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The market premium for the option to close: Evidence from Australian gold mining firms

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Abstract

This paper assesses whether the market valuation of gold mining firms contain a premium for the option to close. Tests of whether observed market values incorporate operating flexibility is central to our understanding of the processes that drive market values and has implications for the relevance and suitability of known theoretical pricing frameworks. This paper assesses the relevancy of the option to close for mining firm valuation. This is achieved by examining 41 Australian gold mining firms listed on the Australian Stock Exchange from 1987 to 1994 that are actively engaged in gold mining extraction and production. A pooled cross-sectional regression analysis analyses 234 firm-year observations to identify the degree of association between the actual (market determined) and theoretical option premiums on the basis of the overall sample. Further robustness checks are then undertaken for sub-sample quartiles ranked on a specific firm characteristic, moneyness.

This results show that market prices incorporate a premium that reflects the option to temporarily close operations. A significant portion (73.8%) of the market-assessed value of mining operations is captured by the Hotelling Valuation Principle. The difference between the present value of expected future cash flows and the market value of mining operations is accounted for by the options to close (R^2 = 62.7%). Further, the existence and magnitude of the option premium to close is dependent on other observable attributes of the mining firm, specifically the degree of moneyness of the firm's operations.

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Abstract

This paper assesses whether the market valuation of gold mining firms contain a premium for the option to close. Real options theory states that the managerial flexibility with respect to operating decisions of the firm have a recognisable and identifiable value. Together with the present value of expected cash flows (incorporated via the Hotelling Valuation Principle), existing theory purports that the value of the option to temporarily close a firm's mining operations is embedded in the market price (see Brennan and Schwartz 1985a). Tests of whether observed market values incorporate operating flexibility is central to our understanding of the processes that drive market values and has implications for the relevance and suitability of known theoretical pricing frameworks.

This paper assesses the relevancy of the option to close for mining firm valuation. This is achieved by examining 41 Australian gold mining firms listed on the Australian Stock Exchange from 1987 to 1994 that are actively engaged in gold mining extraction and production. A pooled cross-sectional regression analysis analyses 234 firm-year observations to identify the degree of association between the actual (market determined) and theoretical option premiums on the basis of the overall sample. Further robustness checks are then undertaken for sub-sample quartiles ranked on a specific firm characteristic, moneyness.

This research establishes that market prices incorporate a premium that reflects the option to temporarily close operations, implying that the comprehensive valuation construct of Brennan & Schwartz (1985a) is more representative of the market's assessment of mining firm value. A significant portion (73.8%) of the market-assessed value of mining operations is captured by the Hotelling Valuation Principle. The difference between the present value of expected future cash flows and the market value of mining operations is accounted for by the options to close (R^2 = 62.7%). Further, the existence and magnitude of the option premium to close is dependent on other observable attributes of the mining firm, specifically the degree of moneyness of the firm's operations.

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1. Introduction

The nature and importance of mining projects to the world economy and Australia warrants the use of suitable and accurate asset valuation models[1]. The type of activities undertaken by mining firms makes their valuation different from the valuation of more conventional types of investment activities. In particular, mining activities are characterised by a sequence of distinct stages, typically: exploration, development, and extraction. Each of these stages provides the firm with an option to proceed, defer, or abandon the current stage. When a mine reaches the production stage, it has several operating options in the form of the option to temporarily close operations, abandon or otherwise alter the operating scale of the mine (Paddock, Siegel et al. 1988). Real options theory states that this managerial flexibility has a recognisable and identifiable value[2].

This paper addresses four issues. The principal research question investigates whether market prices for Australian gold mining firms reflect the value inherent in operating flexibility in the mining industry. Second, it examines what portion of any observed operating option premium is attributable to the value associated with temporary mine closures. This contributes to both asset pricing and to valuation literature by validating the use of real options techniques to capture the dimensions of investment projects that are value relevant to the market. Third, the research extends prior research in the area of real options by examining the impact on the value of real options of firm characteristics such as moneyness of the operating options of the firm. Finally, the research empirically tests the construct validity of the Brennan and Schwartz valuation model as descriptive of the value reflected in gold mining operations. In doing so, it provides evidence of the validity of the Hotelling Valuation

[1] The mining industry had estimated sales of $52.6 billion contributing around $31 billion to the gross domestic product of Australia during 2000-2001 (IBISWorld Pty Ltd 2002). The United States Geological Survey ranks Australia fourth after South Africa, USA and Uzbekistan in terms of gold resources. In 1999-2000 gold was Australia's second biggest export earning commodity, accounting for 5% of exports at a value of $5.0b (Australia Bureau of Statistics, 2002).

[2] Options on natural resources are the focus of Brennan, M. J. and E. Schwartz (1985a, 1985b), Brennan M.J (1986), Paddock, J., D. Siegel, et al. (1988), Morck, R., E. Schwartz, et al. (1989), Gibson, R. and E.S Schwartz (1990), Pickles, E. and J. L. Smith (1993) and Kelly, S (1998). This list is not exhaustive but indicative of the interest.

Principle as descriptive of market prices for Australian gold mining firms that operate deep-in-the money.

The empirical analysis isolated the theoretical-option premium by deducting the present value of cash flow, as measured by the Hotelling Valuation Principal (Hotelling 1931), form the Brennan and Schwartz (1985a) valuation. The market premium over and above the present value of cash flows is found by deducting the Hotelling Valuation Principal estimates from the market value of mining operations. The findings suggest that the market valuation of gold mining firms contain a premium for the option to close This research establishes that market prices incorporate a premium reflecting the option to temporarily close operations. In addition, a 73.8% of the market-assessed value of mining operations is captured by the Hotelling Valuation Principle. The difference between the present value of expected future cash flows and the market value of mining operations is accounted for by the options to close (R2 = 62.7%). The existence and magnitude of the option premium to close depends on the moneyness of the firm's operations.

2. Valuation Perspectives

The gold mining industry offers a unique research platform to determine the existence and magnitude of the market value of operating option premiums. First the gold commodity markets provide observable data such as the value of the underlying asset gold that is required as input parameters from valuation models. Second, there exist two theoretical-valuation approaches that when applied together help to isolate the estimated value of the option to close and the value of all operating options reflected in market prices.

Brennan and Schwartz Real Options Valuation

The first theoretical approach is the Brennan and Schwartz (B&S) model (1985a). The B&S model is one of the seminal models in the real-options literature. Of the real option pricing models available Brennan and Schwartz (1985a) provides the most suitable model to value operating flexibility in open and operating mining projects, characterising listed mining firms. The initial investment or development decision has already been made, and the producer only has the managerial flexibility option of optimising production. Brennan and Schwartz (1985a) derive a valuation process for an operating natural resource project based on Black-Scholes (1973) option pricing methodology. The option for an open operating mine is the value of the opportunity to temporarily close the mine down and avoid future losses if commodity prices fall to far below the extraction cost. The value of the mine will depend upon whether it is currently open and producing or closed and incurring maintenance costs. It will also depend upon the unexploited inventory remaining in the mine, and upon the current spot price of the commodity (Brennan and Schwartz 1985a). Details of the model specifications are contained in appendix 1 but the key equations are as follows:

$$\max_{q\in(\underline{q},\bar{q})}[\frac{1}{2}\sigma^2 S_0^2 \frac{\delta^2 v}{\delta S_0{}^2} + (r-k)S_0 \frac{\delta v}{\delta S_0} - q\frac{\delta v}{\delta Q} + q(S_0 - a_0) - \tau - (r+\lambda_1)v] = 0 \quad (1)$$

$$\frac{1}{2}\sigma^2 S_0^2 \frac{\delta^2 w}{\delta S_0^2} + (r-k)S_0 \frac{\delta w}{\delta S_0} - f - (r+\lambda_0)w = 0 \quad (2)$$

And

$$\tau = t_1 q S_0 + \max\,[t_2 q[S_0(1-t_1) - a_0],0] \quad (3)$$

Where:

$v(S_0,Q)$	=	open mine value
$w(S_0,Q)$	=	closed mine value
S_0	=	the commodity price
σ^2	=	the commodity price variance
Q	=	the mine resource inventory (reserves)
q	=	the annual extraction rate (q is assumed to be costlessly variable between the upper and lower bounds $\bar{q}$ and $\underline{q}$).
r	=	real annual interest rate = $\rho - \pi$
ρ	=	nominal annual interest rate
π	=	the annual inflation rate
k	=	the commodity convenience yield[3]
f	=	periodic maintenance cost for a closed mine
λ_1	=	proportional rate of property tax on the value of the open mine
λ_0	=	the proportional rate of property tax on the closed mine value
a_0	=	average cost of production per unit of commodity
t_1	=	royalty rate
t_2	=	income tax rate

The real-options approach has two advantages. First, a discount rate, derived from any market equilibrium model, is not required. The option-pricing approach uses

[3] The commodity convenience yield is the benefits realised from ownership of the physical commodity that are not realised by the holders of a future contract (refer to Hull 1998). A specific definition and measurement of the convenience yield are discussed later in this chapter.

risk-free rather than risk-adjusted discount rates. Second, the need for estimates of the expected rate of change of the underlying cash flow and therefore of the output price is not required. Unlike DCF analysis, the model is not dependent on predictions of future prices and inventory levels. Instead, uncertainty is modelled directly by selecting an appropriate stochastic process. Thus, the model easily incorporates the flexibility that arises from managerial control over the output rate (Kester 1984; Trigeorgis and Mason 1987; Dixit and Pindyck 1994; Trigeorgis 1995).

