</tr>
<tr>
<td>65</td>
<td>Lazo, Pacheco et al. 2009</td>
<td>Real Options Theory Intelligent Systems in Oil Field Development under Uncertainty</td>
<td>General</td>
<td>MAD</td>
<td>Equation</td>
<td>Project value volatility</td>
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<tr>
<td>66</td>
<td>Li and Knights 2009</td>
<td>Integration of real options into short-term mine planning and production scheduling.</td>
<td>General / Strategy</td>
<td>Unknown</td>
<td></td>
<td>Diesel</td>
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<tr>
<td>68</td>
<td>Barton and Lawryshyn 2010</td>
<td>Reconciling Real Option Models: An Approach to Incomplete Market and Private Uncertainties.</td>
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<td>All methods</td>
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<td>69</td>
<td>Jin-feng, Yan et al. 2010</td>
<td>Analysis on coal mine investment decision based on binomial tree pricing model.</td>
<td>Coal</td>
<td>Subjective</td>
<td>Binomial</td>
<td>Coal price</td>
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<td>70</td>
<td>Zhou and Yan 2010</td>
<td>Investment and Project Value in Oil Field Development Using Real Option Pricing with Mean-Reversion with Jumps.</td>
<td>Oil</td>
<td>Subjective</td>
<td>Equation</td>
<td>Oil price</td>
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<tr>
<td>71</td>
<td>Arai, Ota et al. 2011</td>
<td>On a General Market Portfolio Acting as the Twin Security of an Arbitrary Project.</td>
<td>General</td>
<td>MAD</td>
<td>Equation</td>
<td>Project value based on a matching portfolio of projects</td>
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<td>72</td>
<td>Groeneveld and Topal 2011</td>
<td>Flexible open-pit mine design under uncertainty.</td>
<td>General</td>
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<td>73</td>
<td>Martinez 2011</td>
<td>Strategic Coal Mine Planning Project Using an Integrated Real Options Model Approach</td>
<td>Strategy</td>
<td>MAP</td>
<td>Equation</td>
<td>Coal</td>
</tr>
<tr>
<td>74</td>
<td>Nishihara and Shibata 2011</td>
<td>The Effect of Costly Exploration on Optimal Investment Timing</td>
<td>Strategy</td>
<td>Subjective</td>
<td>Equation</td>
<td>NA</td>
</tr>
</tbody>
</table>
Proposed model for this study
This study proposes a model in line with the MAD approach. It is based on the assumption of arbitrage free, partially complete markets using a portfolio that replicates payoffs from similar coal projects that have a similar public and private risk profile as the Case Study. It achieves this by constructing a portfolio composed entirely of publically listed Australian companies whose primary function is open cut coal mining. This methodology is in the spirit adopted by several literature studies that all subscribe to the MAD paradigm of RO valuation (Damodaran 2000; Bowman and Moskowitz 2001; Arai, Ota et al. 2011).

This study also argues that the coal portfolio should replicate the volatility characteristics of the mine being valued. It argues that this same approach could be applied to mining projects in other commodities and metals such as iron ore, gold, copper and oil for example. In these cases a portfolio would be constructed in the relevant commodity or metal.

Unlike Smith and Nau (1995) who argue for a partially complete market but treat both the public and private risks independently, this study argues that both private and public risks can be incorporated into the MAD style of real options evaluation. This is achieved by constructing a portfolio whose standard deviation is argued to present the same risk profile as the operating coal mine in the case study. To do this only pure coal mining companies composed of assets which are similar to the case study will be used. Whereas, the integrated approach argues that public and private risks need to be valued separately using classic options methods for market risks and decision trees and utility functions for private
risks this study argues that both forms of risk can be rolled up into the volatility factor if an appropriate portfolio can be constructed.

This study assumes that the volatility parameters derived from the constructed portfolio are the appropriate values for analysis of the case study using ROA. In doing so the study addresses an issue of subjectivity in the volatility parameter that is common in all the studies presented in Table 2. This study whilst still subjective to a degree presents a volatility that is a reproducible auditable parameter that includes both public and private risk. This study argues that by understanding the derivation of the parameter and the sensitivity of the valuation to this parameter the analyst or manager can consider its significance when making decisions\(^5\).

\(^5\) As previously described The Greeks provide measures of analysis that can be used to analyse parameters like volatility in the study of options. It is acknowledged that an analysis of the Greeks would provide insights that could be useful in this study, however, since the aim of this study is to largely demonstrate the viability of using the RO approach to valuing a coal mine and compare the results to a typical DCF analysis of the same project a detailed analysis of the Greeks is considered to be outside the scope of this study.
Chapter 3 – Results

The Case Study
The Case Study Mine is owned by Xstrata coal and is located in the Hunter Valley of New South Wales, operating in an open cut truck and excavator configuration. Mining is performed with a fleet of large excavators and haul trucks supported by ancillary equipment such as bulldozers, drills and wheel loaders (Appendix 1). The sequence of mining involves clearing of vegetation and topsoil, drilling and blasting of overburden followed by the removal of the overburden to waste dumps followed by the removal of coal. Coal is hauled to the Coal Handling and Preparation Plant (CHPP) for benefaction. Coal undergoes benefaction and is then conveyed to product stockpiles ready for loading onto trains where it is transported approximately 120 kilometres to the port of Newcastle for export.

This study constructed a mine schedule in line with the capacity of the main fleet and within the operating constraints of the mine. The physical schedule and fleet capacity are contained in Appendix 1.

A cash flow model was constructed from the schedule of physical quantities on a year by year basis. This methodology is in line with industry practice but deviates from the real options literature that typically use stochastic cash flow models built on parameters derived from historical analysis or subjective forecasts. McCarthy and Monkhouse (2002) in a real options analysis of a copper mine for BHP for example, generated a cash flow model based on what they describe as certainty equivalent costs where they used a cost beta of .4 to estimate mine costs. Other studies present cost functions that account for fixed and
variable costs of production (Smith and McCardle 1998; Lautier 2003; Shafiee, Topal et al. 2009 a) that are convenient for numerical closed form style analysis of real options problems but do not accurately reflect the lumpy nature of cost profiles associated with large mining projects like the Case Study.

**Cost Forecasting**
Nominal cost estimates for mining inputs are forecasted using the Brownian Motion process which is implemented in this study using MS Excel. This model is shown in Equation 19.

\[
\Delta C = \mu C \Delta t + \sigma C \varepsilon \sqrt{\Delta t}
\]

*Equation 19 Brownian Motion*

Where:

\[
\mu C \Delta t = \text{The expected cost drift in the cost (C) in an increment of time (t).}
\]

\[
\sigma C \varepsilon \sqrt{\Delta t} = \text{The volatility of C in a time increment t.}
\]

This model was implemented in MS excel using drift and volatility data derived from historical data sets and then modelled using the NORMSINV() and RAND() functions combined with a custom written Visual Basic Module that allowed a Monte Carlo simulation to be run. The Excel Spreadsheets and associated VB code are included in the study as Appendix 1.
For costs associated with mining the Australian Bureau of Statistics (ABS) Open Cut Coal Mine Materials Used Index was used as a proxy to calculate the volatility and expected growth rate of costs (see Appendix 1 OCMineIndex tab). These drift and volatility parameters were then combined with the current day estimated cost which was then used in the Excel Brownian Motion model to forecast future costs of items. The Open Cut Coal Mine Materials Used Index (OCMMI) measures changes in the prices of materials used in the ongoing mining process. That is, the removal of overburden, the extraction, washing and preparation of the coal, and its transportation to the railhead. As such it is considered to be a reasonable proxy for the individual nominal cost growth of the case study.

**Figure 7** Open cut coal mining materials used index. Source: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/6427.0Explanatory%20Notes1Jun%202011?OpenDocument

<table>
<thead>
<tr>
<th>Open Cut Mining Materials Used Summary Statistics</th>
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<tr>
<td>Mean</td>
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<tr>
<td>Standard Error</td>
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<tr>
<td>Median</td>
</tr>
<tr>
<td>Mode</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Sample Variance</td>
</tr>
<tr>
<td>Kurtosis</td>
</tr>
<tr>
<td>Skewness</td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Sum</td>
</tr>
<tr>
<td>Count</td>
</tr>
<tr>
<td>Confidence Level(95.0%)</td>
</tr>
</tbody>
</table>

Figure 8 shows an example Monte Carlo cost profile derived for a current cost item which is $50 in 2011. Using the model presented in Table 4 with the volatility and expected growth derived from the OCMMI input parameters shown in Table 3 the model was run 500 times and the average cost curve was derived, as shown in red Figure 8 (see Appendix 1 Sim_graphs tab for a description of all cost estimations).

Figure 8 GBM estimate of cost item with initial cost of $50 with parameters derived from the OCMMI.
Table 4 An excerpt from the spreadsheet implementing the GBM model of cost items

<table>
<thead>
<tr>
<th>Item</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift</td>
<td>0.0428933929898713</td>
</tr>
<tr>
<td>Volatility</td>
<td>0.0488546164103026</td>
</tr>
<tr>
<td>Price today</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>N(0,1)</td>
<td>NORMSINV(RAND())</td>
<td>NORMSINV(RAND())</td>
<td>NORMSINV(RAND())</td>
<td>NORMSINV(RAND())</td>
<td>NORMSINV(RAND())</td>
</tr>
<tr>
<td>Log Return</td>
<td>$D$3+$D$4*C9</td>
<td>$D$3+$D$4*D9</td>
<td>$D$3+$D$4*E9</td>
<td>$D$3+$D$4*F9</td>
<td>$D$3+$D$4*G9</td>
</tr>
<tr>
<td>Cost</td>
<td>$D$5*EXP(C10)</td>
<td>$C$11*EXP(D10)</td>
<td>$D$11*EXP(E10)</td>
<td>$E$11*EXP(F10)</td>
<td>$F$11*EXP(G10)</td>
</tr>
</tbody>
</table>

The model demonstrates how the path of a single forecast can differ considerably from the Mean (shown in red, Figure 8).

**Cost estimates Real or Nominal**

Like cash rates, costs can be expressed in either nominal or real terms. A real cost rate is a rate that describes the actual cost of an item in current dollar terms accounting for any inflation or growth in the underlying rate. A nominal cost would be a cost expressed in current dollars that has not made any allowance for expected growth in the underlying cost.

Ross et al. (1996) in a discussion on whether real or nominal rates should be used in a cash flow analysis stress the need for consistency, arguing that both a nominal and real approach will yield the same result as long as a consistent approach is take. This study will apply nominal rates in cash flow modelling.

**Functional Cost Breakdown of the Case Study**

The mining model in the case study is broken into core functional areas as detailed below, and include;

1. Clearing
2. Drill and Blast
3. Load Haul and Dump (Coal and Waste)
4. Overheads
5. Sustaining Capital
6. Benefaction
7. Rail
8. Port
9. Levies and Royalties

Costs are broken into pit top costs (PTC), free on rail (FOR) and freight on board (FOB). Pit top costs contain all mining functions including initial land clearing, drill and blast, load haul and dump, overheads and any capital required to sustain the operation. The FOR component describes the cost associated with producing coal and getting it loaded onto a train for transport to the port. The FOB component includes all costs up to ship loading. Once loaded the coal becomes the property of the buyer.

