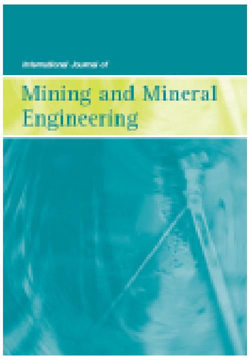

International Journal of Mining and Mineral Engineering

ISSN online: 1754-8918 - ISSN print: 1754-890X
https://www.inderscience.com/ijmme

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DOI: 10.1504/IJMME.2024.10063646

Article History:

Received:	20 June 2023
Last revised:	07 November 2023
Accepted:	08 November 2023
Published online:	29 May 2024

Comparative analysis of discounted cash flow and real options techniques on a gold mining project

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Abstract: This study investigates the effectiveness of two valuation techniques, discounted cash flow (DCF) and real options analysis (ROA), in assessing the economic viability of mineral projects. While DCF is a widely used method, its deterministic nature and neglect of uncertainty and managerial flexibility pose limitations. In contrast, ROA incorporates uncertainty and managerial flexibility, offering a more comprehensive approach to valuation. This research applies both techniques to an underground mining project with two extraction scenarios. Results reveal that ROA consistently provides higher net present values (NPVs) compared to DCF, highlighting the significance of considering uncertainty and managerial flexibility in project valuation. Specifically, scenario 1 demonstrates an NPV increase from US$9.60 million (DCF) to US$17.34 million (ROA), while scenario 2 shows an NPV increase from US$11.35 million (DCF) to US$21.52 million (ROA). These findings underscore the importance of employing ROA to value flexibility and make informed investment decisions.

Keywords: discounted cash flow; DCF; net present value; NPV; real options analysis; ROA; binomial lattice; flexibility.

Reference to this paper should be made as follows: Shivute, A.P. (2024) 'Comparative analysis of discounted cash flow and real options techniques on a gold mining project', *Int. J. Mining and Mineral Engineering*, Vol. 15, No. 1, pp.91–109.

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1 Introduction

Every mining company strives to maximise the value of its operations for all its stakeholders. The three main categories of value are social, intrinsic, and economic value (Jenkins, 2004). The main concern of this study was on economic value. Economic value can be produced in a variety of ways, such as through increasing industrial output and cost-cutting techniques. Unlike other businesses, the mining industry is prone to substantial risks and uncertainties related to ore grade, commodity prices, capital and operating costs and other technical and economic issues. Therefore, it is essential that decisions about investments in mineral projects are supported by adequate valuation techniques that take these risks and uncertainties into account. The market, cost, and income approaches are the three methods of valuation that are frequently used in the valuation of mineral projects. The focus of the study is on the income approach. This paper applies and compares the DCF and ROA valuation techniques on a gold mining project case study with two different exploitation scenarios.

2 Discounted cash flow analysis

According to Macfarlane (2001), the DCF technique is the most reliable and frequently used method for valuing mineral projects. Its primary metric of measurement of value are the net present value (NPV), internal rate of return (IRR) and payback period (PP). The DCF technique's fundamental calculation is the yearly cash flow into the firm through its assets, less the annual cash flow out of the business known as the expenditures, using assumed sales and capital investments. This yields the company's annual net cash flow. According to Kamel et al. (2023) expenditures are categorised into operating expenses (OPEX) and capital expenditures (CAPEX) that companies incur over their lifetime. OPEX is a company's daily expenses, whereas CAPEX is its primary, long-term spending. For taxation, operating expenses can be written off as a tax deduction, but capital expenditures cannot (Chen, 2021). The anticipated cash flows are projected over the life of the business as shown in equation (1)–(2) (Kamel et al., 2023), and a suitable discount rate is then applied to the annual cash flows to account for the risks and uncertainties involved with the business. The sum of the discounted cash flows (DCF) gives the net present value (NPV) of the project and is calculated using equation (3) (Brigham and Gapenski, 1997):

$$X_t = (P_t - C_t) \times Q_t - F_t - D_t \tag{1}$$

$$\begin{Bmatrix} NCF_t = X_t(1 - T_t) + D_t & if\ X_t > 0 \\ NCF_t = X_t + D^t & if\ X_t \leq 0 \end{Bmatrix} \tag{2}$$

where

X_t is the taxable income

P_t is the price

C_t is the operating cost

Q_t is the tonnage of production

F_t is the fixed cost

D_t is the depreciation

T_t is the tax rate.

$$NPV = -C_0 + \sum_{t=1}^{t=n} \frac{NCF_t}{(1+r)^t} \tag{3}$$

where

C_0 is the initial capital invested in the project for its development

NCF_t is the yearly projected future net cash flows

r is the discount rate which represents the risk associated with the project

n is the life of the project

t is the cash flow period.

Despite the wide use of the DCF technique across different industries, the technique has several limitations. Torries (1998) and Kelly (1998) noted that it is challenging to determine the most suitable discount rate for accurately calculating the NPV. This is because the calculation of the discount rate is subjective in reality and it depends on the experience of the individual (Park and Matunhire, 2011). Additionally, the DCF technique's discount rate does not take into consideration all the risk over the course of the project's lifetime. Conversely, the risks of a project may vary during the project's life (Mun, 2006). The DCF technique does not integrate the flexibility of management to make decisions when trying to adjust themselves to survive turbulent economic times (Zettl, 2002; Drieza et al., 2002; Gilbert, 2004; Lilford and Minnit, 2005; Mayer and Kazakidis, 2007; Kvalevag, 2009; Silitonga, 2015).