The limitations of this approach are embodied within the model's assumptions. The B&S model presupposes the existence of a futures market in the commodity extracted for calculation of what is known as the convenience yield. It values the future revenue inflows and cost outflows based on a known relationship between present and future values captured by the Hotelling Valuation Principle and a specified stochastic behaviour for mining revenues. The value obtained using the B&S model thus captures the present value of expected future cash flows and the value of the option to close.

Table 1 summaries the empirical evidence of estimates of the value of real operating options in actual mineral asset valuations. The table provides a comparison of DCF and real option valuation approaches demonstrating the option premium over the DCF value

Table 1: Empirical Evidence of the Value of Real Options in Operating Mining Ventures

Author	Type of Asset	Managerial Options Valued	Option Premium Value ($M)	% of DCF Value
(Mardones 1993)	Homogenous copper oxide project (Chile 1990)	Cut-off grade flexibility temporary stockpiling option	n/a	2.4
(Cavender 1992)	Small open-pit U.S. gold project. Hypothetical case	Shut-down/re-open flexibility	3.8	16.6
(Palm, Pearson et al. 1986)	Large high-cost ($0.98/lb. Copper mine 20 year mine life, current price $0.58/lb hypothetical case	Shut-down/re-open flexibility; option to abandon	120	n/a
(Brennan and Schwartz 1985a)	Hypothetical case. Copper mine Low cost of $0.50/lb. 15 year mine life	Shut-down/re-open flexibility; option to abandon	.37	2.2
(Brennan and Schwartz 1985b)	Hypothetical case. Gold Mine with average cost of $250/oz., gold price	Shut-down/re-open flexibility; option to abandon	17.22	49

	\$300/oz, 20 year mine life			

Notes: Table 1. is partially reproduced from Davis (1996), n/a = not available.

Mardones (1993) shows the option to optimise cut-off grades and stockpile mined material at an operating Chilean copper mine adds 2.4% to a DCF values. Cavender (1992) estimates that the flexibility to shut-down and restart a small US gold mine adds \$3.8 million to the DCF value of the mine. This indicates the option value provides a minimal contribution to the inherent revenue generating capacity of the ore producing mine.

The results of Brennan and Schwartz (1985a) Mardones (1993), Cavender (1992) and Palm et al (1986) indicate that for the average profitable, post development mineral asset, operating flexibility only adds an average of 8% to the DCF value. On an absolute or dollar basis, operating flexibility adds a relatively insignificant premium to gross revenues (Davis 1996).

Paddock, Siegel and Smith (1988) jointly value the timing development option plus the flexibility to vary production once the mine is developed for a sample of offshore petroleum leases. Paddock et al's. (1988) sample of petroleum leases are all deep-in-the-money options making any option premium irrelevant over and above a DCF valuation. They find low correlation between their option-based values and industry bids that generally correspond to market prices.

These results demonstrate that the value associated with operating options depends on whether the current spot price is near the marginal or break-even price of the mine. When the operating option to extract ore is deep in-the-money the option to close has little value, particularly if there is low probability of commodity price change. Likewise, when the option to extract is out-of-the-money (commodity price less than the extraction cost) or near-the-money (commodity price close to the extraction cost) then the option to close should have a significant value as it reflects the value of the saved extraction costs. Hence, the option value to close a currently open mine can be a very substantial fraction of the total value of the mine, particularly when the commodity price is in the neighbourhood of the extraction cost (Brennan and Schwartz 1985a).

The volatility of the underlying commodity contributes significantly to the value of the option, particularly as the commodity price decreases. With higher volatilities there is a larger probability of both high and low commodity prices. As the firm has the option to temporarily close operations, it is able to avoid losses in the event of low commodity prices, but gets the full benefit of high commodity prices. The combination of high volatility and marginal operating mines (near-the-money options) should result in higher option value than low volatility and very low cost profitable (deep-in-the-money) operating mines.

Hotelling Valuation Principal

The second theoretical approach, the Hotelling Valuation Principle (HVP) is an adaptation of the traditional discounted cash flow method. Although there has been an increase in the use of real option valuation techniques for strategic decision making and as an aid in capital budgeting decisions, Adamson (1999) states DCF techniques are the most widely applied technique for valuation of mining assets.

The HVP model asserts that the market value of a mineral in the ground is obtained by multiplying the current net price by quantity of reserves in the mine. It derives the present value of in-ground resources from the theory of optimal mineral exploitation, which is used to forecast future mineral prices and the appropriate risk-adjusted discount rate. The principle relies on Hotelling's (1931) theory of the price path of commodities known as the "R" percentage rule. This rule determines that the expected trend of future net revenues and the appropriate discount rate are linked. The Hotelling (1931) proposition is that the unit price of an exhaustible natural resource, net of extraction costs, should grow at a rate equal to the rate of interest (i.e., the rate of discount). Optimal production requires that the extraction rate of a mine to be chosen such that the discounted marginal net profit of extracting ore today should be constant in all periods (Watkins 1992). This implies the irrelevancy of the interest rate and future commodity prices. The advantage of this model is that it does not require forecasting of future production-cash-flows since the present value of the expected return on holding the reserves cancels out the effect of discounting the future net cash flows regardless of when the resource is extracted.

The equation for the HVP is as follows:

$$V_0 = [(S_0 - a_0)\sum_{t=0}^{N} q_t](1 - t_c) = [(S_0 - a_0)Q_0](1 - t_c) \quad (4)$$

where

$V_0 =$ present value of total reserves at time 0.
$S_0 =$ the mineral's current spot price at time 0.
$a_0 =$ constant unit extraction cost in period 0.
$q_0 =$ number of units extraction in time period q_t.
$Q_0 =$ quantity of remaining reserves.
$t_c =$ effective corporate tax rate.

The HVP provides the present value of total reserves in a discrete-time certainty framework and only values the firm’s mining related activities.

Assuming asset value maximization, if commodity prices follow such a price path the theory implies that the present value of net commodity prices would be the same whenever the resource is extracted. The present value of reserves that are left in the ground until some future point in time to take advantage of a higher price will be discounted at the rate of interest that cancels out the effect of the price increase. If net price exhaustible resource commodities rise at the rate of discount, than each unit of reserve has a present value equal to its current net price.

The logic of the rule is that maximisation of present value profits ensures that they cannot be increased by reallocating output. This holds only if marginal present value profits were constant over all periods. Consequently, marginal profits must rise at the discount rate (Watkins 1992). In other words, an unconstrained, profit-maximising, price-taking owner of an exhaustible resource will choose to produce so that net price rises at the rate of interest r%. The rule is always interpreted as price net of extraction costs. Thus the market price to users could fall or stay constant while the net price rose, if extraction costs fell. This assumes that the producer is a price taker in a competitive resource industry.

Miller and Upton (1985a) extended Hotelling’s “R” percentage principle to allow its application to the value of the resource firm rather than just the determination of the resource price. The HVP formulation allows its application to firm valuation. Oil and gas resource economics analysing the relationship between commodity prices and resource stocks is dominated by the HVP (Watkins 1992). Solow (1974) sees the HVP as a basis for the economics of exhaustible resources. It has been widely adopted by industry analysts, US National Income accountants and the Bureau of Economic Analysis in their effort to value national oil reserve stocks (Davis and Moore 1998) as well as natural gas export policy assessments in Canada (Watkins

1992). Nabar (1997) also uses the HVP model for gold mining valuation, while Harris and Ohlson (1987) use the HVP model for valuing oil and gas properties.

Many practitioners and academics feel that the traditional valuation techniques including the HVP model do not fully capture all the opportunities faced by the firm (Myers 1984; Cheung 1993; Moyen, Slade et al. 1996; Busby and Pitts 1997). The HVP model is deficient in that it does not take into account possible option value due to changes in the operating mode of a mine. Because of this inability to capture the value of operating options, the HVP model underestimates market values in many circumstances. Empirical evidence suggests that the undervaluation relative to average observed market values might be as great as eighteen percent (Paddock, Siegel et al. 1988).