**Table 5** Unit rate costs per product tonne of coal. See Appendix 1 for a build up of these costs for the Case Study.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>PTC (Pit cost)</td>
<td>$36.25</td>
<td>$35.71</td>
<td>$35.68</td>
<td>$37.30</td>
<td>$38.52</td>
<td>$51.15</td>
<td>$40.44</td>
<td>$68.50</td>
<td>$44.29</td>
<td>$64.71</td>
<td>$66.83</td>
<td>$69.23</td>
</tr>
<tr>
<td>FOR (Free on Rail)</td>
<td>$38.64</td>
<td>$38.16</td>
<td>$38.27</td>
<td>$40.02</td>
<td>$41.37</td>
<td>$54.09</td>
<td>$43.53</td>
<td>$71.75</td>
<td>$47.69</td>
<td>$69.24</td>
<td>$74.09</td>
<td>$76.86</td>
</tr>
<tr>
<td>FOB (Freight on Board)</td>
<td>$54.40</td>
<td>$55.12</td>
<td>$56.50</td>
<td>$59.64</td>
<td>$62.50</td>
<td>$76.84</td>
<td>$68.03</td>
<td>$98.16</td>
<td>$76.16</td>
<td>$99.99</td>
<td>$107.48</td>
<td>$112.87</td>
</tr>
</tbody>
</table>
Table 5 shows the cost profile of production in the Case study. The underlying base cost estimates and assumptions used to develop these costs are shown in Appendix 1 are derived from publically available information or from estimates based on the authors experience. They do not reflect actual costs for any particular mining operation although it is expected that these estimates would be close approximations. The confidential nature of cost information makes it hard to find published data at the functional level described in this study, however, based on the authors experience the cost estimate included here would be expected to be within a 5% tolerance of actual costs in 2012.

As previously alluded to the cost profile of mining operations is typically lumpy because of various capital and mine specific reasons. In the case study for example, the Pit Top Cost (PTC) profile described as shown in Figure 9, shows a spike in period 2017 and 2019 of the project.
The cost spikes in 2017 and 2019 are caused by a requirement to replace mining fleet that have utilised their productive operating lives. Appendix 1 details the effective annual equipment utilisation and their corresponding equipment effective lives, showing, with the current expected production profile the replacement schedule. The main point being made in this description of the cost profile is that for long lived mining projects like the case study it is not valid to use cost estimates that do not make allowance for this lumpy nature.
Figure 10 further illustrates the danger associated with a cost estimation profile in the same spirit as cost profiles described in the literature. This general cost profile is exponential which is not unexpected given the GBM nature of the underlying simulations of many of the inputs and is described by the following equation.

**Equation 20** Cost estimate function for the Case Study

\[
\text{Cost (FOB)} = 46.86e^{0.0716 \times \text{period}}
\]

In reality what the cost function in Equation 20 is describing is the variable cost component of the mining project. Any periods that have significant one off costs like fleet replacements
would not be reflected in the cost profile. In the Case study the cost function would significantly underestimate the cost in period 8 (2019), a fact that could have significant implications for project decision makers if they are unaware of this issue.

Within the literature there is very little evidence of consideration for the lumpiness of costs as described. Implicit in many models is a continuous cost function like that described and hence a significant source of error. Paddock, Siegel et al (1988) developed an options model that utilised a value parameter in its derivation of real options value for an oil field. They argued for value being derived from the following equation.

\[
\frac{dV}{V} = (\alpha_u - \delta_t)dt + \sigma_v dz_v \\

\equiv \alpha_u dt + \sigma_v dz_v,
\]

**Equation 21** Source: (Paddock, Siegel et al. 1988)

Where

\[
\begin{align*}
\alpha_u &= \alpha_u^* - \delta_t, \\
\delta_t &= \gamma [P_t - V_t]/V_t.
\end{align*}
\]

This is a typical diffusion model applied across the literature with only the net value being considered without consideration of the cost profile. Examples of other studies that follow a similar strategy include Brennan Schwartz (1985) in their seminal study, McDonald and Siegal (1986), Jacoby and Laughton (1992) in an oil field study of real options and Slade
(2001), McCarthy and Monkhouse (2002) and Auger and Guzman (2010) for copper projects as well as Zhang and Zou (2008) who present a three factor model using options on a coal project in China. This study argues that unless specific cost profiles are considered then there are significant potential errors being introduced into the evaluation and that this error needs to be considered when evaluating prior studies like those discussed for long lived resource projects.

**Coal Price Model**

Coal prices are analysed historically for the period spanning January 1981 to November 2011 and then forecast with a probabilistic stochastic GBM method until 2023. A premium of 25% is assumed for Semi Soft Coking coal. The detailed price model is presented in Appendix 2.
This section starts by estimating and calculating the required parameters for the thermal coal model. Figure 11 shows the actual coal price volatility shown in red has increased significantly since 2003 with the period from 1981 until 2003 characterised by a reasonably steady coal price. This more recent volatility will have a considerable impact on the forecast model. A limitation of the coal forecasting model is its inability to predict large shocks and jumps like that seen in 2009. The black line in Figure 11 representing the model coal prices whilst being representative of the overall trend does not accurately predict the overall randomness of the coal price.

The thermal coal price information used in the study was obtained from the Index Mundi (http://www.indexmundi.com/commodities/?commodity=coal-australian&months=360) website and represents the FOB price paid for a standard Newcastle coal. Data was adjusted into Australian Dollars from 1991 to 2011. All historical price data is contained in Appendix 2.

---

**Figure 11** Nominal Export Thermal Coal prices (AUD).

---

6 The data: http://www.indexmundi.com/commodities/?commodity=coal-australian&months=360

7 The heat of combustion describes the energy released when coal is burnt. Since coal is heterogeneous different coals have a different amount of energy released when they are burnt in a furnace. Since it is this stored energy that a power company is purchasing for electricity generation the value of a particular coal is determined by its calorific (energy) content. A particular type of coal is priced against a benchmark coal price. A typical benchmark is the Newcastle 6,300 kcal/kg contract which is what is used in this study. Price adjustments are made to a particular coal depending on its calorific value compared to the benchmark. This study assumes no adjustment for calorific value.
Export Thermal Price Volatility

Volatility is the standard deviation of the logarithmic returns and is the uncertainty term used in the GBM price model.

<table>
<thead>
<tr>
<th>Monthly XT AUD 1991-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Standard Error</td>
</tr>
<tr>
<td>Median</td>
</tr>
<tr>
<td>Mode</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Sample Variance</td>
</tr>
<tr>
<td>Kurtosis</td>
</tr>
<tr>
<td>Skewness</td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Sum</td>
</tr>
<tr>
<td>Count</td>
</tr>
<tr>
<td>Confidence Level(95.0%)</td>
</tr>
</tbody>
</table>

Table 6 Historical Newcastle FOB coal descriptive statistics. Source data: http://www.indexmundi.com/commodities/?commodity=coal-australian&months=360

The statistics shown in Table 6 were calculated using the MS EXCEL Data Analysis (descriptive statistics) add in and represent the analysis of the coal price from 1991 adjusted for the Australian exchange rate. Monthly data is used to calculate the volatility and as such any forecasting had to be done using monthly forecasting. Alternatively the monthly returns could have been converted to annualised returns using the square root of time rule.

The GBM model was implemented in MS EXCEL using a Monte Carlo Simulation approach using custom VBA code (see Appendix 2).
Figure 12 Export Thermal Coal Price Forecast using parameters derived in Table 5.

The single simulation shown in Figure 12 is implemented using the MS EXCEL NORMSINV() and RAND() function in the NORMSINV(RAND()) construct. RAND() gives a probability between 0 and 1. The NORMSINV() function translates this into the normal inverse standard distribution. This number is then used to scale the volatility of the expected return essentially adding a shock component to the expected return or drift component. Figure 13 shows the spreadsheet implementation of this coal price simulation.

Figure 13 Spreadsheet implementation of the coal price model.
The simulation data set in Figure 14 is based on historical analysis from the period 1991 to present. This study argues that the longer term trend should be included because it is representative of more longer term supply and demand cycles experienced in coal markets (Brown, Yücel et al. 2004).

The model derivation shown in Figure 14 and implemented as per Figure 15 can be seen in Appendix 2. This study argues that a Monte Carlo Simulation run of 500 iterations should provide a good working model of the expected future export thermal coal prices using GBM. The results of these simulations are shown in Figure 15 where a forecast coal price model is presented.

**Figure 14** Forecast FOB export thermal coal prices from a Monte Carlo Simulation with 500 iterations.
Table 7 Annualised forecast coal prices

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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Export Thermal USD $ / Tonne</td>
<td>$126.02</td>
<td>$134.07</td>
<td>$142.17</td>
<td>$153.25</td>
<td>$163.90</td>
<td>$174.95</td>
<td>$188.74</td>
<td>$202.47</td>
<td>$217.63</td>
<td>$231.71</td>
<td>$246.40</td>
<td>$267.90</td>
<td>$284.28</td>
</tr>
<tr>
<td>Export Semi Soft USD $ / Tonne</td>
<td>$157.52</td>
<td>$167.58</td>
<td>$177.71</td>
<td>$191.56</td>
<td>$204.88</td>
<td>$218.68</td>
<td>$235.92</td>
<td>$253.09</td>
<td>$272.04</td>
<td>$289.63</td>
<td>$308.00</td>
<td>$334.87</td>
<td>$355.35</td>
</tr>
</tbody>
</table>

<table>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Export Thermal AUD $ / Tonne</td>
<td>$125.51</td>
<td>$135.67</td>
<td>$147.05</td>
<td>$159.42</td>
<td>$171.59</td>
<td>$188.88</td>
<td>$205.26</td>
<td>$223.17</td>
<td>$241.51</td>
<td>$264.30</td>
<td>$286.84</td>
<td>$316.40</td>
<td>$346.46</td>
</tr>
<tr>
<td>Export Semi Soft AUD $ / Tonne</td>
<td>$156.89</td>
<td>$169.58</td>
<td>$183.82</td>
<td>$199.28</td>
<td>$214.49</td>
<td>$236.10</td>
<td>$256.57</td>
<td>$278.96</td>
<td>$301.89</td>
<td>$330.37</td>
<td>$358.55</td>
<td>$395.50</td>
<td>$431.82</td>
</tr>
</tbody>
</table>

The forecast coal prices shown in Table 7 represent the average forecast monthly coal price for each year of the mining project based on the statistics previously described Table 6.

Figure 15 Graphical annualised forecast coal prices.

Figure 15 shows that the expected growth rate of the coal price will be approximately 8.4% based on the Monte Carlo Simulation.
Figure 16 shows the expected value for an Oilfield project (Dias 2004). In near periods the spread of modelled values is much tighter about the current value. As time increases the uncertainty of the value increases and this spread increases whilst the expected return grows at the modelled rate. This same pattern is expected for the coal project and it is this price variance that contributes to giving the mine optionality. As the mines forecasts reach further into the future the variance becomes greater as shown in Figure 16, which increases the value of the options.

