# Modern Asset Pricing — A Valuable Real Option Complement to Discounted Cash Flow Modelling of Mining Projects

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## ABSTRACT

For resources projects with healthy net present value (NPV) and low cash flow volatility, conventional discounted cash flow (DCF) analysis will continue to provide the dominant investment decision-making criteria. However, DCF analysis can be biased because it often applies a single risk-adjusted discount rate (RADR) to compare the value of projects with different risk characteristics. Many of the difficulties with DCF modelling arise from analysts' inability to determine appropriate risk discounts and to estimate expected spot prices inputs for the commodities produced over the life of the project. Modern asset pricing (MAP) is a very valuable complement to DCF analysis in addressing some of these issues. Most papers dealing with MAP, however, while academically rigorous, tend not to be explicit in terms of practical application of this methodology in routine project evaluation. This paper has the objective of reviewing the MAP methodology and of demystifying its complexity, by providing a simple but realistic step-by-step evaluation of a mining project, comparing its DCF and MAP NPV values. The paper concludes that MAP provides a minimum, risk-adjusted 'floor' value, thus representing a valuable complement to any DCF valuation.

## INTRODUCTION

### Inherent weakness of and common biases in discounted cash flow analysis

Discounted cash flow (DCF) analysis can be biased because it often applies a single risk-adjusted discount rate (RADR) to compare the value of projects with different risk characteristics (Salahor, 1998). This includes choices between different design options for the development of an orebody featuring different capital-intensity and operating leverage.

In reality the volatility of a project cash flow increases significantly and is positively correlated with the capital-intensity of alternative project designs and their unit cost of production. This makes capital-intensive and expensive projects very sensitive to the level of demand in terms of sales tonnages and, above all, the realised commodity price. Quantified examples of operating leverage effects for a gas project and for a base metal project are given in Salahor (1998) and Guj (2006a, p 110).

In the absence of hedging, the DCF/NPV of projects with different risk characteristics will only be comparable if:

- different RADRs are used for each project with a different risk premium reflecting their different level of risk, and
- alternatively the cash flow estimates of each project are adjusted to compensate for their different risk profiles.

Both these approaches generally tend to be complex and ambiguous.

The consequence of using the same discount rate is that riskier projects may be overvalued compared to less risky ones.

DCF analysis also applies a single RADR to both the revenue and costs functions of the financial model of a mining project, irrespective of the revenue being much more risky than the costs, mainly because of the high volatility of commodity prices. In general the performance and value of a project is significantly more sensitive to factors that affect revenue (eg commodity prices, grades, exchange rates, etc) than those affecting capital and operating costs (Guj, 2006a, p 111). The price of some commodities can vary by as much as ±100 per cent in a single year. This plays havoc with the realism of revenue estimates. By contrast, much of the capital investment is in the present or in the immediate future and thus can be estimated with a higher degree of confidence. Operating costs are generally less risky as their volatility is relatively low and, in addition, can be controlled by sound project management and by stringent contractual arrangements. Depending on the relative timing of revenue inflows and cost outflows, the use of a single RADR, may bias decisions against investing capital now to save recurrent costs in the future and overvalue future revenue inflows even though they are subject to increasingly higher risk over time (Salahor, 1998).

This source of bias can be eliminated, as it will be shown, by discounting the less risky operating costs of a project at a lower rate than that of its riskier revenue using.

## MODERN ASSET PRICING (MAP)

### No-arbitrage and replicating portfolios principles

In an efficient market relevant information is rapidly disseminated and incorporated in the price of assets. As a consequence, assets with similar risk characteristics and producing the same cash flows at the same times in the future should have the same price. This value-consistency principle (Salahor, 1998) implies that arbitrage opportunities should be infrequent and short-lived. Under no-arbitrage conditions, the value of a claim on a series of future cash flows can be replicated by a portfolio, composed of a risky asset and risk-free cash (through borrowing or lending), that has the same present value.

According to Samis (2002), the cash flows of a mining project can be simulated by a 'replicating portfolio' composed of:

- Mineral Forward contracts with quantities and delivery dates matching the risky mineral production schedule of the mine. The resulting cash flows at the delivery date of these contracts would equate to the project's revenue function.
- Bond issues (ie borrowing) matching the more certain estimated annual cash outflows relating to the emerging capital and operating costs of the project, ie with principal repayments and coupons of the same magnitude and maturing at the same time as the various project cost components. The assumption of greater certainty is broadly warranted because capital and operating costs can be estimated with a higher degree of confidence and can, to some degree, be kept on budget by sound technical and financial management and by stringent contractual conditions.