In summary, the HVP method is attractive in its simplicity and avoids the difficulty of forming expected future cash flows and the appropriate cost of capital. Assuming Hotelling's (1931) "R" percentage rule is correct then theoretically the Valuation Principle implicitly incorporates the present value of expected future cash flows from a firm's mining operations, but fails to account for the value of operating real options. That is, the model does not account for the resolution of uncertainty over time and the potential option value in the ability of an operating mining firm to temporarily close operations. In this sense the model may not be rich enough as it currently stands in the literature to incorporate the value of real options.

While, the Hotelling model has not, in general, held up well to empirical scrutiny in the oil and gas industry (with a few noted exceptions, (Miller and Upton 1985a; Miller and Upton 1985b; Crain and Jamal 1991)), the model shows descriptive promise in hard-rock metal and mineral valuation such as gold.

3. Research Design

Table 2 defines the variables used in the B&S Model, and, provides a comparison of variables adopted in the HVP model. The parameters for the B&S model are obtained directly from observable data with the exception of the convenience yield and the price volatility. These two parameters are calculated from published data.

Part A of Table 2 presents the variables that are common to both the B&S and the HVP model. Specifically these are (S_0) current commodity price, (Q) the quantity of mine reserves, the real interest rate (r), the nominal interest rate (ρ), the inflation rate

(π), the extraction costs (a_0), and the royalty (t_1) and corporate tax rates (t_2). Part B of Table 2 contains variables unique to the B&S model, (1985a).

Despite its limitations as a model that captures all values contained in market prices, the HVP methodology can be used in conjunction with the B&S model and market values to isolate theoretical and observed market option premiums. As, the B&S model incorporates both the option to close and the HVP valuation, the difference between these two models isolates the value of the option to close when applied to Australian gold mining firms.

Table 2: Brennan & Schwartz Variable Comparison

Brennan & Schwartz (1985)	Hotelling Valuation Principle
Part A	
S_0 = current commodity price at time 0	S_0 = current commodity price at time 0
Q = quantity of mine reserves	Q_0 = quantity of mine reserves
r = real annual interest rate = $\rho - \pi$	r, the real rate of interest cancels out as ($S_0 - a_0$) grows over time at a rate equal to the real rate of interest and subsequently discounted back at the same rate.
ρ = nominal annual interest rate	ρ = nominal annual interest rate
π = annual inflation rate	π = annual inflation rate
a_0 = constant unit extraction cost	a_0 = constant unit extraction cost
t_1 = royalty rate: Variable not shown separately as average production costs includes the costs of royalties.	t_1 = royalty rate: Variable not shown separately as average production costs includes the costs of royalties.
t_2 = corporate income tax rate	t_c = corporate income tax rate
Part B	
σ^2 = commodity price variance	Not included in model
q = annual production or current rate of extraction	q = current rate of extraction in time period t, $\sum_{t=0}^{N} q_t = Q_0$
k = the commodity convenience yield	Not included in model
f = periodic maintenance cost for a closed mine	Not included in model
λ_1 = proportional rate of property tax on the value of the open mine	Not included in model but assumed to be zero
λ_2 = the proportional rate of property tax on the closed mine value	Not included in model but assumed to be zero

Because B&S values encompass the HVP values and the option to close, the two models may be used to isolate the option to close. The method and constructs used in this study allow confirmation of whether the option to close is reflected in market values and to validate the importance of real option valuation as a suitable framework that is superior to HVP/DCF alone.

To isolate the value of options embedded in market prices, the HVP valuation for an existing mine can be deducted from the market value of mining operations. Thus if the option to temporarily close a firm's mining operations is priced by the market (see Brennan and Schwartz 1985a), the theoretical options to close should explain at least some of the option value observed in market values.

Based on the existing theoretical frameworks, this paper identifies that the market value of a mine can be expressed in terms of three components: the estimated present value of expected future cash flows; the option to close (represented by the theoretical option premium); and, the value of all other operating options. Figure 1 shows these components diagrammatically.

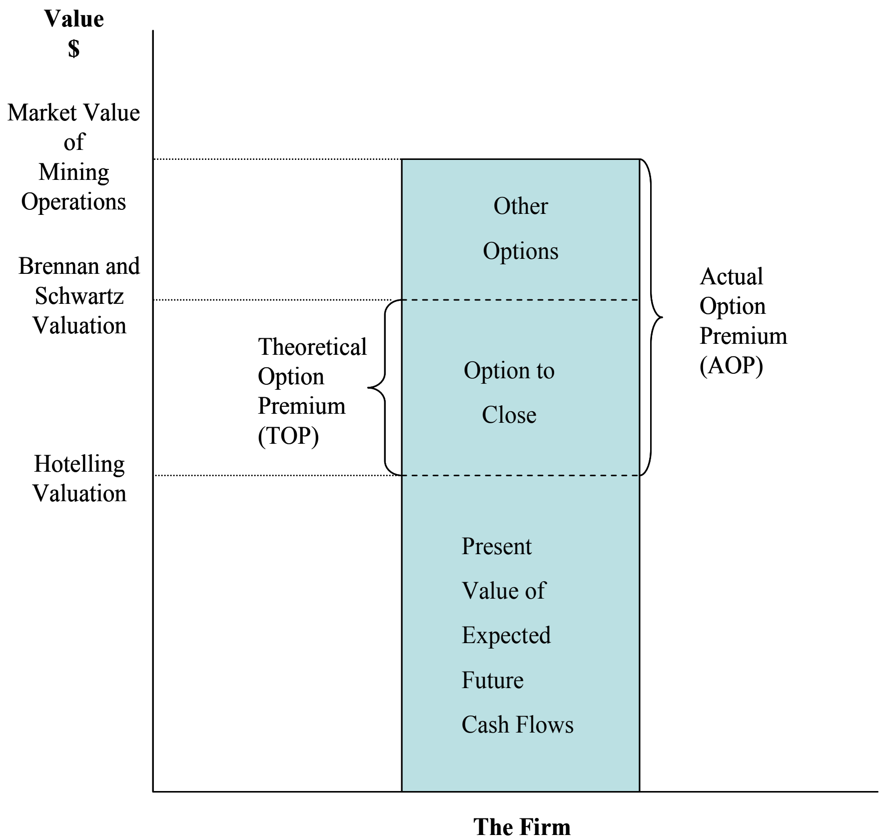

Figure 1: Valuation Framework

The HVP model (Miller and Upton 1985a) provides a theoretical basis for estimating the present value of future expected cash flows from mining[4]. The B&S model (1985a) values both the present value of future expected cash flows plus the value of the option to close. In addition to these two components, the market's assessment of the firm's mining value is assumed to contain any relevant price-related information that includes the other operating options such as option to expand production, or abandon operations. The difference between the market value of mining operations and the HVP captures the value of all options premiums, defined as the Market Option Premium (MOP).

The empirical issue is whether the observed market prices reflect the value of these operating options that arises from the structure of the mining process, and the uncertainties associated with commodity prices. If the market explicitly incorporates these factors into market prices then valuation methods that explicitly capture these characteristics are likely to be more highly correlated with market prices.

Hypotheses

The main proposition is that the market value of mining operations reflects a premium associated with the value of the option to close an operating mine. To test whether share prices reflect an option premium associated with the option to close, two option-premium constructs are developed. The first construct is the market option premium (MOP) measuring the difference between the market value of mining operations (MVMO) and the present value of operating cash flows of a mine as captured by the HVP model. The second construct referred to as the theoretical option premium (TOP) is the difference between the value from the B&S model and the value from the HVP model. The TOP captures the value of the option to close an operating mine.

Five hypotheses test the association between the theoretical option to close and the option premium component of the market value of mining operations. First, evidence for the existence of a premium over and above the present value of a mine's operating cash flows is examined. Hypothesis one supports the relevance of the Hotelling Valuation Principle (HVP) model to the market value of mining operations. An

[4] The HVP and B&S models provide a value of the firm as an entity. Most valuation models focus on valuing a portion of the firm as represented by shares held by equity. Appendix I contains a summary of the common equity valuation models.

ordinary least squares regression, supported by a pooled cross sectional regression, tests the HVP's explanatory power of the market value of a firm's mining operations.

Hypothesis one uses the market value of mining operations (MVMO) as the dependent variable to test the relevance of the HVP valuations. The estimation of MVMO is depicted in the top half of Figure 2. To obtain MVMO the total market value of the firm is first estimated from the market value of equity plus the book value of financial debt. From the total value of the firm is subtracted the present value of non-mine assets and gold inventory on hand to derive the market value of mining operations. Adjustments are required because the observed market value of the firm encompasses both the value of gold mining activities and other aspects of firm value such as the value of non-gold mining activities as well as stores of inventory. However, the B&S and HVP models only estimate the value from gold mining operations.

