

# Valuation of mining projects using option pricing techniques

In corporate finance practice, the standard DCF approach to valuation is gradually being supplemented with real options valuation. This is supported by a substantial body of evidence that valuations which incorporate the value of embedded options provide a better approximation of transaction prices than DCF valuations.



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**THE STANDARD VALUATION TECHNIQUE** – discounted cash flows (DCF) – estimates the present value of expected future cash flows. This technique is typically implemented under the assumption that investment policy is independent of prices. In reality, management responds to fluctuating commodity prices by altering investment policy, such that production expands in a high-price scenario and reduces in response to low prices. Management's ability to exercise these options to alter investment policy is very valuable, as approximately 30% of the value of high-growth, high-volatility firms is directly attributable to the value of embedded options (Hall, 2005). With close to one-third of large, Australian-listed firms now using option pricing techniques to improve decision-making (Truong, Partington and Peat, 2005), this is likely to replace DCF as the standard valuation technique in the foreseeable future.

This paper focuses on the impact of the emerging use of real options valuation in corporate finance practice (Graham and Harvey, 2001; Truong et al, 2005) and its contrasting minimal use by equity analysts who largely rely on multiples-based valuation (Asquith, Mikhail and Au, 2005; Demirakos, Strong and Walker, 2004; Block, 1999; and Bradshaw, 2002). Furthermore, there is growing theoretical and empirical evidence that market prices exceed DCF valuations and this difference can be attributed to option value (Berger, Ofek and Swary, 1996; Schwartz and Moon, 2000 and 2001; Bernardo and Chowdry, 2002; Quigg, 1993). Hence, we expect option pricing techniques to be the predominant valuation method adopted in Australia within 10 years.

We will examine the difference between DCF and real options valuation of mining projects using a simplified example, the objective being to clarify this valuation

technique for corporate finance practitioners. Managers who ignore option value are likely to arrive at valuations substantially below those typically observed in the market, leading them to rely on arbitrary rules of thumb in order to 'gross-up' those valuations to something more intuitively appealing. Rather than increase uncertainty over estimated value, real options techniques apply rigorous finance theory to the estimate of value. This reduces the likelihood of valuations resulting from a pre-disposition towards a preferred multiple, which may not correctly account for project-specific assumptions in relation to risk and growth.

The real options valuation of a project can also be expressed as the value which includes management's options to change the size or scope of that project. By construction, it will exceed the DCF value of that project. The valuation difference occurs because the DCF value is the present value of expected future cash flows. In contrast, real options techniques compute project value as the expectation of the values associated with all possible cash flows. This difference is illustrated in Figure 1, for the simplest formulation where earnings can continue as a perpetual stream of either high or low cash flows.