In addition to the limitations of the DCF technique, it assumes that all input variables are deterministic and known with certainty throughout the life of the project on the day of valuation, and the investment decision is made without considering other factors. In reality, input variables are uncertain, stochastic in nature and can vary in the future which can affect the outcome of the decision criteria of the DCF technique. This makes the cash flows uncertain and can ultimately change the investment decision because a profitable project can become unprofitable due to a change of input variables in future (Mun, 2006). Another limitation of the DCF technique it that it assumes that once a project commences it is passively managed, not taking into consideration possible decision options, budget constraints and milestones over the project's lifetime. However, in reality, investment decision options and budget constraints are common and management has the flexibility to make informed decisions when the business environment changes (Mun, 2006). To improve on the limitations of the DCF, simulation can be done to incorporate uncertainty. Monte Carlo simulation, alternatively known as probabilistic simulation, is a statistical problem-solving technique adopted to understand the effect of risk and uncertainty in compound situations. The technique uses probability distributions to model the uncertainty of input variables and compute all the possible outcomes (Harrison, 2010). Different simulations are run to produce possible outcomes of the problem, resulting in a Monte Carlo DCF (MCDCF). This simulation technique is one of the most used methods for modelling uncertain variables.

Although the MCDCF technique improves on the DCF by incorporating uncertainty and quantifying the risk associated with the project's cash flow, it has limitations. Its major limitation is that it does not incorporate the flexibility that management has to time investments in the face of uncertainty over its life span. Spencer-Young and Durand (2004) mentioned that the DCF technique does not mirror the value of deferring the start of the project up until favourable conditions prevail and input variables are known with a higher degree of confidence. To incorporate uncertainty and managerial flexibility, real options has been recognised as a valuation technique that takes into consideration uncertainty as well as managerial flexibility and can be applied to valuing mineral projects (Kamel et al., 2023; Samis and Davis, 2014; Haque et al., 2016).

3 Real options analysis

Mun (2006) stated that ROA is a systematic methodology of financial options theory that uses financial economics, statistics, decision and management sciences to aid in valuing real physical assets under uncertainty. A business' ability to adjust its operation due to uncertainty is the source of value that an option holds (Eduardo, 2013). An option is a financial contract between parties, giving the holder the right but not the obligation to buy or sell a specified quantity of an underlying asset at a fixed price, known as the strike price or exercise price (Damodaran, 2000). The contract is subject to specific conditions and has a specified time limit on which the option will expire, called the expiration date. The purchaser of this right has the choice of not exercising the right and thus allowing it to lapse. There are two forms of options: a 'call' option and a 'put' option (Palm et al., 1986). A 'call' is also known as an option to buy, while a 'put' is referred to as a sell option of an underlying asset. 'Call' options can only be utilised or exercised when the price of the underlying asset is greater than the strike price; inversely 'put' options can only be utilised when the price of the underlying asset is less than the strike price. Black and Scholes (1973) categorised the call and put options according to a specific timeframe when an option could be exercised. These are the American option and the European option. An American option is an option that can be exercised from the day the option was purchased until the day it expires. A European option is an option that can be exercised on a single agreed date in the future (Black and Scholes, 1973).

3.1 Types of options available to mineral projects

There are four main types of options available in mineral projects, which are the option to expand, contract, abandon and defer or delay the start of a project. The option to expand arises when mineral commodity prices increase remarkably for a prolonged period and when management has the ability to increase its production output which then helps to increase project value (Haque et al., 2014). The option to contract presents itself when mineral commodity prices decrease considerably, giving management the option to scale down operations by decreasing mining rates. This subsequently results in decreased total operating costs, assuming that all the costs are directly related to the level of production (Haque et al., 2014).

The option to abandon arises when low mineral commodity prices continue to prevail for a prolonged period, resulting in continued periods of negative net cash flows. This then forces management to exercise the abandonment option and salvage its physical assets. Management also has an alternative of temporarily suspending operations and placing the operation under care and maintenance, until such a time when mineral commodity prices rise (Haque et al., 2014). The option to delay arises when mineral commodity prices decrease and other economic factors are not favourable, and if management has the flexibility to defer the start of a new project. The option to delay a project can be exercised until economic circumstances improve, and only when the conditions are optimal to invest (Mokenela, 2006).

The management of the mining project being considered in this paper only has the option or flexibility to delay the start of the project before the mining lease expires in December 2032. In order for the company to exercise this option, capital investment must be acquired on or before the day the mining lease expires. The option to proceed with the development of the project will only be exercised if the expected NPV of the project exceeds the initial capital cost to exercise the option, which includes development costs, equipment and infrastructure costs (Kelly, 1998).

There are four main ROA techniques: the Black-Scholes model, Binomial-Lattice model, Finite Difference technique and Stochastic Monte Carlo technique (Gilbert, 2004; Ampofo, 2017). One of the limitations of the Black-Scholes, Finite Difference and Stochastic Monte Carlo techniques is that they only value European options and in the mining industry, projects are complex and are mostly American options (Gilbert, 2004). Additionally, the Finite Difference technique is incapable of incorporating the uncertainty in mineral grade and operating costs over the life of a mine (Dimitrakopoulos and Abdel, 2007).