It is apparent from the price model shown above that there is much uncertainty associated with the behaviour of coal prices. It is obvious that these prices are highly volatile and do not keep a constant trend making it very hard to forecast prices going forward. Exchange rate which is also included in the forecast parameter, since coal is sold in US dollars is also a significant contributor to the risk associated with estimating coal prices. Therefore it is hard to have an accurate estimate of the behaviour of prices going forward.
Table 8 Average Commodity Prices for Xstrata 2011. Source Xstrata PLC Preliminary Results pg 8. All values in USD.

<table>
<thead>
<tr>
<th></th>
<th>Average price 2011</th>
<th>Average price 2010</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrochrome (Metal Bulletin)</td>
<td>£/lb 125.0</td>
<td>124.3</td>
<td>1</td>
</tr>
<tr>
<td>Platinum (LPPM cash price)</td>
<td>$/oz 1,720</td>
<td>1,611</td>
<td>7</td>
</tr>
<tr>
<td>Australian FOB export coking*</td>
<td>$/t 265.0</td>
<td>204.3</td>
<td>30</td>
</tr>
<tr>
<td>Australian FOB export semi-soft coking*</td>
<td>$/t 202.5</td>
<td>137.3</td>
<td>47</td>
</tr>
<tr>
<td>Australian export thermal coal*</td>
<td>$/t 109.6</td>
<td>85.7</td>
<td>28</td>
</tr>
<tr>
<td>Americas FOB export thermal coal*</td>
<td>$/t 101.0</td>
<td>72.6</td>
<td>39</td>
</tr>
<tr>
<td>South African export thermal coal*</td>
<td>$/t 101.2</td>
<td>74.4</td>
<td>36</td>
</tr>
<tr>
<td>Copper (average LME cash price)</td>
<td>$/t 8,826</td>
<td>7,536</td>
<td>17</td>
</tr>
<tr>
<td>Nickel (average LME cash price)</td>
<td>$/t 22,831</td>
<td>21,809</td>
<td>5</td>
</tr>
<tr>
<td>Zinc (average LME cash price)</td>
<td>$/t 2,190</td>
<td>2,159</td>
<td>1</td>
</tr>
<tr>
<td>Lead (average LME cash price)</td>
<td>$/t 2,399</td>
<td>2,148</td>
<td>12</td>
</tr>
</tbody>
</table>

* average received price

Table 8 shows the actual average prices received by Xstrata for export thermal and semi-soft coking coal. These prices are in line with modelled values and also show the gap between semi-soft and thermal coal. This study will assume an 85% premium for semi-soft coal on the underlying export thermal price.

This study uses GBM which has been used throughout the literature to forecast commodity prices (Brennan and Schwartz 1985; Ekern 1988; Gibson and Schwartz 1990; Mardones 1993; Trigeorgis 1993a; Schwartz 1997; Baker, Mayfield et al. 1998; Cortazar, Schwartz et al. 2001; Sabour and Dimitrakopoulos 2011). Even though it does not appear to be able to predict the often extreme fluctuations in price it does provide a simple view of reality that is easy to implement. It enables this study to characterise the multiple sources of risk with a limited number of parameters, and is therefore easier to interpret and calibrate from the historical market prices. Given that the same coal price estimates will be used for both the traditional and real options analysis this study argues that even though it is desirable to
have an accurate forecast of the coal price its absolute accuracy should have no real bearing on the question of how traditional and real options valuation methodologies differ, and whereas others may advocate more complex models like the Mean Reverting Process or Jump Diffusion (Lautier 2005; Zhou and Yan 2010) this study argues that a simple GBM will suffice.

Recognised problems with the GBM price model are that coal prices may not be lognormally distributed, extreme prices may be underestimated, volatilities are based on historical estimates and may not be valid going forward, and the volatility derived may not be constant (Blanco, Choi et al. 2001). Blanco, Choi et al., (2001) argue that prices may not follow a lognormal distribution. They argue for the use of Mean Reversion and Jump Diffusion processes to better characterise the behaviour of commodities. Flowing on from this observation is the fact that GBM does not capture extreme price changes accurately which as seen in Figure 13 occurred in coal markets in 2003. Ideally when using GBM to model prices the volatility that would be used would be the future volatility, however, this is not available and historical estimates need to be used. The volatility used should therefore reflect the expectation of what is going to occur and not necessarily what has occurred as shown in the historical estimates. It is also worth noting that volatilities may not be constant. The two time periods 1981-2003, and 2003 to present are characterised by periods of significantly different price volatility for example. A forecast methodology that somehow makes allowance for this time varying volatility could prove worthwhile in more advanced studies of the coal price behaviour.
The Weighted Average Cost of Capital
As shown in Equation 6, the WACC is a function of debt and equity. This study derives debt statistics from the 2011 annual report and calculates a cost of equity based on traditional CAPM principles with market data derived from the FTSE 100.

Cost of Debt
The Case Study Mine is owned 100% by Xstrata PLC. A review of their 2011 annual report enabled an average corporate debt rate to be calculated. This calculation is shown in Table 9.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Debt</td>
<td>8.149</td>
<td>$B USD</td>
</tr>
<tr>
<td>shares</td>
<td>2.93</td>
<td>Billion</td>
</tr>
<tr>
<td>share price</td>
<td>31-Dec</td>
<td>9.78</td>
</tr>
<tr>
<td>GBP / USD</td>
<td>31-Dec</td>
<td>1.6</td>
</tr>
<tr>
<td>Net Interest Paid</td>
<td>313</td>
<td>$M USD</td>
</tr>
<tr>
<td>Average Debt rate</td>
<td></td>
<td>3.84%</td>
</tr>
</tbody>
</table>

The average debt rate was calculated by dividing the Net Interest Paid by the Total Debt to arrive at the calculated figure of 3.84% for 2011.

Cost of Equity
The cost of equity was calculated using the method described in Ross, Westerfield et al. (1996) and used in various studies in the Resource Valuation Literature (Brennan and

The cost of equity is calculated using the CAPM from data derived from the London stock exchange and the FTSE 100. This Data is Listed in Appendix 3.

Table 10. Beta of Xstrata PLC (Source: http://au.finance.yahoo.com/q/ks?s=XTA.L)

<table>
<thead>
<tr>
<th></th>
<th>Beta Annual</th>
<th>Beta Daily</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cov (XTA, FTSE100)</td>
<td>0.07464</td>
<td>0.00030</td>
<td>0.00029</td>
</tr>
<tr>
<td>Var (FTSE100)</td>
<td>0.03831</td>
<td>0.00014</td>
<td>0.00017</td>
</tr>
<tr>
<td>( \text{Beta} = \frac{\text{Cov}(\text{XTA}, \text{FTSE100})}{\text{Var}(\text{FTSE100})} )</td>
<td>1.94</td>
<td>2.08</td>
<td>1.745</td>
</tr>
</tbody>
</table>

In Table 10 the annual Beta is calculated from average annual returns (see Appendix 3).
Figure 18. XTA.L verses FTSE 100 Calculated on daily returns April 2009 to February 2012 (Source: Appendix 3)

Figure 19. XTA.L verses FTSE 100 calculated on daily returns for 2011 (Source: Appendix 3)

Figure 20. XTA.L verses FTSE 100 calculated on Annual returns (Source: Appendix 3)
The period over which the beta is calculated has an impact on the derived beta. Table 10 demonstrates how depending on the time period being analysed beta can vary and is a well recognised phenomena (Bodie, Ariff et al. 2007). This study argues that the Beta derived for annual returns (1.948) from 2009 to present should be used and is in line with industry betas currently being used for Xstrata PLC.

Risk free rate
The risk free rate was derived from the monthly average of the official Bank of England Rate (IUMABEDR) and represents the official UK Government cash rate used to implement monetary policy (McTaggart, Findlay et al. 1996). This cash rate is assumed to be risk free since it is unlikely that the UK government would default on this debt and is shown to currently be set at 0.5% (Table 11).

<table>
<thead>
<tr>
<th>Date</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>31-Jan-12</td>
<td>0.5</td>
</tr>
<tr>
<td>31-Dec-11</td>
<td>0.5</td>
</tr>
<tr>
<td>30-Nov-11</td>
<td>0.5</td>
</tr>
<tr>
<td>31-Oct-11</td>
<td>0.5</td>
</tr>
<tr>
<td>30-Sep-11</td>
<td>0.5</td>
</tr>
<tr>
<td>31-Aug-11</td>
<td>0.5</td>
</tr>
<tr>
<td>31-Jul-11</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 11 UK Monthly average of official bank rate. Source: http://www.bankofengland.co.uk/mfsd/iadb/Repo.asp?Travel=NlXR

Market Return
The FTSE 100 represents approximately 81% of the market capitalisation of the London Stock Exchange with the top 100 companies listed included across all industries and includes Xstrata. The average return of this index from Apr 2009 until Feb 2012 is used in this study.

<table>
<thead>
<tr>
<th>Date</th>
<th>FTSE</th>
<th>FTSE%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/04/2009</td>
<td>4125</td>
<td></td>
</tr>
<tr>
<td>1/04/2010</td>
<td>5744.9</td>
<td>33%</td>
</tr>
<tr>
<td>1/04/2011</td>
<td>6009.9</td>
<td>5%</td>
</tr>
<tr>
<td>1/02/2012</td>
<td>5790.7</td>
<td>-4%</td>
</tr>
<tr>
<td>Average return</td>
<td>11.1%</td>
<td></td>
</tr>
</tbody>
</table>

Table 12 Return Statistics for the FTSE 100. Source: http://au.finance.yahoo.com

Using an index like the FTSE 100 as a proxy, assumes that it representative of the market as a whole when used in the context of the CAPM. In effect it is assumed that the FTSE 100 represents the efficient portfolio of risky assets (Markowitz 1952; Trigeorgis 1996) that satisfies the assumption of homogenous expectations (Ross, Westerfield et al. 1996) where all investors have the same beliefs concerning returns, variances and covariance. The representativeness of indexes like the FTSE100 is however, often questioned. Temple (2011) makes the point that the structure of market indices like the FTSE 100 can distort the view of the market as a whole. The FTSE 100 for example, is dominated by several of the larger constituents with the top ten companies accounting for 47% of the index and the top five about 28% (Temple 2011). This bias towards the leading companies in the index it could
be argued may cause fluctuations that are the result of company specific risks and are not truly reflective of market conditions as a whole.

Another assumption of the CAPM is that investors can hold the efficient market portfolio. Temple (2011), in his analysis of how representative the FTSE 100 is of the London Stock Exchange, also makes the point that there are constituent companies that are very tightly held by a small number of shareholders. If shares cannot be freely traded from within the index then it would be hard to argue that the index truly satisfies the criteria as a representative market proxy.

Despite the issues with the FTSE 100 being used as a market proxy its large market share and industry acceptance mean that it is generally accepted as the market proxy for the London Stock Exchange, a stance that this study also takes due to its wide spread usage and acceptance. Table 12, shows the calculated annual returns on the FTSE 100 since 2009 that will be used in this study.