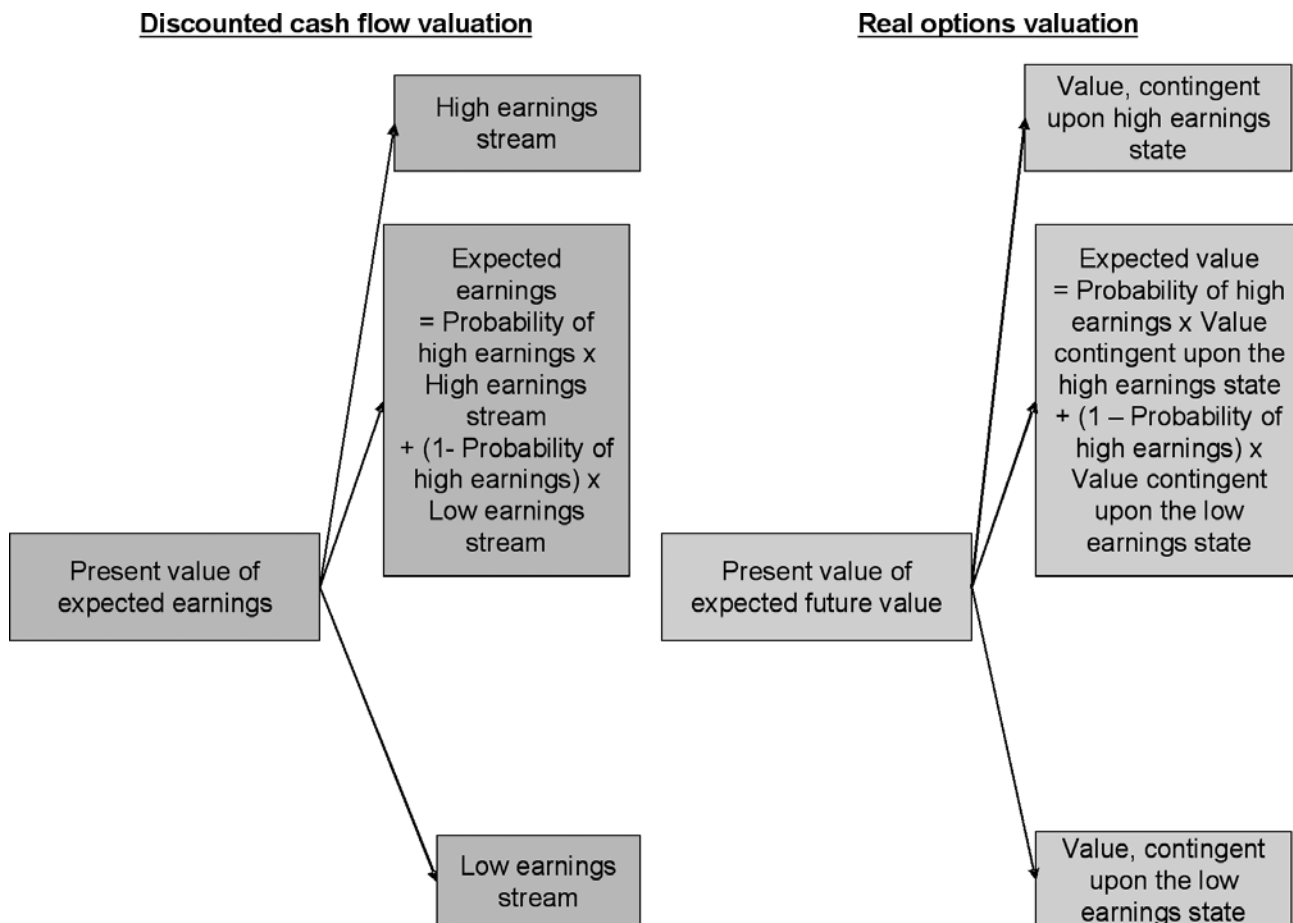
Copeland, Weston and Shastri (2005) classify embedded options into categories of expansion, contraction, abandonment, extension, deferral, compound

and rainbow options. This sort of classification is merely terminology provided to managers to assist in their understanding of the options available to them, and which can contain considerable value. The primary valuation technique for real options – binomial tree valuation – is applicable to all projects, regardless of the number or type of options available.

We prefer to think of embedded options within a growth versus abandonment spectrum. The primary way management can increase shareholder value is by altering investment policy in response to signals about the investment environment. If management receives signals that it is operating in a high-growth environment, it can respond by exercising the option to expand, and take the opposite approach in response to signals that it is entering a low-growth environment. The extreme case of a contraction option is the option to abandon a project. It is this dynamic investment policy which is valuable, but which is typically ignored in a DCF valuation.

The concept of dynamic investment in response to high- and low-growth signals is similar to the treatment of real options by Brennan and Schwartz (1985) who argue that DCF valuations neglect the time-varying nature of output prices and possible managerial responses to price variations. The implication is that, 'the practice of

FIGURE 1: Illustration of real options versus discounted cash flow valuation.



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replacing distributions of future prices by their expected values is likely to cause errors in the calculation of both expected cash flows and of appropriate discount rates and thereby lead to sub-optimal investment decisions (pp. 136)'. Our view is that because commodity prices fluctuate at every point in time, management faces a continuous expansion–contraction decision. Large mine expansions or shutdowns are merely extreme examples of this continuous production decision.

Consideration of real options valuation is especially important for the high-volatility mining sector. The volatility associated with value drivers such as commodity prices, exchange rates and costs demands that management has the ability to alter investment plans in response to these drivers. Hence, the value of the firm's abandonment option is likely to be greater than average. Furthermore, the heightened volatility of revenue streams and margin growth means that their growth options also have above-average value, given that investment policy is expected to change in response to feedback regarding the firm's growth prospects.