4 Binomial-lattice

The Binomial-Lattice model was developed by Cox et al. (1979) and was used to value stocks in both the European and American options (Gilbert, 2004). It is based on a basic concept of constructing a probability tree in which the value of an option is computed from an expected discrete state of prices throughout the life of the option. The model assumes that the interest rate is constant and the stock price has a multiplicative binomial relationship over each period resulting in two likely values: an upside (*u*) outcome with probability *p* or a downside (*d*) outcome with probability 1–*p*. The Binomial-Lattice model is expressed by equations (4)–(8) (Smith et al., 2017).

$$C_{j,i} = \frac{p \times C_{j+1,i} + (1-p) \times C_{j+1,i+1}}{er_f{}^{\times dt}} \tag{4}$$

$$dt = \frac{T}{N} \tag{5}$$

$$p = \frac{e^{(r_f ndt)} - d}{u - d} \tag{6}$$

$$u = e^{\sigma \times \sqrt{dt}} \tag{7}$$

$$d = e^{-(\sigma \times \sqrt{dt})} = \frac{1}{u} \tag{8}$$

where

C is the option value

rf is the risk-free rate

σ is the volatility of the stock price or the underlying asset

dt is the time incremental step when major decisions are made in a company

T is the life of the option of the project

N is the number of periods selected

p is the risk-neutral probability

j is time index

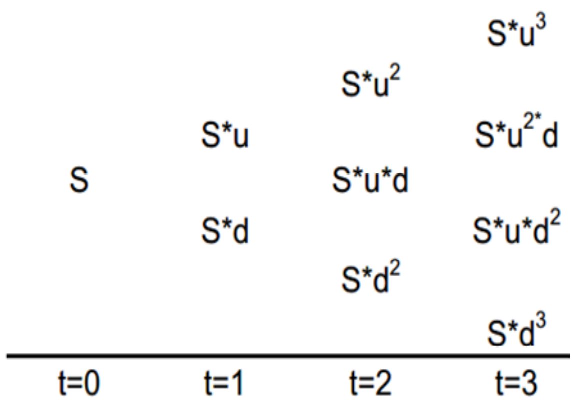
i is state at time index

u is > 1

d is < 1.

An example of a multiplicative Binomial-Lattice of an underlying asset (S) is shown in Figure 1.

Figure 1 Underlying asset value (s) of the Binomial-Lattice



Source: Kvalevag (2009)

The initial value of the asset is entered in the far-left node of the lattice and is denoted by *S*. This value is the NPV of the asset, excluding the initial capital investment. The value of the underlying asset can either increase by a factor *u* or decrease by a factor *d*. These factors that influence the value of the underlying asset are influenced by the price volatility of the asset and the length of time *t*. The nodes of the second time step are expanded from the nodes of the first-time step. The value of each node increases or decreases by a factor of *u* or *d*, respectively, resulting in the expansion of the lattice until end of life of the underlying asset (LoM).

The construction of the option value lattice starts from the right and ends at the left and is calculated using equation (4). First, an option value for the last time steps in the lattice is calculated by subtracting the option cost (initial investment) known as the exercise price X from each of the values of the underlying asset S obtained in the asset value lattice. This calculation can be summarised by equation (7) (Bailey et al., 2004).

$$C_{j,i} = \max\{S_{j,i} - X; 0\} \tag{9}$$

where $S_{j,i}$ is the value of the underlying asset at different time steps and X is the exercise price of the option.

The option value of the preceding time step is equivalent to the weighted average value of the future option values based on the risk-neutral probability p of the asset values in the occurring nodes, multiplied by the risk-free discount rate for one time step as shown in equation (4). The initial asset value in the lattice is then compared to the criteria of value from the traditional DCF analysis. The increase in asset value in the ROA is not the real option value, but rather the discrepancy in asset value generated by the ROA value and the NPV of the DCF analysis (Zdravlje, 2011). The probability of each node occurring is based on the size of the lattice and number of paths leading to the final time increment. The number of paths resulting in each outcome in the lattice results in its formation and is simplified by Pascal's triangle represented by equation (8) (Zdravlje, 2011).

$$a_{nr} \equiv \frac{n!}{r!(n-r)!} \equiv \binom{n}{r} \tag{10}$$

where $\binom{n}{r}$ is a binomial coefficient; n and r are integers. The probability of each call option value in the lattice is influenced by the number of paths that leads to its outcome. The resultant distribution of the lattice is identical to that of Pascal's triangle, which is a normal distribution (Maistrov, 1974). The probability of a call option value of different time states occurring in the lattice is calculated by equation (9) (Maistrov, 1974).

$$p_{c_j i} = \frac{X}{2^n} \tag{11}$$

where X is the number that appears in a node in Pascal's triangle; and n in number of branches leading to a node in a specific column.

5 Gold mine case study

The current production at the mine comes from two conventional open pit mines (Pit A and Pit B) that have been in operation since 2014, and as of 2018 together have an expected LoM of nine years. The mine plans will account for two years for processing stockpiles and seven years for active mining. Pit B has a newly discovered mineral resource of 1.49 million tonnes of gold ore that extends deep underground. The mine plans to exploit this newly discovered mineral resource using an underground mining method from 2026 before its mining lease expires in 2032. The mine is considering the following two scenarios to exploit the mineral resource:

- Scenario 1: The development of the preproduction phase will be conducted by a contractor, thereafter the company will proceed with production; alternatively
- Scenario 2: The company will develop the mine and operate throughout.

As demonstrated in Tables 1 and 2, the two scenarios produced two distinct production schedules and costs.