If forward prices, to be received with certainty on the delivery date, are used as price inputs in an evaluation model, the main source of risk (ie the commodity price risk) is 'neutralised'.

Given that the most significant source of risk has been neutralised, and assuming (for the purpose of the exercise) that

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the cost estimates are certain, the resulting model cash flows would also be certain. Under these circumstances, it would be inappropriate to discount the project cash flows using a risk-and time-adjusted discount rate, as they are no longer subject to risk. The appropriate rate of discount becomes the risk-free rate of interest to compensate only for the time-value-of-money.

This evaluation technique is an elementary form of real option valuation (ROV) (Samis, 2001; Salahor, 1998, p 15; Laughton, 1998), which is known as modern asset pricing or MAP for short. MAP is generally easy to apply and gives reliable, conservative estimates of the value of a project under the assumption that the bulk of its risk is linked to the volatility of the price of the commodity produced. More sophisticated forms of ROV entail neutralisation of the volatility of the overall cash flows of a project, encompassing all other sources of risk besides that of the commodity prices.

Although there are a number of authoritative papers that discuss the MAP evaluation methodology, they may appear to the uninitiated reader hard to apply in day-to-day practice. The main purpose of this paper is to demystify this apparent complexity by first reviewing the methodology and then by developing in the following sections a realistic mining-related evaluation model in a step-by-step fashion.

## Sources of input data

Historical daily prices for base metals and for gold and other precious metals can be downloaded from the LME and the KITKO web sites respectively. Oil prices are easily available from the Energy Information Administration (EIA). The LME site also provides futures contract quotes up to 27 months in the future for base metals, while gold futures quotes are available for up to four years from KITKO and oil ones up to five years from the New York Mercantile Exchange (NYMEX).

If the life of a project is shorter than these delivery dates, then actual futures market quotes can be used as price inputs, making its MAP evaluation very accurate and convenient.

For projects with longer lives futures prices must be forecasted beyond the longest market quote using sophisticated stochastic models. A high level of accuracy (as discussed later) can be achieved by calibrating the price-forecasting model using the available market futures quotes.

## Estimating price forecasting parameters and the ‘price of nickel price risk’

According to Crowson (2003) the most important factor in deriving spot prices is the futures price for the three-months delivery contract of a commodity.

Forwards and futures prices are certain because they are guaranteed on the delivery date by binding contracts and by the brokers’ clearing processes respectively. Implicit in the prices of futures, which are to be received with certainty, is a risk (but not time) discount or markdown from the risky spot prices expected on the corresponding delivery dates. The futures prices also embody a convenience yield (the balance between funding, storage and insurance costs and dividends such as leasing rents), which accrues to the holder of the physical metal.

The risk discount rate ($R_{Min}$) between the expected spot and the futures prices is a function of the commodity price risk (Salahor, 1998): the higher the price volatility ($\sigma_{Min}$) and the further in time the delivery date the greater the markdown. In essence it is a measure of the return on the mineral that the holder of the physical metal would need to justify the risk associated with acquiring and holding the metal inventory until the delivery date.

The ratio between $R_{Min}$ and $\sigma_{Min}$, ie the percentage of price risk discount per unit of price volatility, is known as the ‘price of mineral price risk’ ($Prisk_{Min}$) (Salahor, 1998):

$$\text{Price of mineral price risk} = Prisk_{Min} = R_{Min} / \sigma_{Min}$$

It reflects the natural tendency of markets to increase the risk discount on a given series of cash flows as a function of their volatility and of how far in the future they will be received. The ‘price of mineral price risk’ is, together with more basic price statistics, a significant input in stochastic price forecasting models.

For example, Figure 1 displays the historical daily nickel spot prices from 1997 to the end of 2006.

On 31 October 2006 the spot price was US$32 795 per tonne of nickel. On that date the LME also listed the nickel futures quotes displayed in Table 1.