For projects which contain no embedded options, the valuation arrived at using a binomial tree is, in theory, exactly the same as that which would be derived by discounting expected cash flows at the risk-adjusted cost of capital. Any difference between these two valuations results from an inconsistency in the inputs to valuation. This could result from the volatility of cash flows, implicitly incorporated into the binomial tree, being different to the volatility incorporated into the discount rate, generally made with reference to comparable firm analysis. Another common inconsistency results from the analyst's use of most likely cash flows in valuation, rather than expected cash flows which are a probability-weighted average of all possible cash flows. Regardless of the reason for any inconsistency, the key point is that there is no theoretical reason why a binomial tree valuation should differ from a DCF valuation in the absence of embedded options.

## Literature

In corporate finance practice, the standard DCF approach to valuation is gradually being supplemented with real options valuation. This is supported by a substantial body of evidence which concludes that valuations which incorporate the value of embedded options provide a better approximation of transaction prices than DCF valuations.

### *Equity markets*

Berger, Ofek and Swary (1996) attribute a median 10% of equity value to equity-holders' abandonment option for 7102 firm years from 1984 to 1990. Firms with a higher probability of financial distress and greater ability to re-deploy assets had higher market values relative to the present value of expected cash flows, which is consistent with the market placing a positive value on the abandonment option. However, the evidence from this indirect valuation cannot necessarily be interpreted as the value of the abandonment option, but rather the combined value of the firm's growth options and abandonment option.

### *Oil*

Paddock, Siegel and Smith (1988) developed a method for valuing offshore petroleum leases, and applied the model to a sample of 21 actual bids. Valuations which considered the option to defer development were closer to transaction prices than the net present value of expected cash flows. Importantly, the authors note five major weaknesses of the DCF approach that inhibit correct lease valuation determination:

1. The proper timing of exploration and development is not transparent.
2. Different companies, as well as the government, may have different assessments of future statistical distributions (and thus expected paths) of hydrogen prices, none of which need conform to the aggregate expectations held by capital markets.
3. The process of choosing the correct set of risk-adjusted discount rates in the presence of the complex statistical structure of the cash flows is a difficult task, and is also subject to a great deal of subjectivity and error.
4. The DCF calculations, particularly Monte Carlo applications, are very complex and costly.
5. Because tract information is often relatively sparse at the bidding stage, the assessments of geological and cost distributions can vary, perhaps widely, across companies and the government.

### *Plantations*

Bailey (1991) reasoned that the option to close and then reopen commodity plantations producing rubber and palm oil was particularly important in these highly cyclical businesses. Using data from seven companies for the period 1983–85, he valued them using DCF and real options. In six out of seven cases, the real option valuations were closer to the actual market price than DCF-based prices.

## Land

Quigg (1993) considered the case in which the owner of undeveloped property has a perpetual option to construct an optimal-sized building. For 2,700 transactions in Seattle from 1976–79, the average option premium was 6% and the model generated an implied standard deviation of prices of 19–28%. Variation in transaction prices was partly explained by the option premium.

## Gold

Kelly (1998) applied a binomial option approach to the investment timing option, relying on data already available from published sources such as futures and spot markets. She determined the value of the undeveloped mine of Lihir Gold and compared the value derived from the option model to the final offer price of the IPO. The traditional NPV investment rule would have the firm invest as soon as the price of gold exceeds the development and extraction costs. Under the option approach it is not optimal to commence development unless the value of the commodity is high enough to cover both the cost of development and the cost of foreclosing the mine at a later date. Transaction prices approximated valuations which included the value of these embedded options.

Moel and Tufano (2002) studied the opening and closing decisions of 285 developed gold mines in North America during the period 1988–1997. They concluded that openings and closings are better explained by switching options than other approaches. As predicted by their model, mine closings are influenced by the price of gold, its volatility, costs of operating the mine, proxies for closing costs and the amount of estimated reserves.

## Copper

Cortazar and Casassus (1998) present a case study in which they value the option to expand copper mine production. Depending upon the initial copper price assumption, the value of embedded options was estimated at between 8 and 98% of total value. This illustrates that, for cases in which the DCF valuation is close to zero, option value can be substantial, which is what we observe in equity markets in relation to speculative resource companies.

While there is substantial evidence that the value of real options is recognised by the market and not accounted for in DCF valuations, Slade (2001) cautions against using valuations which result from a large number of simplifying assumptions. For example, researchers often assume that commodity prices are a random variable, rather than model the more complex mean-reversion typically observed in the market.