Table 1 Economic and technical parameters for scenario 1 (see online version for colours)

Description	*Unit*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Total/average*
	Year	*2026*	*2027*	*2028*	*2029*	*2030*	*2031*	*2032*	*2033*	
Ore milled	tonnes	0	0	164,269	273,750	273,760	273,699	234,748	207,608	1,427,834
Grade	g/t	0	0	6.13	5.93	5.77	5.26	4.38	5.79	5.52
Unit variable costs	US$/t milled	0	0	114.92	131.35	133.25	135.68	127.13	99.98	123.72
Capex	US$ million	27.31	47.62	18.90	0	0	0	0	0	93.83
Sustaining capital cost	US$ million	0	0	5.65	0.41	0.69	0.35	0	0	7.10

Source: Shivute (2019)

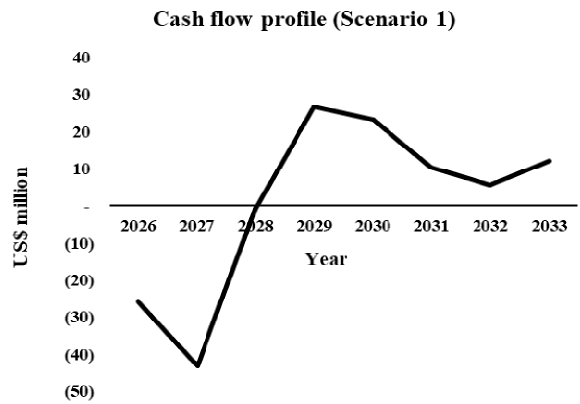
Table 2 Economic and technical parameters for scenario 2 (see online version for colours)

Description	*Unit*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total/average*
	Year	*2026*	*2027*	*2028*	*2029*	*2030*	*2031*	*2032*	*2033*	*2034*	
Ore milled	tonnes	0	0	18,899	239,148	273,699	273,749	273,751	234,852	113,735	*1,427,834*
Grade	g/t	0	0	3.85	5.80	5.89	5.86	5.00	5.11	5.57	*6*
Unit variable costs	US$/t milled	0	0	0	147.76	144.31	117.36	115.32	112.61	87.13	*106.23*
Capex	US$ million	21.48	25.04	38.4	0	0	0	0	0	0	*84.92*
Sustaining capital cost	US$ million	0	0	0	8.99	0.47	0.10	0.09	0.02	0	*9.67*

Source: Shivute (2019)

Parameters in the tables were the input parameters used in the DCF analysis. The other input parameters used were the same for both scenarios. These are gold price (US$1 300/oz), processing recovery (97%), discount rate obtained from the company (5%), royalty and tax rate in the country of case study; 4% and 37.5%, respectively.

Figure 2 Life of mine cash flow profile for scenario 1 (see online version for colours)

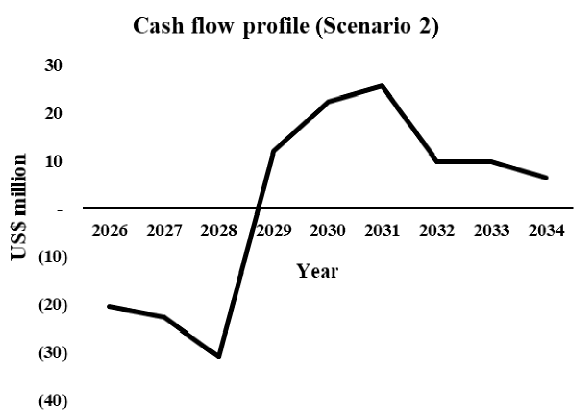


Source: Shivute (2019)

5.1 DCF results

The discounted net cash flow of scenarios 1 and 2 resulted in an NPV of US$9.60 million and US$11.35 million, respectively, at a 5% discount rate. The graphical plot of the cash flow for scenarios 1 and 2 generated over the LoM is illustrated in Figures 2 and 3.

Figure 3 Life of mine cash flow profile for scenario 2 (see online version for colours)



Source: Shivute (2019)

Table 3 shows a summary of the DCF analysis results for scenarios 1 and 2.

As shown in Table 3, both scenarios have positive NPVs. Based on the NPV decision criteria the project is viable for both scenarios. The IRRs of the project are both greater than the discount rate of 5% for both scenarios. Therefore, based on the IRR decision criteria, the project is also viable for both scenarios. Furthermore, scenario 1 had a PP of 5.21 years. For a mining project with a six year LoM, a PP of 5.21 years would likely make the project unviable. However, the major decision criteria of the DCF that have more weight on deciding on the viability of a project are NPV and IRR (Awomewe and Ogundele, 2008). The cash flow of scenario 2 resulted in a PP of 5.49 years, which is approximately the LoM. The viability of the project based on the PP decision criterion is dependent on how fast the investors want their initial investment back. Although the outcomes of the decision criteria of the DCF in investment decision making show that the project is viable, it is possible that based on the three decision criteria a project may be viable at face value, but with a low probability of being viable. To address the limitations of the DCF stated before, ROA was done and the Binomial-Lattice of real options assumptions and results are presented in the following section.

Table 3 Summarised DCF analysis results for scenarios 1 and 2

	Scenario 1	*Scenario 2*
NPV (US$ million)	9.60	11.35
IRR (%)	8.67%	8.95%

Source: Shivute (2019)

5.2 *Binomial-Lattice ROA input parameters*

Of the four main types of options available in mineral project discussed, the management of the mining project only have an option to defer the start of the project in both scenarios. The initial asset values (S_0) were calculated in the DCF analysis. The price of exercising the option, which is also known as the strike price (X), is equivalent to the present value of the initial capital expenditure. The present value of the net cash flow and the initial capital expenditure were calculated using equation (3).