**CAPM**  
As described in the Equation 4, the best estimate of the cost of company equity is calculated using the CAPM. For Xstrata the following parameters have been calculated:

\[ \beta = 1.948 \]
\[ r_f = 0.5\% \]
\[ r_m = 11.1\% \]

Cost of Xstrata equity = \( E(r) \)

\[
E(r) = r_f + \beta[E(r_m) - r_f] \\
= 0.5\% + 1.948(11.1\% - 0.5\%) \\
= 21.154\% \]

**Xstrata PLC WACC Calculation**

Analysis of the 2011 preliminary annual financial statements for Xstrata revealed the following financial parameters.

<table>
<thead>
<tr>
<th>Table 13 Xstrata Issued Debt and Equity. Source: Xstrata Annual Report</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equity</strong></td>
</tr>
<tr>
<td><strong>Debt</strong></td>
</tr>
<tr>
<td><strong>Debt</strong></td>
</tr>
</tbody>
</table>

The figures were calculated for the December 31, 2011 where 2.93 Billion shares were active at £9.78 per share. The WACC for Xstrata PLC was then calculated using Equation 6.

Where:

\[ S = £28.66 \text{ Billion} \]

---

\(^9\) See Xstrata WACC V3.xlsm

\(^{10}\) pg 15 of Xstrata 2011 preliminary annual report

\(^{11}\) pg 11 of Xstrata 2011 preliminary annual report

\(^{12}\) Calculated using exchange rate on pg 11 of Xstrata 2011 preliminary annual report
B = £5.09 Billion

\( r_s = 21.154\% \)

\( r_b = 3.84\% \)

\( T_{c}^{13} = 22\% \)

\[
\text{Wacc} = \frac{28.66}{28.66+5.09} \cdot 0.21154 + \left( \frac{5.09}{28.66+5.09} \cdot 0.0384 \right) \cdot (1 - 0.22)
\]

\( = 18.41\% \)

**Discounted Cash Flow (DCF) Model**

The seminal work of Modigliani and Miller (1958) argued that a project’s cash flow should be discounted at a rate that reflects the project’s risk characteristics. This study discounts cash flows using the previously defined WACC but this practice despite being widespread in practice (Bierman 1993; Ross, Westerfield et al. 1996; Graham and Harvey 2001; Grinblatt and Titman 2002; Bodie, Ariff et al. 2007) is controversial (Kruger, Landier et al. 2011).

**Table 14 DCF analysis of the Case Study**

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</tr>
</thead>
<tbody>
<tr>
<td>Net Cash Flow</td>
<td>Million</td>
<td>$226.6</td>
<td>$212.2</td>
<td>$258.1</td>
<td>$284.5</td>
<td>$311.5</td>
<td>$300.9</td>
<td>$410.5</td>
<td>$494.9</td>
<td>$314.9</td>
<td>$150.4</td>
<td>$170.5</td>
</tr>
<tr>
<td>Discounted Cash Flow</td>
<td>Million</td>
<td>$188.5</td>
<td>$146.8</td>
<td>$148.6</td>
<td>$136.2</td>
<td>$124.1</td>
<td>$99.7</td>
<td>$113.1</td>
<td>$69.4</td>
<td>$94.4</td>
<td>$50.0</td>
<td>$19.8</td>
</tr>
<tr>
<td>Net Present Value</td>
<td>Million</td>
<td>$1,209.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discount Rate</td>
<td></td>
<td>18.41%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Table 14, shows the discounted cash flows for the Case Study Mine (see Appendix 1).

13 22% tax rate based on highest Swiss corporate tax rate where Xstrata is headquartered.
If as Modigliani and Miller (1958) argue, discounting should be done at a rate that reflects the project risk, then discounting at a rate that is firm specific (WACC) will therefore be inappropriate if the risk of the project differs in riskiness from the project at hand. This raises the question as to whether it is appropriate to apply the Xstrata WACC to the Case Study.

Evidence from the literature and the authors personal experience indicate that industry practice is to use the WACC as the discount rate. Graham and Harvey (2001) found that a majority of firms reported using a companywide discount rate in project evaluations, independent of their risk profile. Bierman (1993) had similar findings when investigating the top 100 firms of Fortune 500 companies with 93% of companies using the WACC to discount individual projects within the firm. The use of a firm wide WACC as the discount rate to individual projects contrasts the standard financial texts (Ross, Westerfield et al. 1996; Bodie, Ariff et al. 2007) that argue that it is inappropriate to use a discount rate that is not directly related to the project being evaluated.

The implications of using WACC inappropriately as the discount rate are discussed by Kruger, Landier et al. (2011). They argue a company using a single company wide WACC will tend to overestimate the NPV of a project since the project is riskier than a typical company project. For a diversified company like Xstrata plc this could have significant implications for their allocation of capital. For example if the riskiness of a coal project like the case study is competing for funding with a gold project, both using the firm WACC, then coal project may be disadvantaged if it's appropriate discount rate is lower than the firms overall
WACC. In contrast if the gold projects appropriate rate is higher than the firms WACC (assuming it is riskier) then it will be overvalued in terms of its NPV. Hence a diversified company like Xstrata could be overinvesting in divisions that have betas above the firms beta and vice versa in divisions with lower betas. The practical problem with this intuition is that there is no mechanism to calculate a divisional beta since it is not independently listed.

An alternative method discussed in the literature for calculating an appropriate discount rate for resource projects is the risk-adjusted discount rate (RADR) approach (Park and Matunhire 2011) whereby the RADR is derived by calculating a project specific risk premium that is added to the risk free rate of return. This is similar to the CAPM approach but derives the risk component from subjective assessments of risk factors specific to the project like technical, economic and political risks. This is in contrast to the WACC approach that uses beta and market returns to calculate the project specific risk component. Park and Matunhire (2011) propose that the RADR required by mining companies should ideally range between 7.2 and 21.2 % but offer no real explanation as to how this figure was derived.

Although the RADR method offers a viable alternative to the WACC approach, its implementation is beyond the scope of this study whose primary aim is to assess the Real Options approach to valuing a coal mining project and compare it to a traditional company NPV valuation. As such, this study proposes to follow the industry standard practice of discounting using the WACC despite its recognised shortcomings.
Portfolio construction

This study makes a significant contribution to the real options literature by constructing a replicating portfolio for open cut coal mines in Australia whose aim is to capture as much public and private risk within the risk and return statistics as possible. The portfolio was constructed by selecting coal mining stocks from a universe of securities listed on the Australian Stock Exchange. A primary search of Australian stocks involved in coal mining activities was conducted and then refined further. The selection criteria is listed below;

1. Listed on the ASX
2. Principle activity is coal mining
3. Principle mining location is in Australia
4. Majority of the companies mining assets must be open cut
5. Export Thermal and Metallurgical coal products

Stocks that meet these criteria are argued to have the same risk profile as the case study and as such are argued to represent a proxy for the asset in terms of market volatility and expected returns.

Table 15 Coal mining stocks listed on the ASX

<table>
<thead>
<tr>
<th>ASX code</th>
<th>Australian Coal Mines</th>
<th>Currently listed</th>
<th>Principally a Coal Mining Company</th>
<th>Location Australia</th>
<th>Majority of Assets Australian</th>
<th>Majority of Assets Open cut Mines</th>
<th>Export Thermal and Metallurgical</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNA</td>
<td>Coal and Allied</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Delisted Dec 2011</td>
</tr>
<tr>
<td>NHC</td>
<td>New Hope</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIV</td>
<td>Riversdale Mining</td>
<td>✔</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Exploration only</td>
</tr>
<tr>
<td>AQA</td>
<td>Aquila Resources</td>
<td>✔</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Exploration and diversified interests</td>
</tr>
<tr>
<td>MCC</td>
<td>Macarthur Coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Delisted Dec 2011</td>
</tr>
<tr>
<td>WHC</td>
<td>Whitehaven Coal</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AZT</td>
<td>Aston Resources</td>
<td>✔</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Principally exploration and shareholder</td>
</tr>
<tr>
<td>GCL</td>
<td>Gloucester Coal</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPL</td>
<td>Coalspur Mines</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Canadian mines and exploration</td>
</tr>
<tr>
<td>BND</td>
<td>Bandanna Energy</td>
<td>✓</td>
<td>x</td>
<td>Exploration only</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------</td>
<td>---</td>
<td>---</td>
<td>------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZA</td>
<td>Coal of Africa</td>
<td>✓</td>
<td>✓</td>
<td>South African based</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GNM</td>
<td>Gujarat NRE Coking Coal</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>Underground hard coking coal producer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COK</td>
<td>Cockatoo Coal</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>Principally hard coking coal</td>
<td></td>
</tr>
<tr>
<td>Hun</td>
<td>Hunnu Coal</td>
<td>x</td>
<td></td>
<td>Delisted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRC</td>
<td>Pike River Coal</td>
<td>x</td>
<td></td>
<td>Delisted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RES</td>
<td>Resource Generation</td>
<td>✓</td>
<td>x</td>
<td>Exploration in South Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEC</td>
<td>Northern Energy</td>
<td>x</td>
<td></td>
<td>Delisted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCR</td>
<td>Nucoal resources</td>
<td>✓</td>
<td>x</td>
<td>Currently developing new mine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BGG</td>
<td>Black Gold International</td>
<td>x</td>
<td></td>
<td>Not currently listed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KRL</td>
<td>Kangaroo resources</td>
<td>✓</td>
<td>x</td>
<td>Indonesian coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLR</td>
<td>Continental resources</td>
<td>✓</td>
<td>x</td>
<td>Developing resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCC</td>
<td>Continental Coal Limited</td>
<td>✓</td>
<td>x</td>
<td>South African Mines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CWK</td>
<td>Coalworks</td>
<td>✓</td>
<td>x</td>
<td>Developing resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMR</td>
<td>Stanmore</td>
<td>✓</td>
<td>x</td>
<td>Developing resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REY</td>
<td>Rey Resources</td>
<td>✓</td>
<td>x</td>
<td>Developing resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Three company stocks met all the criteria, New Hope Coal, Whitehaven Coal and Gloucester Coal. It is worth noting that these companies represent a small component of the Australian Coal Mining industry, with most coal mining projects part of much larger diversified mining portfolios like BHP Billiton, Rio Tinto and Xstrata.