Slade assesses the consequences of these assumptions using data from a sample of 21 Canadian copper mines which operated between 1980 and 1993. The consequences of alternative assumptions regarding the evolution of prices and costs are startling. For example, in the case which best fits the data, prices and costs were assumed to be time-varying and had initial values set at their means. Total value almost doubles when the assumption of mean-

**Ultimately, real options techniques are one of the most important corporate finance decision-making tools to have been introduced in the past 30 or 40 years. They capture the present value of flexibility of managerial decisions at a future date in response to the arrival of new information. Traditional NPV methodology implicitly assumes pre-commitment, i.e. no flexibility.**

reversion is relaxed. Furthermore, the option component of value increases by almost 10 times when mean-reversion is ignored. Relaxing the mean-reversion assumption generates more extreme inputs into the valuation, which increases option value.

In contrast, Schwartz (1997) presents a model in which project values are higher under the mean-reversion assumption. In his model, the timing of entry is flexible but operation thereafter is not. His conclusion is due to the fact that if price is low today, and prices are mean-reverting, the situation for project owners is expected to improve, thereby increasing the value of the option to delay investment.

Given the sensitivity of valuations to these assumptions, one may think that real options valuations are too unreliable to be useful in a real-world context. However, this is not the case. DCF valuations simply replace the distribution of valuation inputs (which includes the process by which those inputs could potentially move over time) with expected values. The valuation which results from this replacement does not become more accurate simply because uncertainty is ignored.

Suppose we could make three alternative assumptions regarding the evolution of commodity prices: (1) prices are expected to be mean-reverting but fluctuate according to random factors which affect supply and demand; (2) prices evolve according to geometric Brownian motion, so can increase to very high levels or decrease to close to zero; or (3) we model expected commodity prices and incorporate the risk associated with their fluctuation into the discount rate – the assumption underlying DCF valuation. If the way in which commodity prices evolve is highly uncertain, this should be reflected in a high degree of uncertainty over the discount rate, implying a reasonably wide valuation range. The key point is that uncertainty over the distribution of parameter inputs increases the estimation error in valuation, regardless of the valuation technique used.

**Example: Valuation of a coal mine**

To illustrate the usefulness of real options valuation we present the valuation of a coal mine which incorporates two options: we can abandon the project for no cost and realise zero value for the mine; and/or we can invest \$200 million in an expansion which will increase production.

This example is a simplification of the real-world decision-making undertaken by mining company executives. Its purpose is to illustrate the process by which a real options valuation is conducted using a binomial tree. In no way is it meant to be indicative of the actual value attributed to embedded options in a mining project, and we do not imply that valuation is as simple as presented here.

Our assumptions are as follows. A coal mining project reports the following financial statement data for the past year: revenue of \$300 million from production and sales of 6 million tonnes at \$50 per tonne; fixed operating costs of \$130 million; and variable operating costs of \$22 per tonne. These costs include depreciation and we will assume that maintenance capital expenditure is equal to depreciation. Hence, the project is not in an expansion or contraction phase – it is in what we would typically consider to be a steady-state position. The mine has reserves of 60 million tonnes, so has a 10-year mine life if

mining continues at its present rate. The corporate tax rate is 30%. If we expand production to 10 million tonnes per year, we will incur additional fixed costs of \$30 million per year.

The only risk factor we will consider in this case is uncertainty over coal price movements, which we can reasonably assume are positively associated with overall economic growth. This is both a risk to the viability of the mine, but also a source of value, given that we can alter investment policy in response to information about coal prices. Suppose we assume that coal prices can increase by 13% in any given year, or decrease by 11% with the additional constraint that coal prices cannot fall below \$30 per tonne, or rise above \$100 per tonne. Potential coal price movements of this type are consistent with the distribution of export coal prices reported by ABARE for the most recent 30-year period (ABARE, 2005).

For each of these potential future coal prices, there is an associated Free Cash Flow to the Firm, computed as:

$$FCFF = [(Price - Variable costs) \times tonnes - Fixed costs] \times (1 - tax rate)$$

Figure 2 illustrates a distribution of potential coal price movements and associated cash flows which we can use to value the project. A DCF valuation assigns a

FIGURE 2: Potential future coal prices over a 10-year period and associated cash flow estimates.