Scenarios 1 and 2 have asset values of US$95.13 million and US$87.69 million, respectively. Although both scenarios are valued on the same mineral resource, their asset values differ because of the different production schedules that also resulted in different LoMs for the project. The next input variable that was calculated is the exercise price of the delay option which was also calculated using equation (3).

The present value of initial capital resulted in an exercise price of US$90.4 million and US$76.34 million to exercise the option of commencing the project in 2026. The option must be exercised before the company's mining licence expires in 2032, otherwise, the project must be sold. Currently, the company is producing from the surface operation which is expected to close in 2025, therefore the company has the right to exercise the option any time from the year 2026 but before the end of 2032.

The incremental time step (dt) of the lattice is influenced by a company's decision-making process on investments and the lifetime of the project (Smith et al., 2017). The company under study makes large investment decisions once a year in September. Therefore, according to Smith et al. (2017) the incremental time step of the lattice can be calculated using equation (12). These were calculated to be 0.17 and 0.14 for scenario 1 and scenario 2, respectively.

$$dt = \frac{1}{project\ lifetime} \tag{12}$$

Alternatively, one can select the size of the lattice and according to Kelly (1998), the incremental time step of a lattice can be calculated using equation (5). In this paper, 35-time increments were selected because this was a reasonable number for presentation purposes. The larger the number of nodes in a lattice, the more simulations the lattice does, making the results more accurate and with a larger lattice. Using equation (5), the incremental time step for both scenarios was calculated to be 0.2 years.

The volatility of the underlying asset (σ) was taken to be the same as the volatility of the historical gold prices. During the time of study, the annualised volatility of gold prices was calculated from the daily gold spot prices for the period from January 2010 to December 2018. The standard deviation of the logarithmic changes in the daily gold price was computed and converted to the volatility of the lattice's incremental time step of 0.2 years using equations (13) to (16) (Dmouj, 2006):

$$\rho = log\frac{d_n}{d_{n-1}} \tag{13}$$

$$\sigma^2{}_n = \frac{1}{m}\sum_{i=1}^{m}\rho_{n-i}{}^2 \tag{14}$$

$$d_v = \sqrt{\sigma_n} \tag{15}$$

$$\sigma_{dt} = dt\sqrt{d_v} \tag{16}$$

where

ρ is the daily logarithmic change in gold spot price

n is today's gold price

m is the number of days in the period

σ^2 is the variance

d_v is the standard deviation

d_t is the incremental time step in days

σ_{dt} is the gold price volatility.

The resultant gold price volatility was calculated to be 6.06%. From the above input parameters, the upward (u) and downward (d) factors in the lattice were calculated to be 1.03 and 0.97 using equations (7) and (8), respectively. The risk-free rate (rf) for the project was provided by the company to be 2.032%. The risk-neutral probability (p) was calculated to be 0.57 using equation (6).

5.3 Binomial-Lattice results

The risk-neutral probability, risk-free rate and incremental time step were used to construct the option value lattice using equation (2). The resultant Binomial-Lattices for both scenarios are illustrated in Tables 5 and 6.

Table 5 Binomial-Lattice option value for scenario 1 (see online version for colours)

	Option value																	
Nodes	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*
Delay period (years)	*0*	*0.20*	*0.40*	*0.60*	*0.80*	*1.00*	*1.20*	*1.40*	*1.60*	*1.80*	*2.00*	*2.20*	*2.40*	*2.60*	*2.80*	*3.00*	*3.20*	*3.40*
	17.34	19.41	21.60	23.91	26.34	28.87	31.50	34.23	37.05	39.96	42.97	46.07	49.27	52.56	55.95	59.43	63.03	66.73
		14.79	16.71	18.77	20.96	23.27	25.69	28.22	30.85	33.57	36.40	39.31	42.31	45.41	48.60	51.89	55.28	58.76
			12.40	14.17	16.08	18.13	20.31	22.61	25.03	27.56	30.19	32.92	35.74	38.65	41.65	44.75	47.94	51.22
				10.19	11.80	13.55	15.44	17.48	19.66	21.95	24.37	26.90	29.53	32.25	35.07	37.98	40.98	44.08
					8.19	9.61	11.19	12.92	14.80	16.83	18.99	21.29	23.70	26.23	28.86	31.58	34.40	37.31
						6.41	7.64	9.02	10.57	12.28	14.14	16.16	18.32	20.61	23.03	25.55	28.18	30.91
							4.86	5.89	7.08	8.43	9.95	11.63	13.48	15.49	17.64	19.93	22.35	24.87
								3.55	4.39	5.38	6.52	7.83	9.32	10.98	12.81	14.80	16.95	19.24
									2.49	3.14	3.93	4.86	5.96	7.23	8.68	10.31	12.13	14.11
										1.66	2.14	2.74	3.47	4.35	5.40	6.62	8.03	9.64
											1.04	1.38	1.81	2.35	3.02	3.84	4.83	6.01
												0.61	0.83	1.11	1.49	1.97	2.58	3.34
													0.32	0.46	0.63	0.87	1.19	1.61
														0.16	0.23	0.33	0.46	0.66
															0.07	0.10	0.15	0.22
																0.02	0.04	0.06
																	0.01	0.01
																		0.00