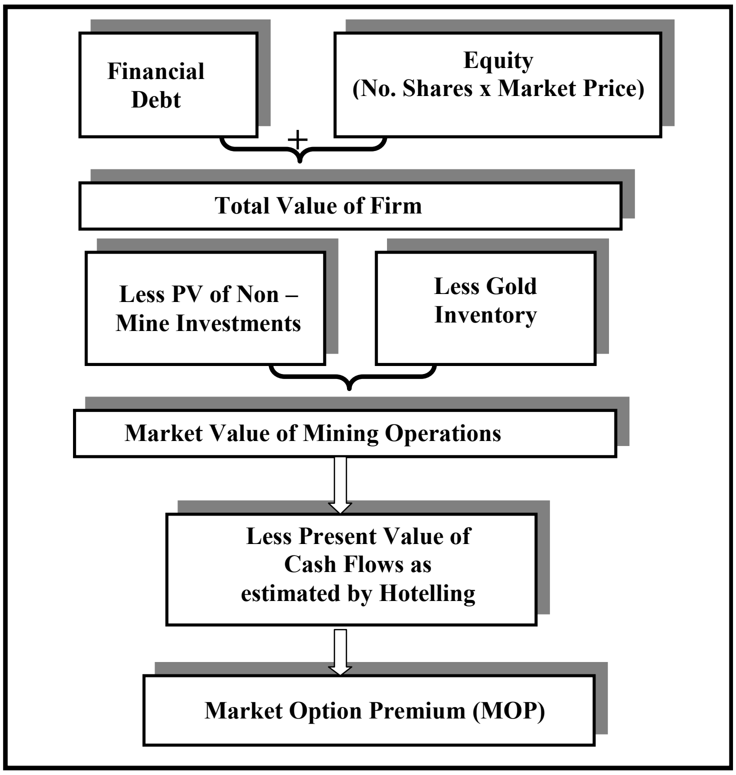

Figure 2: Market Option Premium

After controlling for the present value of expected cash flows, hypothesis two predicts that the market value of mining operations will be positively related to the value associated with the option to close. Hypothesis two isolates whether there is an association between the option to close and the option premium component reflected in market values that are in excess of the present value of cash flows from mining operations. Ordinary least squares regression and a pooled cross-sectional GLS fixed effects model tests the association between the two option components.

Hypothesis three examines the extent to which the value of the option to close varies with the degree of moneyness. Firms operating deep in-the-money having smaller option to close values relative to firm's operating out-of-the-money or near-the-money. Hypothesis four considers whether the value of the market option premium varies with moneyness. Again firms operating in-the-money are expected to display smaller option premiums than firms operating out-of-the money or near-the-money. The test of these hypotheses uses pooled cross sectional regressions with moneyness as the explanatory variable.

Figure 3 depicts the formulation of TOP that is used as the independent variable in Hypothesis two and four as well as being the dependent variable in Hypothesis three. The four shaded boxes at the top of Figure 3 represents the theoretical intrinsic value of the firm separated into components comprising the present value of cash flows from mining; the present value of operating flexibility; the present value of other miscellaneous cash flows, such as central administration costs; and the present value of non-mine assets. Not all of these components are captured in the mining valuation models. The HVP model only values the present value of expected future cash flows from mining. The B&S model values both the present values of expected cash flows from mining and the value of operating flexibility related to the option to close.

The present value of operating options in the second shaded box also encompasses the value of all other operating options that may affect firm value. These other options together with the present value of other cash flows are not valued in either of the mine valuation models used in this thesis. However by using a fixed-effect pooled regression model these omitted variables are captured explicitly in a time-constant term of the regression that is allowed to be different for each pool member. An unobserved, time-constant variable is called an unobserved effect in panel data analysis. When t represents different time periods for the same firm, the unobserved effect is often interpreted as capturing unobserved characteristics of a firm, such as mine location, management quality or structure. In this study other operating options other than the option to close can be viewed as being (roughly) constant over the period in question (Wooldridge 2002).

As depicted in Figure 3 the difference between B&S valuations and HVP valuations isolates the value of TOP the option to close.

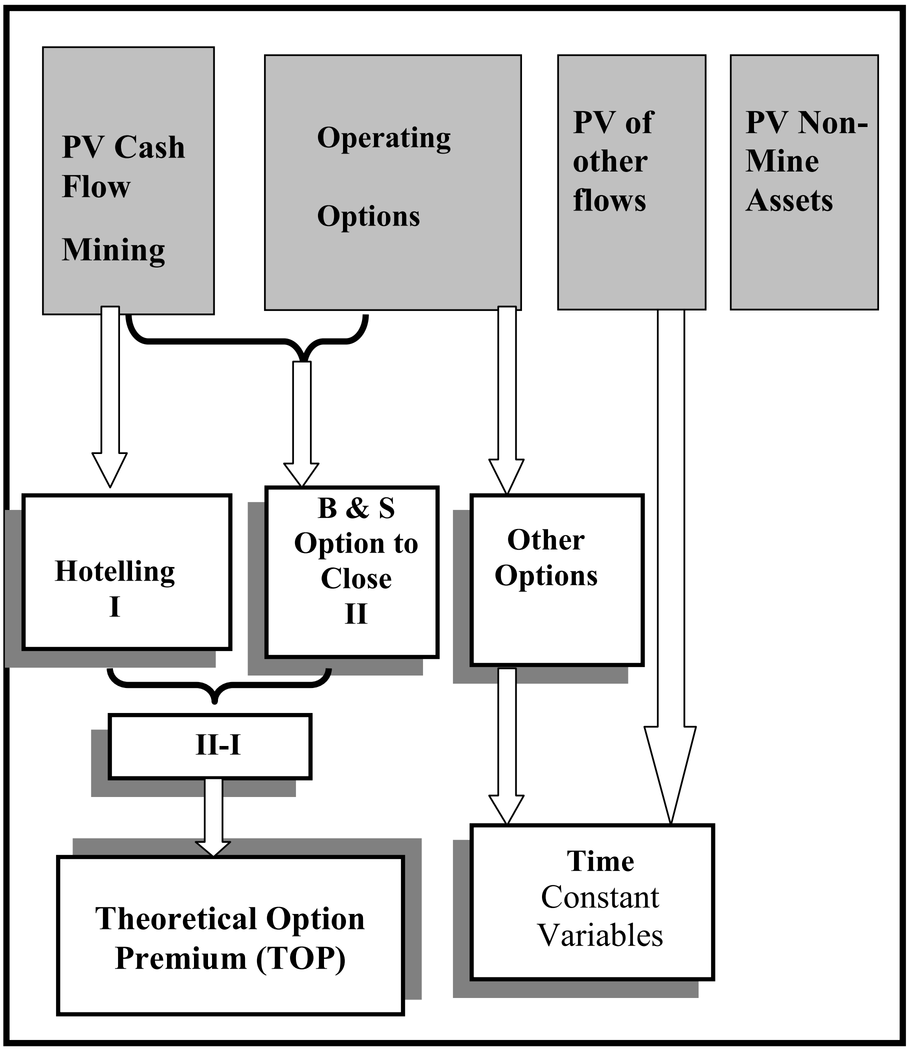

Figure 4: Theoretical Option Premium

The relationship between the TOP and the MOP measures the degree to which market values reflect the value associated with the option to close an existing operating gold mine.

Hypothesis five proposes that the strength of the association between MOP and TOP is inversely related to the degree of moneyness. There should be a stronger relationship between the observed market option premium and the option to close as moneyness decreases. An interaction term is added to the MOP, TOP regression to test the hypothesis. The sample is divided into quartiles based on moneyness. A test is performed to determine if the slope coefficients between quartiles differ.

Table 3 provides a summary of these variable names and their measurement.

Table 3: Variable Definitions

Variable Reference	Variable Name	Variable Measurement
HVP	Hotelling Valuation Principle	HVP = (spot price of gold – cost of extraction)* quantity of proven and probable reserves.
B&S	Brennan and Schwartz	PV of cash flows from mining + value of the option to close.
MVMO	Market value of mining operations	Total value of the firm (MV of Equity + Financial Debt)-PV of non-mine assets – gold inventory on hand
MOP	Market option premium	Excess of MVMO over HVP valuations.
TOP	Theoretical Option Premium	Excess of B&S values over HVP values

Table 4 provides a summary of the hypotheses and a short description of their measurement and statistical tests.

<u>Sample Selection</u>

Yearly intrinsic values are calculated for a sample of 41 Australian gold mining firms over the years 1987 to 1994. The sample firms are relatively homogeneous with respect to their operating activities, debt levels, and exposure to macroeconomic factors such as interest rates. The homogeneity of these firms contributes to the internal validity of this study by reducing the number of potentially confounding factors and helps to reduce measurement error in the valuations. The major disadvantage of using a single industry sample is that it reduces the ability to generalise the results. For example, the sample firms on average have low levels of debt in contrast to the greater cross-sectional variation in debt of firms in different industries. The mean and median amount of debt as a percentage of firm capitalization is 22 percent and 5 percent respectively. Table 5 summarises the sample selection procedures. This final sample consisted of 41 gold producing firms yielding 234 firm-year observations.