Constrained price	0	1	2	3	4	5	6	7	8	9	10
	50.00	56.37	63.56	71.67	80.80	91.11	100.00	100.00	100.00	100.00	100.00
		44.35	50.00	56.37	63.56	71.67	80.80	91.11	100.00	100.00	100.00
			39.33	44.35	50.00	56.37	63.56	71.67	80.80	91.11	100.00
				34.88	39.33	44.35	50.00	56.37	63.56	71.67	80.80
					30.94	34.88	39.33	44.35	50.00	56.37	63.56
						30.00	30.94	34.88	39.33	44.35	50.00
							30.00	30.00	30.94	34.88	39.33
								30.00	30.00	30.00	30.94
									30.00	30.00	30.00
										30.00	30.00
											30.00
Expected price	\$50.00	50.54	51.12	51.75	52.44	53.35	54.15	55.23	56.18	57.42	58.53
Free cash flow to the firm	0	1	2	3	4	5	6	7	8	9	10
	27	53	84	118	156	199	237	237	237	237	237
		3	27	53	84	118	156	199	237	237	237
			-18	3	27	53	84	118	156	199	237
				-37	-18	3	27	53	84	118	156
					-53	-37	-18	3	27	53	84
						-57	-53	-37	-18	3	27
							-57	-57	-53	-37	-18
								-57	-57	-57	-53
									-57	-57	-57
										-57	-57
Expected FCFF		28.86	31.31	33.97	36.85	40.66	44.03	48.58	52.55	57.76	62.43

probability to each of these potential cash flows in order to compute expected cash flows, and discounts those expected cash flows at the risk-adjusted cost of capital, according to the following equation:

$$DCF = \sum_{t=1}^n \frac{FCFF_t}{(1+r)^t}$$

where:

- DCF = discounted cash flow valuation;
- FCFF<sub>t</sub> = Expected free cash flow to the firm in year t; and
- r = the risk-adjusted cost of capital.

In this instance, the stream of expected cash flows ranges from \$29 million in forecast year 1 to \$62 million in forecast year 10, which assumes a nominal drift in coal prices of around 1–2% per year. Consider the stream of expected coal prices and expected free cash flow to the firm and an assumed discount rate of 15%. These inputs are sufficient to perform a DCF valuation.

This is a risky project, given that two consecutive falls in coal prices will result in negative cash flows. If changes in coal prices are essentially driven by changes in the economic environment, intuitively we have a project with a relatively high degree of systematic risk. We have deliberately constructed a volatile project to highlight the incremental value which can result from the abandonment and expansion options. In the absence of any volatility of potential cash flows, these options will be worthless. Discounting these expected cash flows at 15% implies a DCF valuation of \$199 million.

Now consider the lower right-hand corner of Figure 2, in which the firm incurs a series of negative cash flows. At some point it will be optimal to abandon the project, rather than incur these negative cash flows. One year of negative cash flows does not necessarily mean the project should be abandoned, given that prices could recover in the following year. But if prices are sufficiently low, so that there is no reasonable prospect of recovery in the near future, the project should be abandoned. The value created is in the avoidance of negative cash flows. Of course, in the real-world, the project could be put on care and maintenance, and restarted once prices recover. In that instance, we would have to account for the annual maintenance costs and any one-off costs associated with restarting production. For the moment, let's simply consider the case in which the mine can be abandoned forever at zero cost.

The question is, how can we determine the optimal point at which to abandon, given that one year of negative cash flows does not necessarily trigger the exercise of the abandonment option? First, we work out the value of the project at the end of its life for each possible coal price. If that value is negative, it seems rational to abandon before we incur that negative cash flow. Second, we work out the value of the project in the second-last year, for each possible coal price, given the information about our optimal strategy in the last year. At each node of the valuation tree in year 9, we ask, 'Is the project worth more to us if we keep operating, or we abandon today?' This requires us to

compare two valuations at each node: (1) the value of maintaining production, which is the sum of the discounted expected value at the end of year 10 plus the cash flow received in year 9; versus (2) the value of ceasing production, which we have assumed to be zero in each case.