	Option value																	
Nodes	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*
Delay period (years)	*3.60*	*3.80*	*4.00*	*4.20*	*4.40*	*4.60*	*4.80*	*5.00*	*5.20*	*5.40*	*5.60*	*5.80*	*6.00*	*6.20*	*6.40*	*6.60*	*6.80*	*7.00*
	70.54	74.46	78.50	82.66	86.94	91.34	95.87	100.54	105.35	110.29	115.38	120.61	126.00	131.55	137.25	143.12	149.16	155.38
	62.36	66.05	69.86	73.78	77.81	81.97	86.25	90.65	95.18	99.84	104.65	109.59	114.67	119.90	125.29	130.83	136.53	142.40
	54.60	58.09	61.68	65.37	69.18	73.09	77.13	81.28	85.55	89.95	94.48	99.14	103.94	108.88	113.96	119.19	124.57	130.11
	47.26	50.55	53.93	57.41	60.99	64.69	68.49	72.40	76.43	80.58	84.85	89.25	93.77	98.43	103.23	108.16	113.24	118.47
	40.31	43.40	46.58	49.86	53.24	56.72	60.30	63.99	67.79	71.70	75.73	79.88	84.14	88.54	93.06	97.72	102.51	107.44
	33.73	36.63	39.63	42.72	45.90	49.18	52.55	56.03	59.61	63.30	67.09	71.00	75.02	79.17	83.43	87.82	92.34	97.00
	27.50	30.23	33.05	35.95	38.95	42.03	45.21	48.49	51.86	55.33	58.91	62.59	66.39	70.29	74.31	78.45	82.72	87.10
	21.66	24.19	26.82	29.54	32.36	35.26	38.26	41.34	44.52	47.79	51.16	54.63	58.20	61.88	65.67	69.58	73.60	77.73
	16.26	18.54	20.96	23.50	26.13	28.86	31.67	34.57	37.56	40.64	43.82	47.08	50.45	53.92	57.49	61.17	64.96	68.86
	11.43	13.41	15.55	17.84	20.26	22.80	25.44	28.16	30.98	33.87	36.86	39.94	43.11	46.38	49.74	53.20	56.77	60.45
	7.38	8.95	10.72	12.69	14.83	17.13	19.56	22.10	24.74	27.46	30.28	33.17	36.16	39.23	42.40	45.66	49.02	52.48
	4.27	5.39	6.71	8.25	10.00	11.96	14.10	16.41	18.85	21.40	24.04	26.76	29.57	32.46	35.44	38.52	41.68	44.94
	2.15	2.84	3.70	4.76	6.03	7.53	9.26	11.22	13.37	15.68	18.13	20.69	23.33	26.05	28.86	31.75	34.73	37.80
	0.92	1.27	1.74	2.35	3.13	4.12	5.33	6.79	8.50	10.45	12.62	14.95	17.42	19.98	22.62	25.34	28.14	31.03
	0.32	0.46	0.67	0.95	1.34	1.87	2.57	3.47	4.61	6.02	7.71	9.67	11.86	14.23	16.71	19.27	21.90	24.62
	0.09	0.13	0.20	0.30	0.45	0.67	0.97	1.41	2.00	2.81	3.87	5.22	6.89	8.87	11.11	13.51	15.99	18.54
	0.02	0.03	0.04	0.07	0.11	0.17	0.27	0.42	0.64	0.97	1.45	2.13	3.08	4.36	6.02	8.07	10.39	12.79
	0.00	0.00	0.01	0.01	0.02	0.03	0.05	0.08	0.13	0.21	0.35	0.56	0.90	1.43	2.23	3.41	5.09	7.35
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.07	0.13	0.22	0.39	0.70	1.23	2.18
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Shivute (2019)

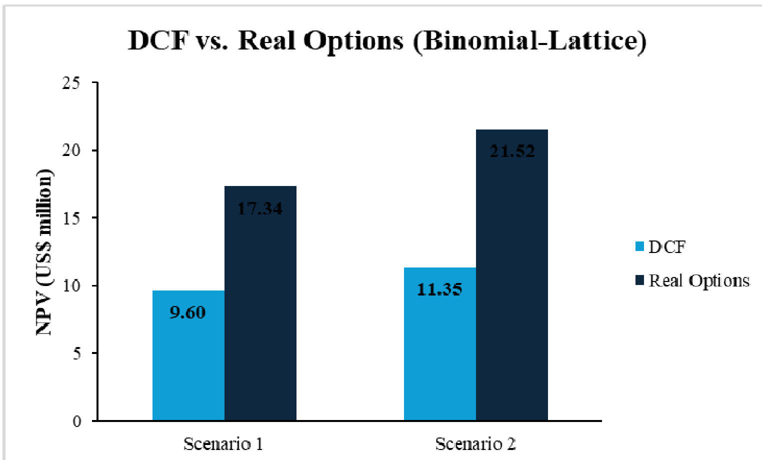
Table 6 Binomial-Lattice option value for scenario 2 (see online version for colours)