The long-term median on 31 October 2006, was US$11 616 per tonne having grown by 13.25 per cent over that of the previous year (US$10 257). The corresponding annualised

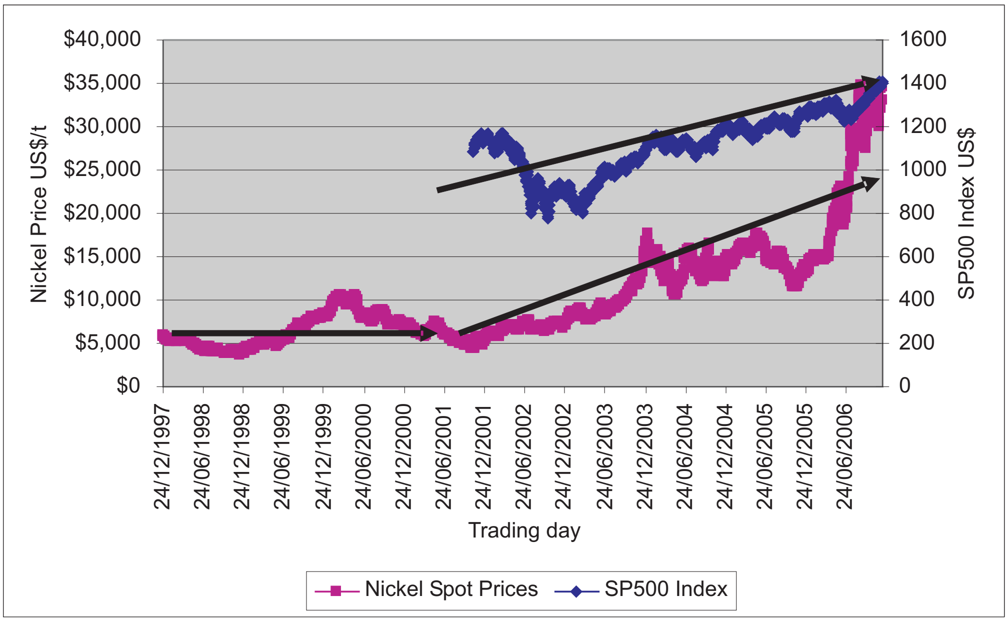

FIG 1 - Nickel spot prices and SP 500 index correlation.

**TABLE 1**

*Nickel futures contract quotes 31 October 2006.*

| Delivery time | Futures quotes (US$/t of nickel) |
|---|---|
| Spot | 32 795 |
| 3 months | 31 650 |
| 15 months | 25 650 |
| 27 months | 21 725 |

volatility of the daily nickel prices over the same period was 53.78 per cent. The latter was calculated following Benninga's (2001, p 282) methodology as the standard deviation of the logarithmic returns on holding physical nickel stock.

Figure 1 also displays the daily values of the 'market portfolio' as reflected in the S&P 500 index over the same period as obtained from the Yahoo finance web site. The annualised volatility of this index is 13.17 per cent. Long-term time series studies by Officer (1989) indicate that the average risk premium on the return on the market portfolio ($R_{Mkt}$) above the risk-free rate of return ($R_f$), ie $R_{Mkt}$ - $R_f$, is of the order of six per cent per annum.

A high correlation of 0.7312 exists between movements in the market index and in daily nickel prices calculated from December 2001, when a major change in price trend occurred. This change was possibly due to the emergence of China as a major source of additional demand for the nickel.

To the extent that physical nickel stock is just one of many assets that an investor could hold, an order of magnitude of the risk discount ($R_{Min}$) associated with the nickel price volatility can be derived using a variation of the capital asset pricing model (CAPM) (Peirson *et al*, 2002, p 220):

$$R_{Min} = \textit{Risk-free discount for timing of cash flows} \\ + \textit{Mineral risk premium} = R_f + \beta_{Min} * \left(R_{Mkt} - R_f\right)$$