Table 4: Summary of Hypotheses

Hypothesis	Hypothesis Name	Hypothesis Description	Measurement and Statistical Test
H1	HVP hypothesis	The associated between HVP values and market values of firms' mining operations.	$Log(MVMO_{it}) = \alpha_0 + \beta_1 LogHVP_{it} + \varepsilon_{it}$ OLS and GLS Fixed Effect model performed on overall sample and quartiles.
H2	Option to close hypothesis	The ability of TOP to explain MOP.	$MOP_{it} = \alpha_0 + \beta_1 TOP_{it} + \varepsilon_{it}$
H3	TOP and moneyness	There is an inverse relationship between the value of the option to close and moneyness	$TOP_{it} = \alpha_0 + \beta_1 Moneyness_{it} + \varepsilon_{it}$
H4	MOP and moneyness	There is an inverse relationship between MOP and moneyness	$MOP_{it} = \alpha_0 + \beta_1 Moneyness_{it} + \varepsilon_{it}$
H5	Strength of MOP, TOP relationship	There will be a stronger relationship between MOP and TOP when real options are less-in-the-money.	$MOP_{it} = \alpha_0 + \beta_1 TOP_{it}^{M} -$ $\beta_2 (Moneyness * TOP) + \varepsilon_{it}$ Chow's breakpoint test

Table 5: Sample Selection

Total number of firms listed in the 1994 Jobson's Mining Year book	**445**
Less: Firms that do not have gold related mining activities or were exclusively explorers over the sample period.	**(385)**
Firms forming initial sample	**60**
Less: Firms involved in diversified mineral extraction in addition to gold mining	**(13)**
Less: Firms for which Annual Reports could not be obtained or disclosures were inadequate for the purpose of measuring the proven and probable reserves or extraction costs.	**(3)**
Less: Firms involved in substantial activities outside of gold mining	**(3)**
Total number of firms in final sample	**41**

The degree of moneyness is argued to affect the value of real options. In terms of the sample investigated Table 6 shows that 10 out of 234 firm year observations (4.27 percent) are out-of-the-money. Further break-up of firm year observations are according to the following classifications based on moneyness of sample firms operating options. Where as defined before moneyness is calculated as the underlying commodity price less the extraction cost on a per ounce basis. Three classifications are constructed for firms with operating options in-the-money to differentiate the degree of moneyness exhibited. These categorises are from $0 to $50 operating with-in-the money, $51 to $100 in-the-money and more than $100 in-the-money.

Table 6: Moneyness of Sample Firm Years

Moneyness	Number of Firm Years	Percentage of Firm Years
Out-of-the-money	**10**	**4.27**
$0-$50 in-the-money	**20**	**8.55**
$51-$100 in-the-money	**30**	**11.97**
More than $100 in-the-money	**174**	**75.21**
Total	**234**	**100**

5 Results

Descriptive Statistics

Estimates of HVP and B&S valuations that underlie the option premium constructs depend on key attributes of the sample firms. Table 7 presents the descriptive statistics for these attributes for the sample firms at fiscal year-end. All monetary values are measured in Australian dollars. The average firm has a mean (median) annual current extraction level of 149,100 (83,411) ounces of equivalent gold at a mean (median) extraction cost of $330 ($328.50). The mean (median) level of proven and probable reserves is 1,259,189 (428,830) ounces of equivalent gold.

The mean (median) gold price of $500 ($492) shows that on average the gold price is greater than the extraction cost for sample observations, with the majority of the sample (224 out of a total of 234) exhibiting extraction options that are in-the-money. The remaining ten observations exhibit out-of-the-money extraction options but remain open and operating. For example, Herald Mining Ltd is operating out-of-the-money from

The time to maturity of an option is an important variable in the valuation of a traditional financial option. The equivalent in the B&S real options model is mine life. Mine life is not an explicit input variable in the B&S model but is implied by the relationship between the quantity of reserves (Q) and the annual extraction rate (q). Financial option pricing theory suggests that the longer the time to maturity of the option the higher its value. Therefore, the option value will be greater the longer a mine's extraction horizon.

Table 8 reports the descriptive statistics for two different estimates of mine life. Mine life is calculated for each firm on a yearly basis as the total reported proven and probable reserves divided by the corresponding annual current extraction. The resulting mine lives based on this calculation are sometimes distorted by a lower than normal extraction rate in any one particular year. This may occur when there is a lower rate of extraction due to production difficulties, industrial relation issues where the mine is only operating for a portion of the year. Estimated mine life based on current extraction rates has a standard deviation of 36 years with the maximum life as high as 513 years. Such extreme mine life estimates result in non-sensible B&S valuations.

Taylor's estimates assume that the average mine life is approximately 6.5 years and adjustments are made to take into account individual firms proven and probable reserves[5]. This adjustment increases mine life for firms who report small quantities of reserves and decreases mine lives where reported-current extraction is low relative to the quantity of proven and probable reserves.

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[5] Refer to Chapter 3 for a detailed discussion of the Taylor's mine life calculation and Appendix V for individual firm calculations.

Table 7: Sample Firm Descriptive Statistics

	Mean	Median	Max.	Min.	S.D.	Skewness
Gold Price ($)	500	492.00	649	412	60	1.5
Extraction Cost ($)	330	328.50	617	111	87	0.3
Market Value of Mining Operations ($M)	260	106	2,302	.663	391	3
Reserves (ounces)						
Proven & Probable	1,259,189	428,320	11,068,000	5,263	1,833012	2.3
Current Extraction	149,100	83,411	1,046,315	2,287	179,605	2.3
Taylor's Extraction Rate (q)	86,964	45,189	517,919	1,668	96,551	1.8
Mine Life (years)						
Actual Est. Mine Life	11.6	5.9	513	0.3	36	12.5
Taylor's Mine Life	10.5	9.5	21	3.2	4	0.6
Intrinsic Valuations						
B&S ($M)	435	137	6,130	.74	756	3
HVP ($M)	241	74	2,970	-42.31	433	3

For excessive mine lives, Taylor's method winzorises the data by setting a maximum mine life of approximately 20 years. This is consistent with there being little value attached to very distant expansion options in mines with very large reserves. A comparison of Taylor's mine life estimates and actual mine lives shows it is only for extreme observations that there is a difference.

Table 7 also provides descriptive statistics on intrinsic valuations calculated from the two mine valuation models. As expected the mean (median) 435 (137) B&S[6] valuations are considerably higher than the mean (median) 241 (74) HVP valuations because the B&S valuations includes the HVP values as well as the value of the option to close. The B&S values are always positive and higher than the HVP values. Negative HVP values occur when the real option to extract ore is out-of-the-money (extraction cost exceeds spot price). Both HVP and B&S distributions are non-normal, where outliers due to differences in firm size are prevalent. Problems associated with firm size and non-normal distributions are overcome in the analysis by using relative measures, MOP and TOP, capturing the percentage difference between the market value of mining assets and HVP, and the percentage difference between B&S values HVP values.

[6] The statistics for the B&S valuations reported in the chapter relate to B&S valuations based on gold price volatility of 20%.

The first hypothesis (H1) examines the strength of the relationship between HVP values and the market value of mining operations. Support was found for a significant positive association between HVP values and market values with HVP explaining approximately 74% of the variation in market prices. Tests by quartiles indicate that the HVP model explains a larger portion of market values when moneyness of the option to extract increases. This suggests that the market attributes little value to operating options for firms' options operating well-in-the-money as they are less likely to change current operating status.

This result is consistent with there being a missing explanatory variable for the market value of mining operations. This is confirmed for tests of omitted variables.

Table 8

Hotelling Valuation as an Explanation of the Market Value of Mining Operations: Pooled regression

41 Firms, 1987 to 1994

Number of observations = 234

$$Log(MVMO_{it}) = \alpha_0 + \beta_{it} LogHVP_{it} + \varepsilon_{it}$$

The dependent variable is the market value of mining operations MVMO. The independent variable HVP is defined as the present value of cash flows from mining activities using the Hotelling Valuation Principle.

Regression	Intercept	Coefficient β_1	T Statistic	Adjusted R^2	Standard Error of Regression[7]
OLS	5.422	0.720	18.329*	0.605	1.042
GLS Fixed Effect No weights	10.753	0.420	6.045*	0.738	0.069
GLS Fixed Effect crossectional Weights	11.19	0.394	13.830*	0.738	0.029
AR(1) model	0.343	0.286	3.927*	0.800	0.073

* p<.0001

The robustness of the results from Table 8 for the overall sample is tested by examining the hypothesised relationship between HVP and MVMO across quartiles ranked on the moneyness of the option to extract. Table 9 presents the results of testing the relationship between HVP values and the MVMO by quartile. As predicted, the relationship is stronger when firms' options are operating well-in-the-money (quartile 4) as evidenced by a larger slope coefficient and higher adjusted R^2.