**New Hope Corporation (NHC)**

New Hope Corporation Limited is an independent energy company that undertakes exploration, development, production, and processing of coal in Australia. Its projects include the New Acland project situated in the Darling Downs region of Queensland; the New Lenton Project, an open cut and underground resource of coking/PCI and thermal coal project located at Lenton; The Colton Project, an open cut coking coal project situated near Maryborough; and Elimatta, a thermal open cut coal deposit located in the northern Surat Basin. The company produces and sells thermal coal in both export and domestic markets.
Figure 21  New Hope Coal, Share Price and Trading Volume


<table>
<thead>
<tr>
<th>Date</th>
<th>Adj close</th>
<th>Annulised capital return</th>
<th>Dividend</th>
<th>Div Yield</th>
<th>Total Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>16/09/2003</td>
<td>0.62</td>
<td>-1%</td>
<td>0.00</td>
<td>0.00%</td>
<td>-1.0%</td>
</tr>
<tr>
<td>31/12/2003</td>
<td>0.60</td>
<td>-1%</td>
<td>0.00</td>
<td>0.00%</td>
<td>-1.0%</td>
</tr>
<tr>
<td>31/12/2004</td>
<td>1.32</td>
<td>79%</td>
<td>0.77</td>
<td>57.95%</td>
<td>136.8%</td>
</tr>
<tr>
<td>31/12/2005</td>
<td>1.21</td>
<td>-9%</td>
<td>0.19</td>
<td>15.50%</td>
<td>6.8%</td>
</tr>
<tr>
<td>31/12/2006</td>
<td>1.38</td>
<td>13%</td>
<td>0.09</td>
<td>6.52%</td>
<td>19.7%</td>
</tr>
<tr>
<td>31/12/2007</td>
<td>2.24</td>
<td>48%</td>
<td>0.08</td>
<td>3.39%</td>
<td>51.8%</td>
</tr>
<tr>
<td>31/12/2008</td>
<td>3.36</td>
<td>41%</td>
<td>0.14</td>
<td>4.09%</td>
<td>44.6%</td>
</tr>
<tr>
<td>31/12/2009</td>
<td>4.57</td>
<td>31%</td>
<td>0.82</td>
<td>17.94%</td>
<td>48.7%</td>
</tr>
<tr>
<td>31/12/2010</td>
<td>4.85</td>
<td>6%</td>
<td>0.24</td>
<td>4.85%</td>
<td>10.8%</td>
</tr>
<tr>
<td>31/12/2011</td>
<td>5.53</td>
<td>13%</td>
<td>0.25</td>
<td>4.57%</td>
<td>17.7%</td>
</tr>
</tbody>
</table>

Table 16 shows the total yield for NHC. It demonstrates the volatility of the returns associated with the project with the total yield ranging between -1% and 136.8%. This is graphically shown in Figure 22 below.
**Whitehaven Coal Limited (WHC)**

Whitehaven Coal Limited, engages in the development, production, and operation of coal mines in New South Wales. It operates in the Gunnedah Coal Basin with the Tarrawonga, Rocglen, and Sunnyside open cut mines; the Werris Creek project; the Narrabri underground mine; and the Vickery open cut mine. The company produces thermal and metallurgical coal.

![Figure 22 Annual returns for NHC](image)

![Figure 23 Whitehaven Coal Share price and trading volume](image)

Table 17 reveals that annual returns for WHC are like NHC and are highly volatile. Unlike NHC however, WHC coal has experienced years of considerable negative returns. Whilst its dividend yield has continued to deliver a dividend to shareholders its return on capital has fluctuated significantly.

<table>
<thead>
<tr>
<th>Date</th>
<th>Adj close</th>
<th>Annulised return</th>
<th>Dividend</th>
<th>Div Yield</th>
<th>Total Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/06/2007</td>
<td>1.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/12/2007</td>
<td>3.22</td>
<td>30.96%</td>
<td>0</td>
<td>0.00%</td>
<td>31.0%</td>
</tr>
<tr>
<td>31/12/2008</td>
<td>1.43</td>
<td>-81.17%</td>
<td>0.017</td>
<td>1.19%</td>
<td>-80.0%</td>
</tr>
<tr>
<td>31/12/2009</td>
<td>5.21</td>
<td>129.29%</td>
<td>0.085</td>
<td>1.63%</td>
<td>130.9%</td>
</tr>
<tr>
<td>31/12/2010</td>
<td>6.72</td>
<td>25.45%</td>
<td>0.056</td>
<td>0.83%</td>
<td>26.3%</td>
</tr>
<tr>
<td>30/12/2011</td>
<td>5.29</td>
<td>-23.93%</td>
<td>0.074</td>
<td>1.40%</td>
<td>-22.5%</td>
</tr>
</tbody>
</table>

Figure 24 Annual returns for WHC
Gloucester Coal Limited (GCL)
Gloucester Coal Limited produces both coking and thermal coals. It has interests in the Stratford mine comprising the Bowens Road North pit and Roseville pits located in the Gloucester Basin; and the Duralie mine consisting of Weismantel and Clareval pits situated in the southern part of the Gloucester Basin. The company also holds interests in the Middlemount mine, a development mine located in Queenslands Bowen Basin; and Donaldson Open Cut Mine near the Newcastle. In addition, it owns interests in the Tasman underground mine located near Maitland and Abel underground mine, also situated near Newcastle. The company is headquartered in Sydney, Australia.

![Gloucester Coal - GCL.AX](http://au.finance.yahoo.com)

**Figure 25** Gloucester Coal's Share price and trading volume [http://au.finance.yahoo.com](http://au.finance.yahoo.com)


<table>
<thead>
<tr>
<th>Date</th>
<th>Adj close</th>
<th>Annulised retreat dividend</th>
<th>Dividend</th>
<th>Div Yield</th>
<th>Total Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/04/2004</td>
<td>0.41</td>
<td>128.5%</td>
<td>0</td>
<td>0.00%</td>
<td>128.5%</td>
</tr>
<tr>
<td>31/12/2004</td>
<td>2.19</td>
<td>31.5%</td>
<td>0.1</td>
<td>3.33%</td>
<td>34.8%</td>
</tr>
<tr>
<td>30/12/2005</td>
<td>3</td>
<td>31.5%</td>
<td>0.1</td>
<td>3.33%</td>
<td>34.8%</td>
</tr>
<tr>
<td>29/12/2006</td>
<td>4.03</td>
<td>29.5%</td>
<td>0.23</td>
<td>5.71%</td>
<td>35.2%</td>
</tr>
<tr>
<td>31/12/2007</td>
<td>6.6</td>
<td>49.3%</td>
<td>0.14</td>
<td>2.12%</td>
<td>51.5%</td>
</tr>
<tr>
<td>31/12/2008</td>
<td>3.88</td>
<td>-53.1%</td>
<td>0.21</td>
<td>5.41%</td>
<td>-47.7%</td>
</tr>
<tr>
<td>31/12/2009</td>
<td>9.1</td>
<td>85.2%</td>
<td>0.135</td>
<td>1.48%</td>
<td>86.7%</td>
</tr>
<tr>
<td>31/12/2010</td>
<td>12.35</td>
<td>30.5%</td>
<td>0</td>
<td>0.00%</td>
<td>30.5%</td>
</tr>
<tr>
<td>30/12/2011</td>
<td>8.6</td>
<td>-36.2%</td>
<td>0</td>
<td>0.00%</td>
<td>-36.2%</td>
</tr>
</tbody>
</table>
Like WHC, GCL’s total yield as seen in Table 18, has fluctuated considerably a considerable negative result in 2008. Figure 26 shows the relative magnitude of negative results for 2008 and 2011.

![Figure 26 Annual returns for GCL](image)

**Table 19** Expected return and standard deviations for NHC, WHC and GCL based on annual historical data as shown in Tables 15, 16, 17.

<table>
<thead>
<tr>
<th>Equity</th>
<th>SD</th>
<th>ER</th>
</tr>
</thead>
<tbody>
<tr>
<td>NHC</td>
<td>0.420</td>
<td>0.373</td>
</tr>
<tr>
<td>WHC</td>
<td>0.778</td>
<td>0.171</td>
</tr>
<tr>
<td>GCL</td>
<td>0.581</td>
<td>0.354</td>
</tr>
</tbody>
</table>

**An open cut mining portfolio composed of NHC, WHC, GCL**
The primary purpose for constructing the portfolio is to derive a volatility and expected return parameter for use in the real options analysis that is representative of public and private risks an open cut coal mine in Australia could expect to face. The Markowitz portfolio optimisation methodology (Markowitz 1952; Bodie, Ariff et al. 2007) was
employed to derive the statistics from the portfolio. In this context a portfolio optimiser was constructed in MS Excel (See Appendix 4). The optimum portfolio based on the Maximised Sharp ratio was also calculated using the optimised portfolio. The portfolio with the maximised Sharpe ratio was then used in the Real Options Analysis.

**Table 20 Correlation Matrix**

<table>
<thead>
<tr>
<th></th>
<th>NHC</th>
<th>WHC</th>
<th>GCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>NHC</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHC</td>
<td>0.22</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>GCL</td>
<td>0.34</td>
<td>0.94</td>
<td>1.00</td>
</tr>
</tbody>
</table>

The Correlation Matrix shown in Table 20 is based on historical data for NHC, WHC and GCL. To compute the efficient frontier, which is the set of portfolios that are considered as potential investment candidates the correlation matrix is used to construct a covariance table using the relationship \( \text{Cov} (r_i, r_j) = \rho_{ij} \sigma_i \sigma_j \). Table 21 shows both the cell formulas and numerical results (see Appendix 4 for detailed analysis).
Table 21  Formulas in the Portfolio Optimiser Spreadsheet

To calculate the portfolio parameters, portfolio weights are entered in Cell B31:B33. The variance of the portfolio is then calculated in Cell D38. The entry in this cell equals the sum of each element in the covariance matrix where each element is multiplied by the portfolio weights. The standard deviation and expected returns are also calculated. Table 22 shows the numerical results of the optimised portfolio.
Table 22 Numerical results of optimised portfolio

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
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<tr>
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<td>FR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>NHC</td>
<td>42%</td>
<td>37%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>WHC</td>
<td>78%</td>
<td>17%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>GCL</td>
<td>58%</td>
<td>35%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
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<td>Correlation Matrix</td>
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</tr>
<tr>
<td>11</td>
<td></td>
<td>A</td>
<td>NHC</td>
<td>WHC</td>
<td>GCL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>NHC</td>
<td>1.00</td>
<td>0.22</td>
<td>0.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>WHC</td>
<td>0.22</td>
<td>1.00</td>
<td>0.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>GCL</td>
<td>0.34</td>
<td>0.94</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>B</td>
<td>NHC</td>
<td>WHC</td>
<td>GCL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>NHC</td>
<td>0.18</td>
<td>0.07</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>WHC</td>
<td>0.07</td>
<td>0.61</td>
<td>0.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>GCL</td>
<td>0.08</td>
<td>0.43</td>
<td>0.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td>C</td>
<td>NHC</td>
<td>WHC</td>
<td>GCL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
<td>NHC</td>
<td>0.05</td>
<td>-0.03</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>WHC</td>
<td>-0.03</td>
<td>0.38</td>
<td>-0.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td></td>
<td>GCL</td>
<td>0.05</td>
<td>-0.45</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>Portfolio Variance</td>
<td>0.16</td>
<td> </td>
<td> </td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>Portfolio SD</td>
<td>0.40</td>
<td> </td>
<td> </td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>Portfolio Mean</td>
<td>0.51</td>
<td> </td>
<td> </td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To compute points along Efficient Frontier Excel's solver tool is used. In this study the objective is to minimise the portfolio variance for an expected return by changing the portfolio weights. Table 23 shows the results of this method. This study assumes that shorting is possible in constructing the portfolio, however, the constraint that the total portfolio weighting must equal 1 (cell B36) is enforced in solver.
Table 23 Calculated Portfolio Statistics