Ignoring in the first instance the time-value-of-money (Rf) the mineral risk premium is:

$$\beta_{Min} * \left(R_{Mkt} - R_f\right)$$

where:

$$\beta_{\mathrm{MIN}} = \frac{Covariance_{Min,Mkt}}{Variance_{Mkt}}$$

However, remembering the relationship between correlation and covariance (Ellery and Strickland, 1992, p 337):

$$\rho_{Min,Mkt} = \frac{Covariance_{Min,Mkt}}{\sigma_{Mkt} \times \sigma_{Min}}$$

the beta index of the return on holding mineral stock ($\beta_{Min}$) becomes:

$$\beta_{Min} = \frac{\rho_{Min,Mkt} \times \sigma_{Min}}{\sigma_{Mkt}}$$

which, if substituted in the CAPM formula, gives:

$$R_{Min} = \frac{\rho_{Min,Mkt} \times \sigma_{Min}}{\sigma_{Mkt}} \times \left(R_{Mkt} - R_f\right)$$

Hence the 'price of mineral price risk' ($PRisk_{Min}$) in general can be obtained from the following equation:

$$\frac{R_{Min}}{\sigma_{Min}} = \frac{\left(R_{Mkt} - R_f\right) \times \rho_{Min,Mkt}}{\sigma_{Mkt}}$$

Applying this formula to the 'price of nickel price risk' on 31 October 2006 gives (0.06 * 0.7312)/0.1317 = 0.3331.

Under normal market conditions and because of its volatility, the nickel price (as well as those of most other commodities with the exception of gold) follows a random geometric Brownian motion (GBM) around a mean trend (Baker, Mayfield and Parsons, 1998). This type of random and non-deterministic evolutionary processes, (in the case in question the price set by the last sale does not fully determine those of following sales), are generally referred to as stochastic from the Greek word 'stochos' (meaning goal) and can be described using probability distributions. For commodity prices time series the best fitting probability distribution is generally the log-normal distribution.

Furthermore, following any price-shock, the prices of most mineral commodities gradually revert to their mean trend because market forces react by bringing new supplies into production in the case of significant price increases, or reduce supplies following falls in price. As a consequence the price volatility of reverting commodities initially grows unbound over time, but then moderates because of reverting forces.

The half-life, ie the number of years that it takes for a commodity price to revert to the mean after a price shock, is a measure of the speed of reversion and is incorporated in the reversion factor $\gamma$ = ln(2)/half-life. The latter together with the price of mineral price risk is one of the main components of the price reversion factor ($RDF_{Min}$) including reversion effects (as computed below) using the formula presented by Samis, Poulin and Blais (2005):

$$RDF_{Min} = e^{\left(-\frac{PRisk_{Min} \times \sigma_{Min}}{\gamma}\right) \times \left(1 - e^{-\gamma \times t}\right)}$$

The $RDF_{Min}$ is a key component of price forecasting models.

## Stochastic price forecasting model

The formulation of the stochastic forecasting model for reverting commodity prices as used in our evaluation example was presented in a number of previous studies (Smith and McCardle, 1998; Baker, Mayfield and Parsons, 1998; Salahor 1998) and was recently clearly summarised by Samis, Poulin and Blais (2005).

Table 2 and Figure 2 show nickel spot and futures prices forecasts using the standard GBM formula for continuous spot price changes (dS), including reversion to the mean and error factors as presented by Samis, Poulin and Blais (2005) ie:

$$dS = \left[\alpha^* + \frac{1}{2}\sigma^2 - \gamma \ln\left(\frac{S}{S^*}\right)\right] S dt + \sigma S dz$$

where:

$\alpha^*$ =short-term growth rate of the price median

S =current spot price

$S^*$ =current long-term price median

$\sigma$ =short-term price volatility

$\gamma$ =ln(2)/half-life = reversion factor

z =standard random variable

Given that this is a continuous function, the short-term growth rate of the median and price volatility should be instantaneous. In practice these parameters may prove difficult to derive and indeed may prove to be unrealistic. Some degree of judgement needs to be applied on the side of the analyst drawing from his/her knowledge of the relevant markets and with cognisance as to where the time of the evaluation rests relative to the economic cycle. For the purpose of the exercise that follows, the rates of growth of the median and price volatility were calculated over the last 250 days, which is a general average number of trading days in a calendar year.