[7] Standard Error of the Regression is a summary measure based on the estimated variance of the residuals. The standard error of the regression is computed as $s = \sqrt{\frac{\hat{\varepsilon}'\hat{\varepsilon}}{(T-k)}}$.

Quartile 1 in Table 9 containing both the out-of-the-money option firms and the near-the-money option firms exhibit the weakest relationship between HVP values and MVMO. Quartiles 2, 3 and 4 contain option observations that are all well-in-the-money and hence their market values should reflect little option to close value, providing a stronger association between HVP values and market values.

The Ramsey Reset test for model misspecification indicates that the market is valuing something in addition to the basic HVP valuation. It is suggested this additional value is associated with the value of operating flexibility. Hypothesis two (H2) tests this proposition by examining the relationship between the two constructs, the market option premium (MOP) and the theoretical option premium (TOP). The MOP measures the excess of the market value of mining operations over the present value of expected cash flows estimated by HVP.

Table 9

Hotelling Valuation as an Explanation of the Market Value of Mining Operations: OLS Regressions by Quartiles ranked on Moneyness of the option to extract.

$$Log(MVMO_{it}) = \alpha_0 + \beta_{it} LogHVP_{it} + \varepsilon_{it}$$

The dependent variable is the market value of mining operations MVMO. The independent variable HVP is defined as the present value of cash flows from mining activities using the Hotelling Valuation Principle.

Quartile	Intercept	Coefficient	T Statistic	Adjusted R2	Standard Error of Regression
1	10.214	0.462	4.355*	0.320	1.216
2	1.482	0.933	11.999*	0.737	0.886
3	2.403	0.874	7.322*	0.531	1.115
4	0.963	0.942	12.839*	0.747	0.865

* p<.0001

The TOP measures the excess of B&S values over HVP values, which is intended to yield the estimated value of the option to close. Both the theoretical and market options premiums are scaled by HVP values to overcome size differences between firms. A comparison of the option premium constructs isolates whether the option to close measured by TOP explains a significant portion of excess market values as measured by MOP. An unbalanced fixed-effects pooled cross-sectional model establishes a statistically significant relationship between the theoretical and market option premiums. The results support the hypothesis that market values of mining operations reflect an option premium associated with the option to close with approximately 62% of the difference between HVP and the market value of mining operations being explained by the option to close.

Table 10 presents comparative results of a standard OLS regression using the Newey-West correction for autocorrelation. The Durbin-Watson statistic indicates there is no serial correlation and this is supported by an insignificant Breusch-Godfrey Serial Correlation LM test for the model (χ^2 = 3.469) at the .05 probability level.

Table 10

Association between MOP and TOP

41 Firms, 1987 to 1994, Number of Observations = 234

$$MOP_{it} = \alpha_0 + \beta_1 TOP_{it} + c_i + \varepsilon_{it}$$

The dependent variable is MOP representing the excess of MVMO over HVP values, scaled by HVP. The independent variable TOP represents the excess of B&S values over HVP values, scaled by HVP.

Variable	OLS	GLS Fixed Effect
Intercept	0.627	0.612[8]
t-statistic	1.283	n/a
TOP	0.745	0.832
t-statistic	5.240*	12.172*
Adjusted R-squared	0.507	0.628
S.E. of regression	6.703	5.826
Sum squared resid	10423.45	7806.6
Durbin-Watson stat	2.0332	1.8170
Akaike info criterion	6.6515	6.3795
Schwarz criterion	6.6810	6.4385

* $p < 0.01$.

The estimated TOP values account for a substantial portion of the variation in MOP values of the sample firms. As predicted the coefficient on TOP is positive and statistically significant at the .01 level for both the GLS fixed effects model at 0.8321 and for the OLS model at 0.7453. The adjusted R^2 of 63% for the GLS fixed effect design (50.68% for OLS), indicates substantial explanatory power for the theoretical option premium.

Hypotheses three and four examine whether TOP and MOP vary with moneyness. It is hypothesised that the size of TOP and MOP are inversely related to the degree of moneyness because firms with real options operating out-of-the-money and near-the-money find the option to close most valuable and this should be reflected in larger

[8]The fixed effects model generates a separate intercept for each of the 41 cross-sectional units of which we report the average. The model treats this as a nuisance term and no significance level is given.

option premiums. Support was also found for a statistically significant and positive association between both option premiums and moneyness.

Table 11 presents the results for tests of the pooled GLS fixed-effect models of Hypotheses 3 and 4. For both regressions, the coefficient on moneyness is negative and highly statistically significant. Consistent with expectations the results suggest that there is both an inverse relationship between moneyness and the value of the option to close and moneyness and MOP. As moneyness increases, TOP and MOP decreases. As a firm's option to extract becomes deep in-the-money the value of the option to close becomes smaller. Because TOP explains a significant portion of MOP (R^2 62.74% reported in Table 11) then it is consistent that MOP will also decrease as the firm's extraction option moves deeper in-the-money.

Table 11

Effect of Moneyness on TOP and MOP

41 Firms, 1987 to 1994, Number of Observations = 234

$$TOP_{it} = a_0 + \beta_1 Moneyness_{it} + \varepsilon_{it}$$

$$MOP_{it} = a_0 + \beta_1 Moneyness_{it} + \varepsilon_{it}$$

The dependent variable in the first regression TOP represents the excess of B&S values over HVP values, scaled by HVP. The dependent variable in the second regression MOP represents the excess of MVMO over HVP values, scaled by HVP. The independent variable Moneyness is the spot price of gold less the average extraction cost.

Variable	TOP	MOP
Intercept	1.187[9]	2.488[10]
Moneyness Coefficient	-0.002	-0.007
t-statistic	190.644*	75.137*
Adjusted R-squared	0.554	0.521
S.E. of regression	8.172	9.375
Sum squared resid	12822.15	16873.81

* p < significant at 0.0001.

The explanatory power of moneyness is similar for TOP (55.37%) and for MOP (52.10%). The slightly lower explanatory power of moneyness for MOP may be attributable to the existence of these other operating options that are not related to moneyness.

The sample was divided into quartiles ranked on moneyness with quartile one consisting of firms with real options operating out-of-the-money and near-the-money

[9] The fixed effect model generates a separate intercept for each of the 41 cross-sectional firms. The average of the intercepts are reported, however a pooled cross-sectional regression treats these as a nuisance term and hence no significance level is given.

[10] As per footnote 35.

and the remaining quartiles consisting of firms with real options deeper in-the-money. As hypothesized, the mean and median values of TOP and MOP for each sub-sample are not equal, with quartile one being statistically and significantly different from the remainder of the sample.

Table 12 presents the results of tests of the equality of the means and medians of quartile one against the remaining combined quartiles two, three and four. This test is based on a single-factor, between-subjects, analysis of variance (ANOVA). The basic idea is that if the subgroups have the same mean, then the variability between the sample means (between groups) should be the same as the variability within any subgroup (within group).

Table 12

Equality Tests of Mean and Median TOP Quartile 1 Based on Moneyness Against Combined Quartiles 2, 3, & 4.

Panel A Mean			
Analysis of Variance	**df**	**Value**	**Probability**
Anova F-statistic	(3.230)	13.57	0.0001
Source of Variation		Sum of Sq.	Mean Sq.
Between	3	2673.61	891.203
Within	230	15110.56	65.698
Total	233	17784.17	76.327
Panel B Median	**df**	**Value**	**Probability**
Med. Chi-square	3	86.90	0.0001
Adj. Med. Chi-square	3	82.74	0.0001
Kruskal-Wallis	3	127.64	0.0001

Table 13 confirms that quartile one is statistically significantly different from the combined quartiles two, three and four. The nonparametric tests of the median support this difference. This result supports the hypothesis that the option to close represented by TOP is also inversely related to moneyness and is more valuable for firms' whose extraction option is out-of-the-money or near-the-money (marginal operators).

Table 13 present the results of tests of the equality of the mean TOP for each pair of quartiles. The F-statistic indicates there is a statistically significant difference between the means of quartile one and each of the individual remaining quartiles two, three and four. Quartile two is also statistically significantly different to quartile four at the 10 percent level[11]. These results provide further support for the view that TOP is inversely related to the degree of moneyness. The market values of mining operations for firms' that operate out-of-the money or near-the-money reflect a larger option to close value.