	Option value																																		
Node	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*
Delay period (years)	*0*	*0.2*	*0.4*	*0.6*	*0.8*	*1.0*	*1.2*	*1.4*	*1.6*	*1.8*	*2.0*	*2.2*	*2.4*	*2.6*	*2.8*	*3.0*	*3.2*	*3.4*	*3.6*	*3.8*	*4.0*	*4.2*	*4.4*	*4.6*	*4.8*	*5.0*	*5.2*	*5.4*	*5.6*	*5.8*	*6.0*	*6.2*	*6.4*	*6.6*	*6.8*	*7.0*
	21.52	23.59	25.76	28.00	30.33	32.73	35.21	37.77	40.41	43.13	45.93	48.82	51.79	54.85	58.00	61.24	64.58	68.01	71.55	75.19	78.94	82.80	86.77	90.86	95.07	99.39	103.85	108.43	113.15	118.00	123.00	128.14	133.42	138.86	144.46	150.22
		19.00	20.98	23.05	25.21	27.46	29.78	32.18	34.67	37.22	39.86	42.58	45.38	48.26	51.23	54.29	57.43	60.67	64.01	67.44	70.98	74.62	78.36	82.22	86.19	90.27	94.48	98.81	103.26	107.84	112.55	117.41	122.40	127.53	132.82	138.25
			16.58	18.46	20.44	22.51	24.67	26.91	29.23	31.63	34.11	36.67	39.31	42.02	44.82	47.70	50.67	53.72	56.86	60.10	63.44	66.87	70.40	74.04	77.78	81.64	85.60	89.69	93.89	98.21	102.66	107.24	111.95	116.80	121.79	126.93
				14.27	16.04	17.91	19.89	21.96	24.11	26.36	28.68	31.08	33.56	36.11	38.75	41.46	44.25	47.13	50.10	53.15	56.29	59.53	62.86	66.29	69.82	73.45	77.20	81.05	85.01	89.09	93.29	97.61	102.06	106.64	111.35	116.19
					12.09	13.73	15.49	17.36	19.33	21.40	23.56	25.80	28.12	30.52	33.00	35.55	38.18	40.89	43.69	46.56	49.52	52.57	55.71	58.95	62.28	65.70	69.23	72.87	76.60	80.45	84.42	88.49	92.69	97.01	101.45	106.03
						10.05	11.56	13.19	14.94	16.80	18.77	20.84	22.99	25.24	27.56	29.96	32.43	34.99	37.61	40.32	43.11	45.99	48.95	51.99	55.13	58.36	61.69	65.11	68.64	72.27	76.01	79.85	83.81	87.89	92.08	96.40
							8.17	9.53	11.02	12.64	14.38	16.24	18.21	20.27	22.43	24.67	26.99	29.39	31.86	34.41	37.04	39.75	42.54	45.41	48.36	51.41	54.55	57.77	61.10	64.52	68.05	71.67	75.41	79.25	83.21	87.28
								6.47	7.67	9.00	10.47	12.08	13.81	15.67	17.63	19.70	21.86	24.10	26.42	28.82	31.29	33.84	36.46	39.17	41.95	44.82	47.78	50.82	53.95	57.18	60.50	63.92	67.44	71.07	74.80	78.64
									4.97	5.99	7.15	8.46	9.92	11.51	13.24	15.09	17.05	19.12	21.28	23.52	25.85	28.24	30.71	33.26	35.88	38.58	41.37	44.23	47.19	50.23	53.36	56.58	59.90	63.32	66.84	70.46
										3.68	4.52	5.51	6.64	7.92	9.35	10.93	12.65	14.50	16.47	18.54	20.70	22.95	25.27	27.66	30.13	32.68	35.30	38.00	40.78	43.64	46.59	49.63	52.76	55.98	59.30	62.71
											2.60	3.27	4.07	5.02	6.11	7.37	8.78	10.35	12.06	13.91	15.88	17.95	20.12	22.36	24.68	27.08	29.54	32.09	34.70	37.40	40.18	43.04	45.99	49.02	52.15	55.37
												1.75	2.25	2.88	3.63	4.53	5.59	6.81	8.20	9.75	11.46	13.31	15.28	17.36	19.53	21.78	24.10	26.49	28.95	31.49	34.11	36.80	39.58	42.44	45.38	48.42
													1.10	1.46	1.92	2.48	3.19	4.04	5.05	6.24	7.60	9.15	10.85	12.70	14.68	16.77	18.94	21.19	23.51	25.89	28.36	30.89	33.51	36.20	38.97	41.83
														0.64	0.88	1.19	1.59	2.10	2.74	3.54	4.51	5.66	7.00	8.52	10.23	12.09	14.08	16.17	18.35	20.59	22.91	25.30	27.76	30.29	32.90	35.59
															0.34	0.48	0.67	0.93	1.28	1.73	2.31	3.04	3.95	5.06	6.37	7.89	9.59	11.46	13.47	15.57	17.75	19.99	22.31	24.69	27.15	29.68
																0.16	0.24	0.34	0.49	0.70	0.98	1.37	1.88	2.54	3.39	4.44	5.72	7.23	8.95	10.84	12.86	14.97	17.15	19.39	21.70	24.08
																	0.06	0.10	0.15	0.22	0.33	0.49	0.71	1.02	1.45	2.04	2.81	3.81	5.05	6.55	8.29	10.22	12.26	14.37	16.54	18.78
																		0.02	0.03	0.05	0.08	0.13	0.20	0.31	0.47	0.70	1.05	1.53	2.21	3.13	4.33	5.84	7.63	9.61	11.65	13.76
																			0.01	0.01	0.01	0.02	0.04	0.06	0.10	0.16	0.26	0.42	0.66	1.03	1.58	2.40	3.55	5.11	7.03	9.00
																				0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.06	0.11	0.18	0.31	0.53	0.91	1.55	2.64	4.50
																					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.07	0.13	0.23
																						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																							0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																								0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																									0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																											0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																												0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																														0.00	0.00	0.00	0.00	0.00	0.00	0.00
																															0.00	0.00	0.00	0.00	0.00	0.00
																																0.00	0.00	0.00	0.00	0.00
																																	0.00	0.00	0.00	0.00
																																		0.00	0.00	0.00
																																			0.00	0.00
																																				0.00

Source: Shivute (2019)

The economic value of the project, if exercised in 2028 as planned, for scenario 1 is US$17.34 million and US$21.52 million for scenario 2, both having a probability of 1. The graphical comparison of the option value at node 0 (initial value without delaying) versus the value generated by the DCF is illustrated in Figure 3.