### TABLE 2

*Nickel price forecast model as of 31 October 2006 (modified after Samis, Poulin and Blais, 2005).*

| **Inputs** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Current spot price ($US/t) | | | $32 795.00 | | | | | |
| Current long-term price median ($US/t) | | | $11 615.75 | | | | | |
| Price of mineral risk (%) | | | 33.31% | | | | | |
| Short-term price growth rate (%) | | | 13.25% | | | | | |
| Shot-term price volatility (%) | | | 53.78% | | | | | |
| Reversion half-life (years) | | | 2.8 | | | | | |
| Reversion factor = Ln(2)/half-life | | | 0.25 | | | | | |
| Confidence interval percentile | | Plus and minus | 10.00% | | | | | |
| **Time (years)** | **Variance (%)2** | **Median spot price ($/unit)** | **Expected spot price ($/unit)** | **Risk discount factor** | **Forward price ($/unit)** | **Lower 10% confidence** | **Upper 10% confidence** | **LME futures** |
| 0 | 0.0000 | $32 795.00 | $32 795.00 | 1.0000 | $32 795.00 | $32 795.00 | $32 795.00 | $32 795.00 |
| 0.25 | 0.0680 | $31 759.18 | $32 857.75 | 0.9575 | $31 461.38 | $22 736.39 | $44 362.62 | $31 650.00 |
| 0.5 | 0.1281 | $30 707.25 | $32 738.48 | 0.9192 | $30 093.34 | $19 410.42 | $48 578.81 | |
| 0.75 | 0.1812 | $29 657.97 | $32 470.49 | 0.8846 | $28 723.44 | $17 187.86 | $51 175.39 | |
| 1 | 0.2281 | $28 625.71 | $32 084.20 | 0.8533 | $27 376.30 | $15 521.35 | $52 793.84 | |
| 1.25 | 0.2696 | $27 621.13 | $31 606.60 | 0.8248 | $26 069.76 | $14 199.37 | $53 729.61 | $25 650.00 |
| 1.5 | 0.3062 | $26 651.83 | $31 061.11 | 0.7989 | $24 816.23 | $13 114.39 | $54 163.41 | |
| 1.75 | 0.3386 | $25 723.00 | $30 467.66 | 0.7754 | $23 623.70 | $12 203.26 | $54 220.99 | |
| 2 | 0.3672 | $24 837.86 | $29 842.90 | 0.7538 | $22 496.80 | $11 425.35 | $53 995.69 | |
| 2.25 | 0.3924 | $23 998.14 | $29 200.54 | 0.7341 | $21 437.56 | $10 752.81 | $53 559.10 | $21 725.00 |
| 2.5 | 0.4147 | $23 204.39 | $28 551.66 | 0.7161 | $20 446.09 | $10 165.63 | $52 967.09 | |
| 2.75 | 0.4345 | $22 456.31 | $27 905.05 | 0.6996 | $19 521.12 | $9 648.90 | $52 263.55 | |
| 3 | 0.4519 | $21 752.93 | $27 267.60 | 0.6843 | $18 660.42 | $9 191.18 | $51 483.07 | |
| 3.25 | 0.4673 | $21 092.86 | $26 644.56 | 0.6703 | $17 861.12 | $8 783.49 | $50 652.83 | |
| 3.5 | 0.4809 | $20 474.37 | $26 039.84 | 0.6575 | $17 119.95 | $8 418.66 | $49 794.15 | |
| 3.75 | 0.4929 | $19 895.54 | $25 456.24 | 0.6456 | $16 433.45 | $8 090.83 | $48 923.60 | |
| 4 | 0.5036 | $19 354.35 | $24 895.68 | 0.6346 | $15 798.09 | $7 795.21 | $48 053.99 | |
| 4.25 | 0.5129 | $18 848.72 | $24 359.33 | 0.6244 | $15 210.36 | $7 527.78 | $47 195.07 | |
| 4.5 | 0.5212 | $18 376.56 | $23 847.82 | 0.6150 | $14 666.85 | $7 285.17 | $46 354.15 | |
| 4.75 | 0.5286 | $17 935.84 | $23 361.32 | 0.6063 | $14 164.29 | $7 064.52 | $45 536.63 | |
| 5 | 0.5350 | $17 524.57 | $22 899.66 | 0.5982 | $13 699.58 | $6 863.37 | $44 746.32 | |