<table>
<thead>
<tr>
<th>ER</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.39</td>
<td>0.605593</td>
</tr>
<tr>
<td>0.4</td>
<td>0.575034</td>
</tr>
<tr>
<td>0.41</td>
<td>0.545963</td>
</tr>
<tr>
<td>0.42</td>
<td>0.518622</td>
</tr>
<tr>
<td>0.43</td>
<td>0.493309</td>
</tr>
<tr>
<td>0.44</td>
<td>0.470345</td>
</tr>
<tr>
<td>0.45</td>
<td>0.450091</td>
</tr>
<tr>
<td>0.46</td>
<td>0.432927</td>
</tr>
<tr>
<td>0.47</td>
<td>0.419235</td>
</tr>
<tr>
<td>0.48</td>
<td>0.409363</td>
</tr>
<tr>
<td>0.49</td>
<td>0.40359</td>
</tr>
<tr>
<td>0.5</td>
<td>0.402094</td>
</tr>
<tr>
<td>0.51</td>
<td>0.404922</td>
</tr>
<tr>
<td>0.52</td>
<td>0.411983</td>
</tr>
<tr>
<td>0.53</td>
<td>0.423068</td>
</tr>
<tr>
<td>0.54</td>
<td>0.43787</td>
</tr>
<tr>
<td>0.55</td>
<td>0.456027</td>
</tr>
<tr>
<td>0.56</td>
<td>0.477157</td>
</tr>
<tr>
<td>0.57</td>
<td>0.500884</td>
</tr>
<tr>
<td>0.58</td>
<td>0.526856</td>
</tr>
<tr>
<td>0.59</td>
<td>0.554759</td>
</tr>
<tr>
<td>0.6</td>
<td>0.584319</td>
</tr>
<tr>
<td>0.61</td>
<td>0.615289</td>
</tr>
<tr>
<td>0.62</td>
<td>0.647474</td>
</tr>
<tr>
<td>0.63</td>
<td>0.6807</td>
</tr>
<tr>
<td>0.64</td>
<td>0.714825</td>
</tr>
<tr>
<td>0.65</td>
<td>0.749716</td>
</tr>
<tr>
<td>0.66</td>
<td>0.78528</td>
</tr>
<tr>
<td>0.67</td>
<td>0.821432</td>
</tr>
<tr>
<td>0.68</td>
<td>0.858085</td>
</tr>
<tr>
<td>0.69</td>
<td>0.895189</td>
</tr>
</tbody>
</table>
Figure 27 The Efficient Frontier for the Open Cut Coal Mining Portfolio with the maximised Sharp ratio shown in red.

To calculate which portfolio to hold along the Efficient Frontier, this study uses the Sharp Ratio (Sharpe 1966). The Sharpe ratio measures the average portfolio excess return over a sample period by the standard deviation of returns over the same period.

\[
Sharpe's \text{ ratio} = \left( \frac{\bar{r}_p - r_f}{\sigma_p} \right)
\]

Equation 22 Sharpe’s ratio.

The maximum Sharpe ratio is found by using MS Solver and setting the target to maximise the Sharpe ratio by changing the weightings in the portfolio optimiser.
The Maximum point shown in Figure 28 represents the point where the excess return as a ratio to the overall risk is greatest. It was selected over Treynor's ratio because it measures the total risk of the portfolio and not just the risk associated with systematic risk of the portfolio. In effect it is capturing both the public and private risks (Smith and Nau 1995; Smith and McCardle 1999; Brandão, Dyer et al. 2005) of the mining projects in the portfolio. Treynor's ratio in contrast only uses the systematic component of risk substituting the portfolio beta for the standard deviation and hence would only capture the public risk component of the mining projects.

\[
Treynor's\ ratio = \frac{(r_p - r_f)}{\beta_p}
\]

Equation 23 Treynor’s ratio.
Because the aim of this study is to capture the total risk associated with coal mining the Sharpe Ratio is considered more appropriate. The Maximised Sharpe ratio is shown in red on Figure 27. Hence the optimal portfolio that is argued to reflect on average, the same risks as those the case study is exposed to is;

\[
\text{Optimum Coal Portfolio} = (0.51 \text{ NHC}) - (0.79 \text{ WHC}) + (1.28 \text{ GCL})
\]

**Equation 24**  The Optimum Coal Portfolio

There are several problems with this approach to constructing a portfolio who's primary aim is to use in RO analysis.

The first problem relates to the problem of inference and representativeness of historical data. The portfolio is relying on a limited sample period to estimate the means and covariance's and its representativeness of future performance is questionable. Anderson (2006) in a study of fund managers performance in relation to portfolio management concluded that there was no evidence to suggest that past performance was a reliable indicator of future performance. This he argues was the same finding as earlier workers like Sharpe (1966).

Despite this problem historical data analysis is at the core of many of the fundamental concepts currently used in financial analysis. The CAPM, for example, analyses historical
market and equity returns to calculate a Beta. Modern portfolio analysis (Markowitz 1952; Sharpe 1966) also relies on expected returns, variances, standard deviations and covariances derived from historical data. The use of historical data as an indicator of future performance is therefore entrenched in modern finance given the prevalence of these methodologies. This study whilst recognising the potential shortcomings of the practice will side with industry practice and also use historical data as an indicator of future performance.

Another problem with the coal portfolio for RO use is the fact that the most significant coal mine operators in Australia, like BHP Billiton, Rio Tinto and Xstrata are diversified across commodities. This study argues that because the coal mining business of these companies cannot be stripped out and evaluated individually, the risk profile presented by these companies would not be in line with that of a coal mine. These mining companies have adopted a strategy whereby they have diversified across the commodities that they mine. This strategy reduces their overall risk in the same way that a portfolio of financial assets does. Because correlation between commodity markets is less than perfect then as the number of commodities are added to the mining portfolio the market risk of the company should be reduced.

Since this study wants to capture the total risk of a coal mining company these diversified companies should not be used to derive risk parameters for the RO analysis since it is argued that they will under predict the risk associated with a coal project. To test this
assumption the same coal portfolio as presented in Equation 24 was analysed with the addition of BHP and Rio Tinto using the same methodology as previously described to construct an Efficient Frontier. Such a portfolio would represent a significant portion of all coal mines but would underestimate the riskiness of these ventures as seen in the portfolio variance.

Figure 29. A comparison of Efficient Frontiers including BHP and Rio Tinto with the coal only portfolio.

Figure 29 demonstrates that the proposition of including BHP and Rio Tinto in the portfolio would reduce its risk with the Efficient Frontier clearly shifting to the left and dropping in expected return.
Table 24 Derived Portfolio Parameters for RO analysis (see Appendix 4)

<table>
<thead>
<tr>
<th>Portfolio Variance</th>
<th>0.16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portfolio Standard Deviation</td>
<td>0.40</td>
</tr>
<tr>
<td>Portfolio Mean</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Real Options Analysis

Introduction
This section develops a model for determining the value of a mining project that produces both thermal and metallurgical coal that both sells in a market, and has a cost profile, dominated by uncertainty. The model aligns itself with the MAD methodology of RO analysis whereby the underlying asset is considered to be the NPV of the project itself and volatility and expected return parameters are derived from the coal portfolio presented in the previous section.

The subjective nature of the derived parameters in the model is reduced by assuming the existence of a portfolio of coal projects that mimics the value of the coal mine in the case study. It is argued that the portfolio is exposed to the same technical and market risks as the case study and as such will capture both market and private risks. Whereas the classical concept of RO analysis assumes complete markets this adaptive MAD approach relaxes this assumption making it more flexible and intuitive for practitioners.
The value of the NPV was previously shown to be $1.209 Billion. The model recognises several operating strategies available to management as the mine proceeds and current uncertainties unfold. These operational options are:

1. The option to abandon
2. The option to Expand
3. The option to contract
4. The option to Wait

A question that may be formed by the practitioners is: What is the probability of exercising the option to abandon the mine or what is the probability of expanding or contracting. The mining real options literature offers little insight into this question, however, A search of real options texts revealed a discussion by Kodukula and Papudesu (2006) on Pascals Triangle. They showed how for a pharmaceutical company the properties of this lattice could be used to predict the probability of abandoning a research and development project. The same principle is applied in this study to calculate the probability of abandoning, contracting or expanding the mining project.

**The option to abandon**
The current Mine Plan for the case study mine is to operate at an annual production rate of between 5.5 million and 6.3 million run of mine tonnes for the next nine years before scaling production back in 2021 as the coal reserve is exhausted. If during this time business conditions change detrimentally, management have the right but not the obligation to
abandon the operation by realising the market value of any existing assets like plant and equipment and ceasing mining operations completely.

The first step in modelling this flexibility using RO is to construct a Binomial Tree. Using traditional DCF analysis has established the current NPV of the mine to be $1.209 Billion. Using the parameters derived from the coal portfolio the volatility that will be applied to expected future cash flows is found to be 40% (Table 23). The risk free rate is currently 4.25%. The salvage value of the mining operation is estimated at $73 million (Appendix 1).

![Figure 30 Binomial Lattice evolution of underlying mine value](image)

Where:

Salvage value \( (K) \) = $73 million
NPV \( (S) \) = $1209 million

\[ \sigma = 40\% \]

\[ T = 14 \]

\[ r_f = 4.25\% \]

\[ e^{\sigma \sqrt{T}} = 1.492 \]

\[ e^{\sigma \sqrt{T}} = \frac{1}{u} = 0.670 \]

\[ p = \frac{e^{r_f t-d}}{u-d} = 0.454 \]

All of the calculations and steps involved in calculating the lattice in Figure 30 are based on the up factor, down factor and risk neutral probability discussed in the Methodology Chapter (see Appendix 5 for calculations).

Creating the Option Valuation Lattice involves firstly valuing the terminal nodes at year 2024 and then using the process of backward induction (Hull 2008) to value intermediate nodes. Figure 31 shows the option value lattice. It is treated like a put option since management has the right but not the obligation to sell the asset (abandon) at a predefined strike (salvage) value. The terminal value is the maximum value of either the value of normal operation or the salvage value. The cells shown in blue represent the floor value where the salvage value is greater than the continued operation. In these cases the salvage value of
plant and equipment is greater than the ongoing value of the mine. Under these scenarios the mine would be abandoned.

Figure 31 The Option Valuation Lattice

By having a way out for management, the project is worth more than its static value of $1,209.4 million at $1,210.13 million. This option value is therefore worth $1,210.13 - $1,209.41 = $726,429. This value would increase significantly for projects that were more marginal.

Whilst the binomial lattice methodology is intuitive it is an approximation of the closed form Black and Scholes (1973) method. Calculation of the abandonment option using this
method (Equation 18) revealed an option value of $1.03 million.

\[
Put = N(-d_2)Ke^{-r(T-t)} - N(-d_1)S
\]

= $1.03 million

Where

\[
d_1 = 3.02
\]
\[
d_2 = 1.53
\]
\[
S = $1,209 \text{ million}
\]
\[
K = $72.87 \text{ million}
\]
\[
r = 4.25\%
\]
\[
T=14
\]
\[
t = 1
\]

Since the binomial lattice in Figure 31 is recombining there are many paths leading to each node and the number of paths contributing to each node must be calculated before estimating the probability of exercising the option.