Figure 4 DCF vs. binomial-lattice results (see online version for colours)



Source: Shivute (2019)

Table 7 The value of delaying the project by 2.6 years of scenario 1

Scenario 1				
Exercise price = US$90.4 million				
State	*Asset value*	*Strategy*	*Option value*	*Probability*
1	135.34	Develop	52.56	0.00012
2	128.20	Develop	45.41	0.00159
3	121.43	Develop	38.65	0.00952
4	115.02	Develop	32.25	0.03491
5	108.94	Develop	26.23	0.08728
6	103.19	Develop	20.61	0.15710
7	97.75	Develop	15.49	0.20947
8	92.58	Develop	10.98	0.20947
9	87.70	Wait	7.23	0.15710
10	83.07	Wait	4.35	0.08728
11	78.68	Wait	2.35	0.03491
12	74.53	Wait	1.11	0.00952
13	70.59	Wait	0.46	0.00159
14	66.87	Wait	0.16	0.00012
Total				*1*

Source: Shivute (2019)

As shown in Figure 3, the value generated by the Binomial-Lattice is greater than the value generated by the DCF. This is because the Binomial-Lattice uses a risk-free rate to discount cash flows. The option to defer the start of the project can only be exercised if the value of the underlying asset in each node is greater than the exercise price. Assuming that the project was deferred by 2.6 years, the outcomes of the option value with their respective probabilities for both scenarios were extracted from their respective lattices. Table 7 shows the outcome of possible mineral asset values and plan of action with their respective probabilities at the different states.

Table 7 shows the plan of action for scenario 1 if the project is to be delayed by 2.6 years as an example. This decision is based on the mineral asset value and the exercise price. However, there is a probability attached to the results, which may change the company's decision about delaying the project for 2.6 years. The minimum and maximum possible option values that the company can gain from delaying the project by this period range from US$0.16 million to US$52.56 million. However, the most likely outcomes with a probability of 0.21 are US$15.49 million and US$10.98 million. It would be very risky to delay scenario 1 for this long. The same results for scenario 2 are shown in Table 8.

Table 8 The value of delaying the project by 2.6 years of scenario 2

Scenario 2				
Exercise price = US$76.34 million				
State	*Asset value*	*Strategy*	*Option value*	*Probability*
1	124.76	Develop	54.85	0.00012
2	118.17	Develop	48.26	0.00159
3	111.93	Develop	42.02	0.00952
4	106.02	Develop	36.11	0.03491
5	100.42	Develop	30.52	0.08728
6	95.12	Develop	25.24	0.15710
7	90.10	Develop	20.27	0.20947
8	85.34	Develop	15.67	0.20947
9	80.84	Develop	11.51	0.15710
10	76.57	Develop	7.92	0.08728
11	72.53	Wait	5.02	0.03491
12	68.70	Wait	2.88	0.00952
13	65.07	Wait	1.46	0.00159
14	61.64	Wait	0.64	0.00012
Total				*1*

Source: Shivute (2019)

The minimum and maximum possible option values that the company can gain from delaying the project by 2.6 years range from US$0.64 million to US$54.85 million. However, the most likely outcomes with a probability of 0.21 are US$20.27 million and US$15.67 million. It would also be very risky to delay Scenario 2 for this long. However, it is evident from the range of values for Scenario 1 of US$0.16 million to US$52.56 million that Scenario 2 has more value in flexibility when delayed because the project generates higher option value in the different states. The company is now able to read the different option values with their respective probabilities from the lattice. From the decision criteria of the Binomial-Lattice, the deferral option can be exercised from the initial start dates of the project in 2028. However, in certain nodes for both lattices, the value of the underlying asset is lower than the exercise price, and in these cases, the option should not be exercised. Furthermore, as the value of the option increases, the longer one waits to exercise the option, but with lower probabilities. This is because the probability is spread over a wider range of possible outcomes in each column.

6 Conclusions

The income approach's valuation techniques are only as accurate as the economic and technical input data at hand to carry out the valuation of mineral projects. The Binomial-Lattice quantifies risk and flexibility, the ultimate investment decision is based on a company's risk appetite from past experiences, which makes investment decision making subjective. In general, the only option available to new mining projects is the delay options because all other options are only applicable to established operations. The Binomial-Lattice illustrated that there is more economic value when mineral projects or operations have flexibility within them. The DCF resulted in an NPV of US$9.60 million and an IRR of 8.67% for scenario 1 while scenario 2 had an NPV of US$11.35 million and an IRR 8.95% at a 5% discount rate. The Binomial-Lattice model resulted in a higher NPV for both scenarios; US$17.34 million and US$21.52 million for Scenario 1 and Scenario 2, respectively. As a consequence of a greater NPV from the DCF and Binomial-Lattice, the study's findings suggested that Scenario 2 is the preferable choice. Therefore, the company should consider implementing Scenario 2. It is however recommended that the company should invest in increasing the confidence level of the project by conducting a feasibility study that will provide more information to accurately determine the economic value of the project at a greater confidence level.

Acknowledgements

The author thanks the anonymous mine for providing the data to make this research paper possible. The work reported in this paper is part of an MSc research study submitted at the University of the Witwatersrand.

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