Table 13

Test of Equality of Means Between Quartiles of TOP Ranked on Moneyness

Quartiles 1 & 2	**df**	**Value**	**Probability**
t-test	116	3.591	0.0005
Anova F-statistic	(1, 116)	12.900	0.0005
Quartiles 1 & 3			
t-test	116	3.698	0.0003
Anova F-statistic	(1, 116)	13.677	0.0003
Quartiles 1 & 4			
t-test	116	3.778	0.0003
Anova F-statistic	(1, 116)	14.273	0.0003
Quartiles 2 & 3			
t-test	114	1.602	0.112
Anova F-statistic	(1, 114)	2.568	0.112
Quartiles 2 & 4			
t-test	114	2.615	0.010
Anova F-statistic	(1, 114)	6.836	0.010
Quartiles 3 & 4			
t-test	114	1.104	0.272
Anova F-statistic	(1, 114)	1.218	0.272

Table 4 presents the results of further tests of the relationship between moneyness and MOP. The results show that there is a statistically significant difference between the means and medians MOP of quartile one compared to the combined mean and median of quartiles two, three, and four.

Tests of the equality of means between each pair of quartiles in Table 15 confirm that quartile one is statistically significantly different to quartile two at the 0.0003 level and to quartiles three and four at the 0.0001 level of significance[12]. Quartile two is statistically significantly different to quartile four at the ten percent level. There is no statistical difference between the remaining quartile combinations.

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[11] Tests of the equality of the median TOP for quartiles are highly statistically significant for all quartile pair-wise combinations.

[12] Tests of the equality of medians using nonparametric Wilcoxon/Mann-Whitney tests provide consistent results with the tests of the means. Quartile one is statistically different to quartiles two, three and four at the 0.0001 level and quartile two and four is statistically different at the 0.0029.

Table 14

Equality Tests of Mean and Median MOP Quartiles based on Moneyness

Panel A Mean			
Analysis of Variance	**df**	**Value**	**Probability**
Anova F-statistic	(3.230)	15.4120	0.0001
Source of Variation	df	Sum of Sq.	Mean Sq.
Between	3	3269	1089.75
Within	230	16262	70.708
Total	233	19532	83.828
Panel B Median	**df**	**Value**	**Probability**
Med. Chi-square	3	48.32	0.0001
Adj. Med. Chi-square	3	45.26	0.0001
Kruskal-Wallis	3	67.15	0.0001

This result supports the view that MOP is inversely related to the degree of moneyness. The market values of mining operations for firms' that operate out-of-the money or near-the-money reflect an operating option premium and this option premium is much larger than for firms that operate in-the-money.

Table 15

Test of Equality of Means between Quartiles of MOP ranked on Moneyness

Quartiles 1 & 2	df	Value	Probability
t-test	116	3.770	0.0003
Anova F-statistic	(1, 116)	14.209	0.0003
Quartiles 1 & 3			
t-test	116	4.008	0.0001
Anova F-statistic	(1, 116)	16.061	0.0001
Quartiles 1 & 4			
t-test	116	4.126	0.0001
Anova F-statistic	(1, 116)	17.023	0.0001
Quartiles 2 & 3			
t-test	114	1.095	0.27
Anova F-statistic	(1, 114)	1.199	0.27
Quartiles 2 & 4			
t-test	114	1.738	0.085
Anova F-statistic	(1, 114)	3.022	0.085
Quartiles 3 & 4			
t-test	114	1.073	0.28
Anova F-statistic	(1, 114)	1.152	0.28

Hypothesis five is formulated to test whether the strength of association between MOP and TOP is inversely related to the degree of moneyness. An interaction term is added to the MOP, TOP regression to test the hypothesis. The sample is divided into quartiles based on moneyness and tests of association are performed within each quartile as well as tests of the equality of slope coefficients between quartiles. The results support hypothesis five indicating the MOP and TOP relationship is more pronounced in the first quartile for out-of-the-money and near-the-money observations.

Table 16 presents the results of a pooled GLS regression using moneyness as an interactive variable with TOP. White's Heteroskedasticity Consistent Covariance estimator is used to correct for heteroskedasticity. The results in Table 17 support Hypothesis 5 with the coefficient on β_1 TOP being of the predicted positive sign and statistically significant and the interaction between TOP and moneyness, β_2 being negative and statistically significant as predicted.

Table 16

GLS Analysis of the Relationship between MOP, TOP and Moneyness
41 Firms, 1987 to 1994, Number of Observations = 234

$$MOP_{it} = \beta_0 + \beta_1 TOP_{it}{}^{M} - \beta_2 (Moneyness * TOP) + \varepsilon_{it}$$

The dependent variable MOP represents the excess of MVMO over HVP values, scaled by HVP. The independent variable TOP represents the excess of B&S values over HVP values, scaled by HVP. The interactive variable moneyness is the spot price of gold less the average extraction cost * TOP.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
TOP	0.89	0.083	10.76	0.0001
Moneyness*TOP	-0.004	0.0003	-13.99	0.0001
Adjusted R-squared	0.623	Durbin-Watson stat		1.96
S.E. of regression	6.72	F-statistic		10.42
Sum squared resid	8615	Prob(F-statistic)		0.0001

The overall results of tests for Hypothesis five support the hypothesis that the MOP and TOP relationship is a function of moneyness. TOP is a statistically significant component of MOP for firms whose option to extract is out-of and near-the-money but not for firms whose options are well-in-the money. This indicates that the attribute of moneyness of a firm's real option is an essential determinate to the existence and magnitude of the value of the option to close and the excess of market value over HVP values.

Table 17 provides a brief review of the empirical support for the hypotheses tested.

Consistent with the work of Miller and Upton (1985a; 1985b), a significant relationship between HVP values and the market value of mining operations was found. This relationship is stronger for firms' whose option to extract is deep-in-the-money and weaker for firms' whose option to extract is near-the-money and out-of-the-money.

Table 17 Summary of the Results of Hypotheses Tests

No.	Hypotheses	Results of Testing
1	The HVP valuation has a significant positive association with respect to the market value of mining operations.	Supported ($p< 0.01$)
2	The excess of the market value of a mine over the HVP value is positively associated with the option to close.	Supported ($p<0.01$)
3	The value of the option to close (TOP) is inversely related to moneyness. That is, it is larger for marginal operating options and smaller for operating options well-in-money.	Supported ($p<0.01$)
4	The excess of the market value of mining operations over HVP values is inversely related to moneyness.	Supported ($p<0.01$)
5	The strength of the association between MOP and TOP is inversely related to the degree of moneyness.	Supported ($p<0.01$)

However, HVP values do not explain all of the variance of the market value of mining operations. Overall the test of Hypothesis two finds that the option to close has explanatory power for the market value of mining operations over and above the present value of expected future cash flows as measured by the Hotelling Valuation Principle. Support was also found for the hypothesis that the degree of moneyness affects the size of both the option to close and MOP values. The relationship between the option to close value and the excess of the market value of mining operations over HVP varies with the degree of moneyness with the option to close values being larger for real options that are out-of or near-the money. There is also evidence of interaction between the theoretical option premium and moneyness to explain the market valuation of mining operations.

6. Conclusion

This research examines whether the market values of mining operations for Australian gold mining firms reflect a premium for the option to close, as proposed by real options theory. It also examines whether the magnitude of any option premium associated with the option to close varies with the moneyness of the option to close.

This research is motivated by the desire to understand the drivers of market prices. The gold industry was chosen as the research site because of the existence of world spot and futures markets that allow the calculation of real option values for mining operations. While an extensive body of literature suggests that real options methodology is often an appropriate capital budgeting tool, there is only limited research to suggest that equity prices capture the value of these real options (Paddock, Siegel et al. 1988; Quigg 1993; Kelly 1998)

Estimating the present value of mining operations via the HVP model enables the calculation of a theoretical option premium. The Brennan and Schwartz (B&S) valuation method provides the value of an open operating mine including the present value of expected future cash flows plus the value of the option to close. The difference between the estimated value of a mine measured by the B&S valuation and the HVP value gives the theoretical value of the option to close (TOP).

The market value of the firm reflects all value relevant variables including the present value of mining operations as well as the value of any real operating options (including the option to close plus the value of non-mine assets). This thesis is concerned with whether market values of mining operations reflect the option to close. The empirical measure used for the market value of operations is the market value of equity for the total firm plus the value of financial debt less the value of non-mine assets. The difference between the market value of mining operations and HVP valuations provides a measure of all value-relevant operating options over and above the present value of expected future cash flows from operations including the option to close.

The results suggest that the value of the option to close, captured by TOP, can account for a substantial portion of the variation in MOPs of the sample firms. This methodology provides a unique method for assessing whether market values contain a premium for real options, in this case the option to close.

This research documents the existence of an option premium reflected in the market value of mining operations. Support was found for the existence of an option premium associated with the option to close for firms that operate out-of-the-money or near-the-money. However, the market does not appear to value as highly the option to close for firms whose operating option is deep-in-the-money. This is consistent with the argument that firms deep-in-the-money are unlikely to exercise their option to close down production. Firms that are marginal operators, experiencing higher extraction costs relative to the price of gold will find the option to close more valuable. The results suggest that market prices reflect this value and differentiate these firms from those that are deep-in-the-money.