These alternatives are presented in Figure 3. Consider the five situations in which the final year cash flow is negative, ranging from negative \$18 million to negative \$57 million. The project would be abandoned in those instances because the revenue stream would be insufficient to cover operating costs. Now consider the series of DCF valuations immediately to the left of this final column. In year 9, if the coal price is at an intermediate level of, say, \$56.37 per tonne, the project is worth \$104 million, the sum of a \$53 million received in year 9, plus the value attributed to the project's potential values next year of \$84 million or \$27 million. Expressed as an equation, we write:

$$\begin{aligned} V_{9,56.37} &= FCFF_9 + \text{Discounted expected value in year 10} \\ &= FCFF_9 + \frac{p \times V_{10,63.56} + (1-p) \times V_{10,50.00}}{1+r_f} \\ &= 53 + \frac{0.47 \times 84 + 0.53 \times 27}{1.06} \\ &= \$104m \end{aligned}$$

where:

- V<sub>9,56.37</sub> = value in year 9 in the case where coal price is \$56.37 per tonne;
- V<sub>10,63.56</sub> = value in year 10 in the case where coal price rises to \$63.56 per tonne;
- V<sub>10,50.00</sub> = value in year 10 in the case where coal price falls to \$50.00 per tonne; and
- r<sub>f</sub> = the risk-free rate of interest.

You will note that we have discounted at the risk-free rate of interest, rather than the risk-adjusted cost of capital. This is the correct valuation approach, provided the probabilities used in estimating expected future values are *risk-neutral* probabilities. One of the contributions made by Black, Scholes and Merton in their work on option pricing is to establish that discounting of risk-neutral expected payoffs at the risk-free rate provides the same present value of *real-world* expected cash flows, discounted at the risk-adjusted cost of capital.

The reason why risk-neutral valuation is useful in binomial option pricing is that risk-neutral probabilities can be assumed to be constant throughout the life of the project and at different parts of the binomial tree, under the assumption that the risk-free rate is constant. In contrast, the actual risk of a project can vary substantially over time, and in different parts of the binomial tree. The variability of returns on investment will be considerably higher for a project which is close to financial distress, compared to a project which is highly profitable. The assumption typically made in DCF valuation – that discount rates are constant over time and in all states of the economy – is made by analysts purely for convenience.

In this particular example, we have estimated risk-neutral probabilities such that the risk-neutral expected coal price remains constant at \$50.00 per tonne – that is, there is no drift in coal prices in the risk-neutral setting assumed here. There is a 47% chance of a 13% rise, and a 53% chance of an 11% fall, which corresponds to an expected price change of zero. In real-world terms, this corresponds to annual rises in the expected coal price of 1–2%.

The detailed discussion underlying the estimation of risk-neutral and real-world probabilities is not necessary for understanding the basic technique of binomial tree valuation. I have highlighted this distinction purely to ensure that the reader clearly understands that risk-neutral valuation does not assume *investors* are risk-neutral. It still assumes investors are averse to risk, but is a useful computational technique where the risk-free rate is assumed to be constant.

Figure 3 illustrates that the project would be abandoned in the case where the coal price falls to \$34.88 in year 3. In real-world terms, there is an 11% chance of this occurring and there is around a 40% chance that the project will be abandoned at some point within the 10-year forecast horizon.

Overall, the real options valuation of the project is \$252 million, implying that the option to abandon was worth one-fifth of total project value when we compare the real options valuation with the DCF valuation. This desegregation is fairly typical of what we observe in the listed equity market.

Now consider the case in which we have the option to expand production to 10 million tonnes per year. This allows us to mine at a faster rate so we receive cash flows

sooner. But it comes at an investment cost of \$250 million, requiring an additional \$30 million per year of fixed costs, and reduces the mine life. This is a negative-NPV project. The DCF of the mine excluding the option to expand was \$199 million. Including the option to expand, the DCF valuation of the mine falls to \$164 million.

However, we may decide to exercise the expansion option only in response to coal price rises. Consider the case where we exercise the option at the end of year 5, which gives us three years of remaining mine life at production of 10 million tonnes per year, rather than 5 years at production of 6 million tonnes per year. If coal prices are at the highest possible level in our scenarios, exercise of this option is desirable. Project value increases to \$1013 million at the upper-most node of year 5, from its prior level of \$967 million. This means that, conditional upon the coal price having five consecutive increases, it is worthwhile proceeding with the expansion, and the incremental value is \$46 million. In all other cases, the expansion does not generate additional value, primarily because we are simply mining the remaining 30 million tonnes at a faster rate, rather than expanding production in perpetuity. The total project value, which includes both the expansion and abandonment options is now \$253 million, relative to its DCF valuation of \$199 million, as summarised in Figure 4.