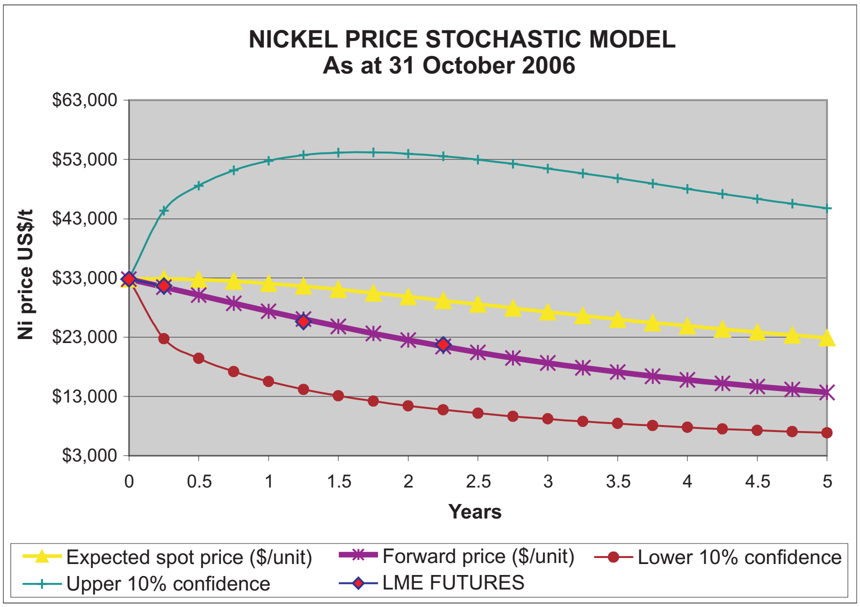

FIG 2 - Nickel price stochastic model as at 31 October 2006 (after Samis, Poulin and Blais, 2005).

## A PRACTICAL EXAMPLE OF MODERN ASSET PRICING MODELLING OF A NICKEL MINE

### Modelling steps and assumptions

As practical numerical examples are commonly the most effective way to fully understand a concept, this section presents the evaluation of a simplified nickel-mining project in a step-by-step fashion. Both the conventional DCF/NPV and MAP/NPV of the project are derived. The steps involved entail the construction of the project cash flow model as follows:

For the DCF valuation:

- forecasting the risky expected spot prices over the life of the project using a stochastic model,
- using the above expected spot prices as inputs in the revenue function of the DCF model, and
- discounting the project's net after-tax cash flows to present value using an appropriate risk-and time-adjusted rate of discount to obtain its DCF/NPV.

For the MAP valuation:

- obtaining available risk-free nickel futures quotes from the LME,
- determining the 'price of nickel price risk' from market statistics,
- forecasting futures prices beyond the longest market quote to the end of the project life using the above stochastic model given the assessed 'price of nickel price risk',
- using the above futures as price inputs in the revenue function of the MAP model, and
- discounting the project's net after-tax cash flows to present value using the risk-free rate of interest to obtain its MAP/NPV.

Once the model is constructed the DCF and MAP results can be compared.

The example assumes that it is 31 October 2006 and that an operating nickel mine with five years of remaining life is offered for outright purchase. The mine produces and sells 12 million pounds of nickel in concentrate per annum to a smelter, which pays 70 per cent of the value of contained nickel. To progress with negotiations it will become imperative to estimate a reasonable expected order of magnitude of the value of the project as well as an idea of its minimum value.

The relevant mine model assumptions are provided in Table 3.

**TABLE 3**

*Nickel mine model assumptions.*

| | |
|---|---|
| Remaining productive life (years) | 5 |
| Annual production/sales of Ni in concentrate (lb million) | 12 |
| Capital items fully depreciable over the mine life on a straight line ($US million) | 45 |
| Real fixed annual recurrent cash costs ($US million) | 4 |
| Real variable cash production cost per pound of Ni ($US/lb) | 1.5 |
| Mineral royalty as a percentage of net smelter returns (%) | 2.5% |
| Corporate income tax (%) | 30% |
| Annual average rate of cost inflation (%) | 3% |
| Nominal risk-free rate of interest (%) | 5.5% |
| Nominal risk- and time-adjusted discount rate (%) | 15% |
| Conversion factor from tonnes to pounds | 2204.6226 |

### Deriving the price inputs for the MAP and DCF models

Both the spot price and risk discount factor formulae from the previous chapter were hard coded in Microsoft Excel. The prices obtained in Table 2 reflect the inputs estimated in previous sections. Inputs are shaded in Table 2 for ready identification.