Figure 32 Pascals Triangle for the Abandonment Option. Cells shown in pink represent scenarios where the mine would be abandoned.
A calculation of the probability of abandonment of the project shows that there is a very low likelihood of abandoning the mine. This is a function of the relatively low value associated with the abandonment option and the overall profitability of the project.

**Table 25 Calculated probability of abandonment option**

<table>
<thead>
<tr>
<th>Year</th>
<th>Probability of Abandonment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>0</td>
</tr>
<tr>
<td>2012</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>0</td>
</tr>
<tr>
<td>2014</td>
<td>0</td>
</tr>
<tr>
<td>2015</td>
<td>0</td>
</tr>
<tr>
<td>2016</td>
<td>0</td>
</tr>
<tr>
<td>2017</td>
<td>0</td>
</tr>
<tr>
<td>2018</td>
<td>0</td>
</tr>
<tr>
<td>2019</td>
<td>0</td>
</tr>
<tr>
<td>2020</td>
<td>0.20%</td>
</tr>
<tr>
<td>2021</td>
<td>0.10%</td>
</tr>
<tr>
<td>2022</td>
<td>0.59%</td>
</tr>
<tr>
<td>2023</td>
<td>1.93%</td>
</tr>
<tr>
<td>2024</td>
<td>1.12%</td>
</tr>
</tbody>
</table>
The option to Expand
The option to expand provides the right but not the obligation to increase production. It is analogous to a call option. This study argues that a realistic expansion option is to increase production capacity by an additional mining fleet, comprising of an additional large excavator, associated trucks and ancillaries (Appendix 1). This increases production by 28%.

An additional upgrade to the CHPP plant is also required under an expansion scenario. The total cost of the plant and equipment is modelled to be $414 million (Appendix 5). This is the strike price of the option, that is, the price that must be paid to exercise the option to expand. The value of the underlying asset is still assumed to be $1,209 million, however, the increased production profile of the schedule imposed on the finite reserve base mean that the mine is exhausted faster.

Figure 34 Binomial Lattice Valuation of the case study by increasing production by 28% (i.e. one additional Mining Fleet and expanded CHPP).
The option value for expanding is calculated as the value of the project with the expansion option less the value of the project without the option. The value is therefore:

\[ \$1,369 \text{ million} - \$1,209 \text{ million} = \$160 \text{ million} \]

The optimal areas for exercise of the option are shaded blue in Figure 35. This clearly shows that it is optimal to expand the operation now. Analysis by Pascals Triangle methodology shows a significant probability of expanding yet this is not what is seen in actuality. The reason for this will be discussed in a later section.

**Figure 35** Pascals Triangle for Expansion Option showing expansion nodes
Figure 36 Histogram of expansion option outcomes

Table 26 Expansion probability

<table>
<thead>
<tr>
<th>Year</th>
<th>Probability of Expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>100%</td>
</tr>
<tr>
<td>2012</td>
<td>100%</td>
</tr>
<tr>
<td>2013</td>
<td>100%</td>
</tr>
<tr>
<td>2014</td>
<td>100%</td>
</tr>
<tr>
<td>2015</td>
<td>94%</td>
</tr>
<tr>
<td>2016</td>
<td>81%</td>
</tr>
<tr>
<td>2017</td>
<td>66%</td>
</tr>
<tr>
<td>2018</td>
<td>50%</td>
</tr>
<tr>
<td>2019</td>
<td>36%</td>
</tr>
</tbody>
</table>

Analysis of the closed form Black and Scholes Method revealed a value of:

$$Call(S, t) = N(d_1)S - N(d_2)Ke^{-r(T-t)} = 1,290$$

$$1,290 - 1,209 = 81 \text{ M}$$
The option to contract
The option to contract by 33% has the same characteristics as a put option, because the option value increases as the value of the underlying asset decreases. At every node shown in Figure 37, management have an option to either continue the operation and keep the option open or contract by reducing the fleet capacity by 33%. To calculate the value at the terminal Node labelled A in Figure 37 for example, the node option value is calculated by determining the maximum value of either the value without exercising the option or the value of reducing production by 33%. Management has the right to reduce production resulting in a 33% drop in cash flow to save $150 million in costs annually.

This calculation is:

\[
\text{Node Value at A} = \max (219,232 \times (1-0.33) + 150, 219,232) = \max (147,035, 219,232) = 219,232
\]

\[
\text{Node Value at B} = \max (7 \times (1-0.33) + 150, 0) = \max (154, 0) = 150.
\]

Like the option to expand the option to contract has a very high probability of being exercised. This probability is discussed more fully in a later section where issues like being optimal to both expand and contract are derived simultaneously. Cells shown in grey in Figure 37 will not be kept open whereas, those options shown in white should be kept open since they have value in the poor market conditions represented by these nodes. These areas overlap with the areas in the expansion case which as alluded to previously are discussed more fully in a later section.
The value of the option to contract is therefore $1,209 - 1,227 = $17.2 million.

The closed form solution for the option to contract comes in at $5.2 million. This is in contrast to the $17.2 million that the lattice solution provides.
Figure 38  Pascals Triangle for Contraction Option showing contraction nodes highlighted in grey.

Table 27 Probability of Contraction

<table>
<thead>
<tr>
<th>Year</th>
<th>Probability of Contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>100%</td>
</tr>
<tr>
<td>2012</td>
<td>100%</td>
</tr>
<tr>
<td>2013</td>
<td>100%</td>
</tr>
<tr>
<td>2014</td>
<td>100%</td>
</tr>
<tr>
<td>2015</td>
<td>100%</td>
</tr>
<tr>
<td>2016</td>
<td>100%</td>
</tr>
<tr>
<td>2017</td>
<td>98.44%</td>
</tr>
<tr>
<td>2018</td>
<td>93.75%</td>
</tr>
<tr>
<td>2019</td>
<td>85.55%</td>
</tr>
<tr>
<td>2020</td>
<td>74.61%</td>
</tr>
<tr>
<td>2021</td>
<td>62.30%</td>
</tr>
<tr>
<td>2022</td>
<td>50.00%</td>
</tr>
<tr>
<td>2023</td>
<td>38.72%</td>
</tr>
<tr>
<td>2024</td>
<td>29.05%</td>
</tr>
</tbody>
</table>

An interesting feature of the contraction option is the overlap it has with option to expand.

Clearly it is not possible to both expand and contract at the same time a fact that introduces the concept of option interaction. An insight into this phenomena is provided by Trigeorgis
(1993a, 1993b) who considers the nature of option interactions within projects and finds that many real options are mutually exclusive and that it would be erroneous to simply add real options together to get an overall project value. Rather he argues that the addition of multiple option values to a project are probably incrementally small due to this offsetting effect. The apparent mutually exclusive nature of the option to expand and contract in this study support this proposition, a fact that can be graphically shown in Figure 39. It shows the probability of exercising either of the options. If an option derives value from a positive move in the value of the mine then its probability is assigned a positive sign, and a negative sign if value is created from a negative movement of the underlying value of the mine. This means that the contraction probabilities become negative and the expansion probabilities become positive. It is not intended to show the probability is greater for expansion than contraction.

![Figure 39 The probability of exercising the contraction option](image-url)
Figure 39 also reveals other characteristics of the option behaviour. The asymmetry of the options reveals that the expansion option which is shorter lived because it depletes the resource faster due to expanded capacity loses value quicker than the contraction option. Coupled with this is the greater value of the expand option. Hence it’s argued that for this project the optimum decision would be to expand production as preference to contracting production. This is in line with intuition that points to an expansive phase of the mining cycle rather than a contraction.

**The option to Wait**
The Case Study has two exploration leases which can be converted into operating pits. The first area known as Pit A represents an area where an additional 2.2 million ROM tonnes can be mined per annum. It assumes that it exposed to the same risk profile as the mine portfolio and with a profit profile the same as the Main Pit. Management has the right to start mining this lease when it feels the opportunity is right within a five year window that the lease is valid. This is analogous to a call option. To exercise the option management must spend $200 million on plant and equipment.
Table 28 Pit A DCF model

<table>
<thead>
<tr>
<th>Year</th>
<th>Tonnes coal mined</th>
<th>Profit / ROM t</th>
<th>WACC</th>
<th>Sum of DCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>2,200,000</td>
<td>$41.20</td>
<td>18.41%</td>
<td>$90,630,241</td>
</tr>
<tr>
<td>2013</td>
<td>2,200,000</td>
<td>$38.24</td>
<td></td>
<td>$84,120,717</td>
</tr>
<tr>
<td>2014</td>
<td>2,200,000</td>
<td>$43.02</td>
<td></td>
<td>$94,649,718</td>
</tr>
<tr>
<td>2015</td>
<td>2,200,000</td>
<td>$47.42</td>
<td></td>
<td>$104,323,556</td>
</tr>
<tr>
<td>2016</td>
<td>2,200,000</td>
<td>$51.91</td>
<td></td>
<td>$114,198,995</td>
</tr>
</tbody>
</table>

Given that the mining lease is for a five year period the option must be exercised after five years, hence the terminal node values are calculated using Max (S-K,0). For the upmost node in 2016 this equates to;

Figure 40 Binomial lattice of underlying asset (Pit A)

Figure 41 Option analysis of Pit A
Max (S-K,0) =Max($1,404-$200,0) = $1,204 million.

Each terminal node is calculated and rolled back as in previous options with the previously calculated parameters derived from the Coal Portfolio.

The closed form Black and Scholes solution came in at $151 million which is slightly higher than the $144 million for the lattice method.

The second exploration area, Pit B has a higher strip ratio (waste/coal) meaning the profit margin is significantly reduced from that seen in Pit A where the strip ratio was the same as the main operation.

Table 29 Pit B DCF model

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonnes coal mined</td>
<td>2,200,000</td>
<td>2,200,000</td>
<td>2,200,000</td>
<td>2,200,000</td>
<td>2,200,000</td>
</tr>
<tr>
<td>Profit / ROM t ROM t</td>
<td>$30.00</td>
<td>$30.00</td>
<td>$30.00</td>
<td>$30.00</td>
<td>$30.00</td>
</tr>
<tr>
<td>Discount DCF</td>
<td>$66,000,000</td>
<td>$66,000,000</td>
<td>$66,000,000</td>
<td>$66,000,000</td>
<td>$66,000,000</td>
</tr>
<tr>
<td>$54,902,273</td>
<td>$45,670,599</td>
<td>$37,991,207</td>
<td>$31,603,085</td>
<td>$26,289,109</td>
<td></td>
</tr>
<tr>
<td>Strike Price</td>
<td>$200</td>
<td>$200</td>
<td>$200</td>
<td>$200</td>
<td>$200</td>
</tr>
</tbody>
</table>
A conventional NPV analysis of Pit A would derive an NPV of $284 million - $200 million = $84 million dollars. Under conventional financial theory management would approve this project since it has a positive NPV. In contrast the NPV of Pit B would be $196 million - $200 million = - $4 million and it would be rejected. However, if management waited until subsequent years where the DCF value was greater than the strike price ($200 million) then the project would be accepted rather than rejected. Erroneously under conventional financial theory this project would be rejected. In effect its benefit could be quantified by using Equation 11 that states;

$$\text{NPV}_{RO} = \text{NPV}_{DCF} + \text{Option value}$$
Therefore:

\[
\text{NPV}_{RO} = -$4 \text{ million} + $69 \text{ million}
\]

\[
\text{NPV}_{RO} = $65 \text{ million}
\]

Clearly the RO approach adds significant value to the project and provides an investment decision that is the opposite to conventional financial thinking. A rational manager would not abandon the project as suggested by the traditional NPV approach.