## Conclusions and implications

The option pricing techniques presented lend themselves to use in a number of related contexts: most obviously to corporations considering when, whether, and how, to

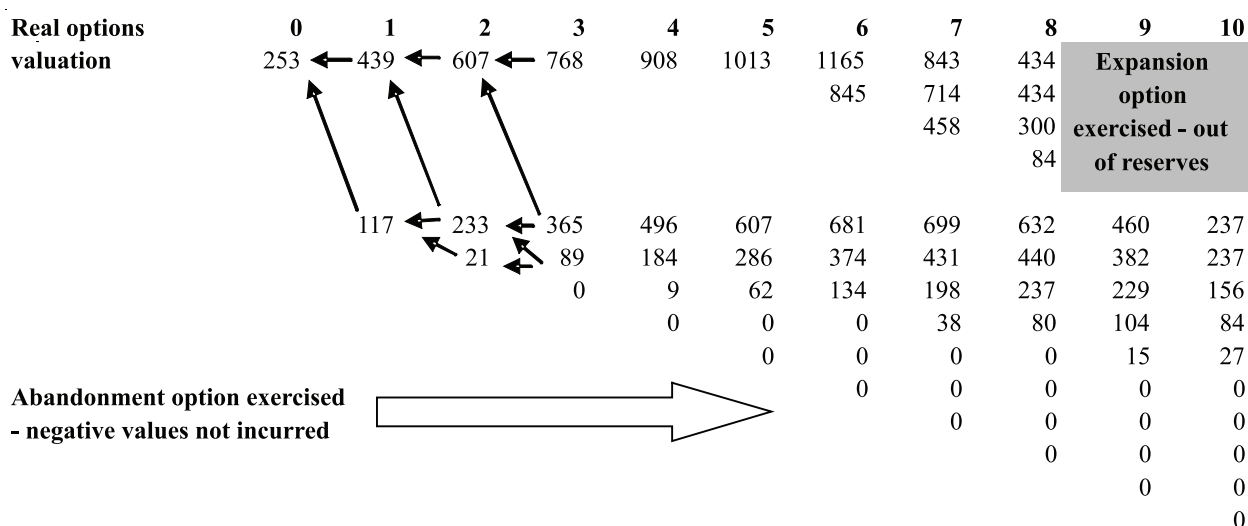
FIGURE 3: Potential future discounted cash flow and real options valuations over a 10-year period.

	0	1	2	3	4	5	6	7	8	9	10
Discounted cash flow valuation	199	414	594	757	888	967	963	850	670	460	237
		31	193	350	491	606	681	699	632	460	237
			-116	23	158	278	373	431	440	382	237
				-216	-100	16	119	196	237	229	156
					-270	-177	-78	10	75	104	84
						-277	-211	-130	-52	6	27
							-252	-200	-140	-72	-18
								-210	-162	-110	-53
									-163	-112	-57
										-112	-57
											-57
Real options valuation	252	437	603	759	888	967	963	850	670	460	237
		117	233	365	496	607	681	699	632	460	237
			21	89	184	286	374	431	440	382	237
				0	9	62	134	198	237	229	156
					0	0	0	38	80	104	84
						0	0	0	0	15	27
							0	0	0	0	0
								0	0	0	0
									0	0	0
										0	0
											0

develop a given resource; to financial analysts concerned with the valuation of such corporations; and to policy makers concerned with the social costs of lay-offs in cyclical industries and with policies to avert them. The techniques are well suited to analysis of the effects of alternative taxation, royalty and subsidy policies on investment, and employment in the mining sector. Ultimately, real options techniques are one of the most important corporate finance

decision-making tools to have been introduced in the past 30 or 40 years. They capture the present value of flexibility of managerial decisions at a future date in response to the arrival of new information. Traditional NPV methodology implicitly assumes pre-commitment, i.e. no flexibility. Yet most applications of real options are more realistic and therefore more complicated models of reality.

FIGURE 4: Discounted cash flow and real options valuations including the option to expand in year 5.



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