A half-life of 2.8 years was assumed to achieve the best fit between the projected futures prices obtained from the model and the actual quotes obtained from the LME as tabulated in Table 1. Thus, within bounds of realism, the half-life was used as a balancing item to calibrate and 'anchor' the model against the certainty of available LME futures quotes. In practice, calibration entails changing the half-life input estimate by small increments until the three dots corresponding to the actual LME futures quotes for three, 15 and 27 months (Figure 2) fall squarely on the futures prices for the same delivery dates as projected by the model. This process improves the reliability of the futures prices projections, which will, in effect, become close to risk-free. The values obtained by this method represent the price input for MAP models.

The model can be used in two ways, ie given the risk discount factor one can project the spot prices or, given the LME actual futures quotes one can achieve greater confidence in the realism of the spot price projections as inputs in conventional DCF analysis models. The authors see considerable value in the latter approach in overcoming the difficult question of what spot prices to input in DCF models.

If a very high half-life value is used in the $\gamma$ formula, then the value of $\gamma$ tends to zero and the GBM algorithm can be used to forecast the behaviour of the price of non-reverting commodities such as gold. Gold represents a notable exception as its quasi-monetary role makes it more akin to financial securities than commodities.

### MAP versus DCF modelling

To facilitate the exercise both the MAP and DCF models are constructed using US$ as the currency and millions of pounds of nickel metal contained in concentrates as the units of production. Please note that the realised price in US$ per pound of nickel used to compute the project gross revenue is a net smelter return (NSR) figure based on transport, smelting and refining charges amounting to around 30 per cent of the value of contained metal.

Table 4 illustrates how in the MAP model of the above project:

- futures prices were used in computing the project revenue; and
- how the net after-tax cash flows were discounted by the risk-free rate of interest (5.5 per cent), because of elimination of the price risk through the use of futures prices, while operational risk has been removed through the turnkey mining contract.

The MAP/NPV at $153.66 million represents a minimum risk-adjusted value for this project. It is in effect what the project would be worth if its whole production were to be sold forward.

Table 5 shows the corresponding conventional DCF model using the estimated expected spot prices (instead of the LME futures prices quotes) and the corporate rate of discount of 15 per cent. The relevant expected DCF/NPV is US$197.53 million. The difference of US$43.87 million represents the monetary value of the price risk discount.

The above DCF/NPV is 'expected', ie it is the mean of all possible NPVs weighted by their respective probability of occurrence. Thus the DCF/NPV is risky as both higher or lower NPVs than expected are possible depending on whether the actual prices of nickel during the life of the project are higher or lower than forecast. By contrast, the risk due to the volatility of

**TABLE 4**

*Modern asset pricing (MAP) evaluation in nominal dollars.*

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 kg = lb | 2.2046226 | | | | | |
| Written down value of undepreciated capital investment ($US M) | 45 | | | | | |
| Inflation per annum (%) | 3.00% | | | | | |
| Average net smelter return (NSR) as % of Ni price | 70.00% | | | | | |
| **Time (years)** | **0** | **1** | **2** | **3** | **4** | **5** |
| Estimated forward Ni prices ($US/t) | $32 795 | $26 945 | $21 848 | $17 883 | $14 934 | $12 770 |
| **Modern asset pricing (MAP) Model** | | | | | | |
| Sales (lb*million) | | 12 | 12 | 12 | 12 | 12 |
| Realised forward price ($US/lb) | | $8.56 | $6.94 | $5.68 | $4.74 | $4.05 |
| Total revenue (US$ million) | | 102.66 | 83.25 | 68.14 | 56.90 | 48.66 |
| Royalties @ 2.5% ($US M) | | 2.57 | 2.08 | 1.70 | 1.42 | 1.22 |
| Unit cost of production ($US/lb) | $1.50 | $1.55 | $1.59 | $1.64 | $1.69 | $1.74 |
| Fixed cost of production ($US M pa) | 4.00 | 4.12 | 4.24 | 4.37 | 4.50 | 4.64 |
| Total cost of production ($US M) | | 22.66 | 23.34 | 24.04 | 24.76 | 25.50 |
| Depreciation ($US M) | | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 |
| Profit after 30% tax ($US M) | | 47.91 | 34.18 | 23.38 | 15.20 | 9.06 |
| Net cash flow ($US M) | | 56.91 | 43.18 | 32.38 | 24.20 | 18.06 |
| **Nominal risk-free discount per annum (%)** | **5.50%** | | | | | |
| Risk-free discount factor | 1.0000 | 0.9479 | 0.8985 | 0.8516 | 0.8072 | 0.7651 |
| Discounted cash flow ($US million) | | 53.94 | 38.79 | 27.57 | 19.54 | 13.82 |
| **MAP/NPV ($US million)** | **153.66** | | | | | |