The closed form Black and Scholes Methodology produced a value of $80.5 million which is higher than the $65 million derived using the lattice method.
Chapter 4 - Discussion

Volatility
Debate in the real options literature centres on the volatility parameter and how it is derived (Borison 2005a; Borison 2005b; Barton and Lawryshyn 2010). Despite this there is generally no discussion in published studies on how the value is derived. Damodaran (2000) uses an even 20% when valuing a Gold mine with no discussion of how this number was obtained, leaving the reader to suppose that it is a subjective estimate. Dimitrakopoulos and Sabour (2007) in a study of real options and their applicability to mine planning in Australia, used a value of 13% for gold prices derived from historical spot price data. Although they describe the general source of data they do not discuss the time frame over which the analysis was performed. Smit and Trigeorgis (2003) in a paper describing examples of real options valuations and strategy do not discuss the actual volatility figure, relying only on up and down parameter values to satisfy the readers curiosity about their treatment of underlying volatility. A single coal volatility used in a real options study by Jin-Feng and Yan et., (2010) derives an implied value of 30% from a Monte Carlo simulation. These studies are representative of the literature with most discussions ignoring the volatility parameters derivation or presenting a subjective estimate that is usually not supported. This study address this shortcoming in the literature through its derivation and use of an appropriate volatility measure.

The volatility estimate used in this study is significantly higher than that described in the literature. Literature estimates appear to predominantly be around 20% whereas this study argues that a more appropriate rate is around twice this literature rate at 40%. Whereas most studies (Kemna 1993; Mardones 1993; Dixit and Pindyck 1995; Shafiee, Topal et al.
2009 a) using any of the classifications described by Borison (2005a) are happy to use a volatility subjectively derived or estimated from historical commodity price data, this study argues that this practice underestimates the true volatility. The study by Jin-Feng and Yan et., (2010) provides some support to the notion that the volatility number should be higher than is generally used in the literature but is very brief in nature with little support for its numerical derivations and analysis.

This study argues that by using a volatility derived from commodity statistics alone it will be significantly underestimated because it only captures the market risk of the project whilst ignoring the private, project specific risk. Mining projects are composed of both public and private risks (Smith and Nau 1995) and as such both must be accounted for in any form of analysis. By assuming that the cash flows for a coal mining project reflect the net effect of both public and private risks, and the sum of all mining project cash flows for a firm will be reflected in its market price, then it stands to reason that the share price of a coal mining firm will reflect the total risk of a coal mining company. Hence the more mines held by a firm and the more firms held in a portfolio the closer the derived volatility figure will be to being representative of all of the common private and public risks for an individual mine.

A further extension of the argument for the portfolio of similar projects is that large diversified mining firms such as Xstrata, BHP Billiton or Rio Tinto are uniquely positioned to take advantage of their corporate knowledge base to derive a company specific volatility parameter. This would be done by constructing a portfolio of what are subjectively
assessed to be similar projects from within the firms portfolio and then assessing the actual historical cash flows from the projects. The volatility derived from such an analysis would have the advantage of being firm specific.

A question that rises from the preceding discussion surrounding volatility is what is the sensitivity of this projects real options value to changes in the derived volatility? To answer this question the real options model was run using various volatility parameters.

<table>
<thead>
<tr>
<th>σ</th>
<th>DCF</th>
<th>Expand</th>
<th>Abandon</th>
<th>Contract</th>
<th>Wait</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>1209.4</td>
<td>77.6</td>
<td>0.0</td>
<td>0.0</td>
<td>115.7</td>
</tr>
<tr>
<td>XT</td>
<td>0.20</td>
<td>1209.4</td>
<td>95.5</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>1209.4</td>
<td>112.6</td>
<td>0.0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>1209.4</td>
<td>129.0</td>
<td>0.0</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>1209.4</td>
<td>144.7</td>
<td>0.3</td>
<td>6.6</td>
</tr>
<tr>
<td>Portfolio</td>
<td>0.40</td>
<td>1209.4</td>
<td>159.7</td>
<td>0.7</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>1209.4</td>
<td>174.1</td>
<td>2.1</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>1209.4</td>
<td>187.7</td>
<td>3.7</td>
<td>23.1</td>
</tr>
<tr>
<td></td>
<td>0.55</td>
<td>1209.4</td>
<td>200.7</td>
<td>5.7</td>
<td>28.7</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>1209.4</td>
<td>213.0</td>
<td>9.0</td>
<td>34.1</td>
</tr>
<tr>
<td></td>
<td>0.65</td>
<td>1209.4</td>
<td>224.5</td>
<td>12.5</td>
<td>39.3</td>
</tr>
</tbody>
</table>

Table 30 shows relationship of volatility to each option. Clearly the value of the options increase significantly as the volatility increases. Two volatility scenarios are highlighted, and are shown as the export thermal coal volatility, labelled XT, and the portfolio volatility. If the methodology adopted in much of the literature was used and the volatility of the commodity, in this case thermal coal was used, the derived value would be much lower. Take the expansion scenario for example, showing a value of $95.5 million for a volatility in
line with the coal price but $159.7 million when the portfolio volatility is used. This demonstrates that by using only the market based component of the overall project risk the project will be significantly undervalued. These same findings can be extrapolated to all other commodity group mining projects like gold, copper, oil etc. If the volatility of the underlying commodity is used then the project is probably being underestimated in terms of options value.

The method of applying risk neutral probabilities to price real options is justified on the basis that a portfolio of traded investments, replicating the cashflows of the real option can be constructed and thereby removing all risk from the asset. The value of the real option is then calculated by looking at the price of the replicating portfolio. In financial markets this method works well, since exchange traded options can be used to hedge all risk. The risk neutral approach is harder to justify in real options, where there are no exchange traded instruments to eliminate risk, such as with coal mining. In a coal mining context it becomes harder to construct a portfolio that exactly replicates the value of a project, since projects are made up of many forms of risk many of which are unique to the current project (Smith and Nau, 1995). The replicating portfolio in this study is justified on the basis, that the nature of the individual mines contained in the portfolio reflect more closely the risks of the coal mine being valued than any other assets. Hence it is argued that although not reflecting exact replication it is the best portfolio that can be achieved to satisfy the condition of replication of cashflows. The author acknowledges that this is an area that warrants further research.
**Project Value**
The total project value has been shown to be the static NPV plus the option value. It has also been shown, however, that the total option value is complicated because it is incorrect to simply add the value of options due to the interactive nature of the options. Trigeorgis (1993a, 1993b) provides discussion on this issue but does not provide a definitive answer on how to treat this interactivity.

**Table 31** Real option values for the Case Study using \( \sigma = 40\% \).

<table>
<thead>
<tr>
<th></th>
<th>DCF</th>
<th>Expand</th>
<th>Abandon</th>
<th>Contract</th>
<th>Wait</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$1,209.4</td>
<td>$159.7</td>
<td>$0.73</td>
<td>$17.2</td>
<td>$143.6</td>
</tr>
</tbody>
</table>

This study argues that the option to expand dominates the option to contract. The option to wait is completely independent of other options in the project since it considers a satellite Brownfield exploration project adjacent to the current operation. The option to abandon is always present. Hence the option value of the case study is:

\[
\text{Case Study Value ROA} = \text{DCF} + \text{Expand} + \text{Abandon} + \text{Wait} \\
= \$1,209.4 + \$159.7 + \$0.73 + \$143.6 \\
= \$1,513.4
\]

This value represents a premium over the standard DCF/NPV value of 25%. This value compares well with published option premiums such as the 16% premium discussed by
Mardoness, (1993) when it is considered that he only used the volatility of the copper price which probably underestimated the total project risk.

Further evidence for this option premium may be found in the literature detailing the performance of mining initial public offerings in Australia. If as this project argues real options are generally ignored in traditional financial evaluations, then this should be reflected in the markets reaction to newly listed companies who have high optionality associated with them which is not built into their value at the time of listing. This is indeed the case as detailed by Dimovski and Brooks (2008) who in a study of Australian Gold Mining IPOs found an average underpricing of IPO gold stocks. Davis (1996) provides further support to the argument finding that mineral assets consistently trade at market values greater than their DCF values arguing that this difference is driven by the option premium value. He quotes an average premiums of about 8% to DCF but provides no discussion on the real options analysis. If he undervalues the volatility significantly then this premium could be much higher and closer to the values described in this study.
Conclusion
This study demonstrates that the evaluation of natural resource projects like those found in the case study have an inherently high degree of uncertainty which cannot be adequately accounted for using traditional NPV analysis. The methodology proposed in this study provides consideration for these uncertainties and finds a premium above traditional NPV's of approximately 20%.

A key issue when dealing with the uncertainties associated with mining projects is the ability to account for both market based (public) and project (private) risks. The method proposed in this study accounts for these risks by constructing an underlying portfolio from similar coal mining projects. The study argues that by generating a portfolio consisting of similar projects to the project being valued, the mine should be exposed to a similar risk profile as reflected in the project portfolio. This study argues that it would be valid to extrapolate this methodology to other commodities and metals projects within the mining industry where suitable portfolios could be constructed.

This study makes a contribution to the valuation methods used in the coal mining industry by demonstrating the practical use of real options analysis in the coal mining industry. It shows the feasibility, viability and advantages of the methodology and its application to an operating coal mine. It makes several key findings;

1. The real options methodology is applicable to coal mining projects.
2. The mathematical complexity of real options analysis needs be no more complex than traditional DCF/NPV analysis to provide meaningful results.

3. A portfolio approach using firms that are indicative of the project being considered will capture the public and private project risks of the project and should be used.

4. The portfolio approach could be used for different commodities.

5. Previous studies probably underestimated the value of the available options by only considering market risk in their analysis.

6. The real options value of the project is in the vicinity of 25% greater than the traditional NPV value. This is broadly in line with the existing literature when the argued underestimate of volatility from previous studies is considered.

7. Real options cannot be simply added together to provide a value. Option additivity is complex and requires further research.

8. Real options analysis may provide conflicting decisions to traditional NPV’s by recognising value when current traditional thinking argues for project rejection.

In summary this study demonstrates a feasible, viable alternative to the traditional NPV valuations of mining projects. It also has the advantage of being computationally simple when compared to more complex real options valuations that are often cited in the literature and could be easily integrated into current corporate valuations of mining projects through the simple extension of current valuation practices. Its applicability to other commodities and metals was also identified through the use of appropriate portfolios constructed from similar projects.
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Appendix 1 - Mining NPV Model

Appendix 2 - Coal Prices

Appendix 3 Xstrata Share price info

Appendix 4 - Portfolio Analysis

Appendix 5 Options Analysis