The results of this research contribute to our understanding of firm valuation and real options analysis in a number of ways. First, evidence is reported that capital markets recognise the value inherent in operating flexibility in the mining industry. Further, a significant portion of the difference between the market value of mining operations and the value inherent in discounted future expected cash flows is attributed to the real option valuation. This contributes to both asset pricing and valuation literature by validating the use of real options techniques to capture the dimensions of investment projects that are value relevant to the market. In the gold mine industry, project appraisal techniques that do not use a real options technique may lead to the rejection of projects that improve the utility of shareholders and maximise shareholder wealth.

Second, the existence and magnitude of the operating option, and specifically the value of the option to close, depends upon the moneyness of the operating options of the firm, where larger differentials between spot commodity prices and the cost of production, result in lower real option values.

Third, the research empirically tests the construct validity of the Brennan and Schwartz valuation model as descriptive of the value reflected in gold mining operations. It also provides evidence of the validity of the Hotelling Valuation Principle as descriptive of market prices for Australian gold mining firms that operate deep-in-the money.

Finally, the study provides a unique methodology to assess whether market prices reflect the value of real options. In this thesis the current framework of B&S that augments the HVP valuation framework with real options compares the theoretical difference in value between the two models to determine the value of the option to close (TOP). A comparison of market values against the present value of expected future cash flows isolates the operating option premium reflected in market prices (MOP). These two constructs MOP and TOP and the relationship between them are uniquely formulated in this thesis and have not been adopted in prior empirical research. This methodology allows confirmation of whether the value of real options is reflected in market prices and validates the importance of real option valuation as a suitable framework that is superior to HVP/DCF valuation alone.

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APPENDIX 1 – BBRENNAN AND SCHWARTZ MODEL SPECIFICAION

The Brennan and Schwartz (1985a) model specifies the value of an open and operating mine, v, and the value of a closed (temporary shutdown) mine, w, in Equations 1 and 1 respectively: Equation 3 describes τ total income tax and royalties levied on the mine when it is operating.

$$\max_{q\in(\underline{q},\bar{q})}[\frac{1}{2}\sigma^2 S_0^2 \frac{\delta^2 \nu}{\delta S_0{}^2} + (r-k)S_0 \frac{\delta \nu}{\delta S_0} - q\frac{\delta \nu}{\delta Q} + q(S_0 - a_0) - \tau - (r+\lambda_1)\nu] = 0 \quad (1)$$

$$\frac{1}{2}\sigma^2 S_0^2 \frac{\delta^2 w}{\delta S_0^2} + (r-k)S_0 \frac{\delta w}{\delta S_0} - f - (r+\lambda_0)w = 0 \quad (2)$$

and

$$\tau = t_1 q S_0 + \max[t_2 q[S_0(1-t_1) - a_0],0] \quad (3)$$

where:

$v(S_0,Q)$ = open mine value
$w(S_0,Q)$ = closed mine value
S_0 = the commodity price
σ^2 = the commodity price variance
Q = the mine resource inventory (reserves)
q =the annual extraction rate (q is assumed to be costlessly variable between the upper and lower bounds $\bar{q}$ and $\underline{q}$).
r = real annual interest rate = $\rho - \pi$
ρ = nominal annual interest rate
π = the annual inflation rate
k = the commodity convenience yield[13]
f = periodic maintenance cost for a closed mine
λ_1 = proportional rate of property tax on the value of the open mine
λ_0 = the proportional rate of property tax on the closed mine value
a_0 = average cost of production per unit of commodity
t1 = royalty rate
t_2 = income tax rate

The specified equations that are used to estimate mine value are second order, non-linear, partial differential equations. The B&S valuation methodology is similar to that of the Black-Scholes (1973) valuation of a call option. But unlike the Black-

[13] The commodity convenience yield is the benefits realised from ownership of the physical commodity that are not realised by the holders of a future contract (refer to Hull 1998). A specific definition and measurement of the convenience yield are discussed later in this chapter.

Scholes valuation model which is based on a European option that can only be exercised at maturity, the B&S model (Brennan and Schwartz 1985a) is based upon an American option that can be exercised at any time up to expiration. The expiration of the option will occur when the mine's reserves are exhausted. The resultant solution determines the optimal policy for opening, closing and abandoning the mine and sets the optimal output rate.

The first term in Equation (3.6) $\frac{1}{2}\sigma^2 S_0^2 \frac{\delta^2 \nu}{\delta S_0^2}$ captures the change in value of the mine given a change in the commodity price as a result of the volatility in the commodity price. Hence, the larger the volatility, the greater the uncertainty surrounding the future value of the underlying commodity all other things equal. This uncertainty is what creates value for the option to temporarily shut down mining operations because if over time the uncertainty resolves such that the spot price of the commodity falls below the cost of extract then temporarily closing the mine avoids operating losses.

The second term $(r-k)S_0 \frac{\delta \nu}{\delta S_0}$ characterises the relationship between the convenience yield and the spot price of the commodity. The model assumes that the convenience yield on the output commodity is written as a function of the output price alone. Hence, the instantaneous change in the futures price is expressed in terms of the relationship between the convenience yield and the spot price. Therefore, the value of the mine is an increasing function of the positive difference between the real rate of interest (r) and (k) the convenience yield.

The third term $-q\frac{\delta \nu}{\delta Q}$ represents the instantaneous change in the mine reserves affected by the selected extraction rate (q). As the extraction rate, q, increases, the fixed quantity of reserves is depleted faster, resulting in a shorter option life which impacts negatively on the value of the mine.

The last term in Equation (3.6), $q(S_0 - a_0) - \tau - (r + \lambda_1)\nu$ represents the current period cash flow from the mine (net of taxes and royalties), and is akin to a continuous dividend rate. The larger current cash flows from operations are the higher the mine value, all other things equal. This last component is most similar to the HVP where, $V_0 = (S_0 - a_0)\sum_{t=0}^{N} q_t(1 - t_c)$.

The following boundary conditions are required to solve the set equations:

Boundary Condition 1 $$\frac{\delta w}{\delta w}(S_0^*, Q) = 0 \qquad (4)$$

The mine value (open or closed) will never be less than the abandoned value of the mine. Brennan and Schwartz (1985a) assume that the abandonment value is zero.

Boundary Condition 2 $$w(S_0^*, Q) = 0 \qquad (5)$$

The closed value of the mine will never be less than the value of an open mine minus the cost of opening the mine. At S_2^*, the optimum spot price at which to open a closed mine, the closed mine value is equal to the open mine value less the cost of opening.

Boundary Condition 3 $$\frac{\delta v}{\delta S_0}(S_1^*, Q) = \max[\frac{\delta w}{\delta S_0}(S_1^*, Q) - c_1(Q), \text{or } 0] \qquad (6)$$

The open mine value can never be less than the closed value minus the cost of closing the operating mine. At S_1^*, the optimum spot price at which to close an open mine, the open value is equal to the closed value less the cost of closing.

Boundary Condition 4 $$v(S_1^*, Q) = \max[w(S_1^*, Q) - c_1, \text{or } 0] \qquad (7)$$

The value of the mine when the commodity reserves are exhausted must be equal to the abandoned value of the mine.

Boundary Condition 5[14] $$\frac{\delta v}{\delta S_0}(S_2^*, Q) = \frac{\delta w}{\delta S_0}(S_2^*, Q) \qquad (8)$$

S_0^* is chosen to maximise the value of the mine.

Boundary Condition 6 $$w(S_2^*, Q) = v(S_2^*, Q) - c_2(Q) \qquad (9)$$

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[14] The Samuelson-Merton "high contract condition" (Merton 1973) may be applied as detailed in Appendix 3.

S_2^* is chosen to maximize the value of the mine.

Boundary Condition 7 $\quad w(S_0,0) = v(S_0,0) = 0 \quad (10)$

S_1^* is chosen to maximize the value of the mine.

where

S_0^* = spot price at which the mine is abandoned

S_1^* = spot price where mine should be closed if it's open

S_2^* = spot price where mine should be opened if it's closed

c_1 = the cost of closing an open mine

c_2 = the cost of opening a closed mine.

The boundary conditions are expressed in terms of unknowns S_0^*, S_1^* and S_2^* that are determined as part of the solution process making it significantly more complicated to solve than the Black-Scholes model. S_0^*, S_1^* and S_2^* are also functions of Q the current reserves of the mine. These conditions can also be expressed as a function of the opening value (v) and the closing value (w) of the mine. This allows derivation of the mine value at changing inventory levels.

The only source of uncertainty relates to the commodity price variance. Geological or technological uncertainty is assumed to be zero to allow the numerical procedure for solving the optimal opening and closing policies to be feasible.