**TABLE 5**

*Discounted cash flow (DCF) evaluation model in nominal dollars.*

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 kg = lb | 2.2046226 | | | | | |
| Written down value of undepreciated capital investment (US$ M) | 45 | | | | | |
| Inflation per annum (%) | 3.00% | | | | | |
| Average net smelter return (NSR) as % of Cu price | 70.00% | | | | | |
| **Time (years)** | **0** | **1** | **2** | **3** | **4** | **5** |
| Estimated Ni Spot Prices (US$/t) | $32 795 | $32 084 | $29 843 | $27 268 | $24 896 | $22 900 |
| **Discounted cash flow (DCF) Model** | | | | | | |
| Sales (lb*M) | | 12 | 12 | 12 | 12 | 12 |
| Realised expected spot price ($US/lb) | | $10.19 | $9.48 | $8.66 | $7.90 | $7.27 |
| Total revenue ($US M) | | 122.25 | 113.71 | 103.89 | 94.86 | 87.25 |
| Royalties @ 2.5% ($US M) | | 3.06 | 2.84 | 2.60 | 2.37 | 2.18 |
| Unit cost of production ($US/lb) | $1.50 | $1.55 | $1.59 | $1.64 | $1.69 | $1.74 |
| Fixed cost of production ($US Mpa) | 4.00 | 4.12 | 4.24 | 4.37 | 4.50 | 4.64 |
| Total cost of production ($US M) | | 22.66 | 23.34 | 24.04 | 24.76 | 25.50 |
| Depreciation ($US M) | | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 |
| Profit after 30% tax ($US M) | | 61.27 | 54.97 | 47.78 | 41.11 | 35.40 |
| Net cash flow ($US M) | | 70.27 | 63.97 | 56.78 | 50.11 | 44.40 |
| **Nominal time and risk adjusted discount rate (%)** | **15.00%** | | | | | |
| Risk- and time-adjusted discount factor | 1.0000 | 0.8696 | 0.7561 | 0.6575 | 0.5718 | 0.4972 |
| Discounted cash flow ($US M) | | 61.11 | 48.37 | 37.33 | 28.65 | 22.07 |
| **DCF/NPV ($US M)** | **197.53** | | | | | |

the nickel price is not hedged in DCF analysis. As a matter of fact at the time of writing this paper (February 2007) the price of nickel was creeping up to US$40 000 per tonne, ie well above the spot price expected on this date (see Figure 2), but also well within the ten per cent to 90 per cent bands of confidence.

## DISCUSSION AND CONCLUSIONS

There is no doubt that MAP represents a powerful complement to DCF analysis in providing a minimum risk-adjusted value for mining projects.

As all the risk-related inputs are sourced from actual market data and subject to limited interpretation, they are fairly objective. As a result MAP also represents a valid quantitative approach to generate realistic assumptions as to what expected commodity spot prices should be input in conventional DCF evaluation models.

Comparison between the MAP and the expected DCF NPVs provides a quantitative dollar value for the risk premium implicit in values derived from conventional DCF analysis. This, in turn, helps to question and assess the realism of the corporate risk-and-time adjusted discount rate used.

Decisions based on maximising expected DCF/NPV imply a risk-neutral attitude to investment, while decisions based on MAP/NPV are consistent with a high level of risk aversion. Clearly MAP produces lower project values, which as a consequence would not be over-emphasised by project proponents, but which may provide a valuable insight for the provider of project finance.

In addition, MAP may prove helpful in better understanding the financial characteristics of a project and in choosing between alternative developments with different possible combinations of capital and operating costs.

For these reasons and because of its relative user friendliness once a financial analyst has become familiar with it, the MAP methodology should be routinely applied when conducting financial modelling and valuation of mining projects.

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