



Determination of the effect of operating cost uncertainty on mining project evaluation

Hesam Dehghani¹, Majid Ataee-pour*

Faculty of Mining and Metallurgical Engineering, Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

Mining projects are complex businesses that demand constant risk assessment. This is because several kinds of uncertainties influence the value of a mine project, typically. These uncertainties may be classified as exploration uncertainties, economic uncertainties and engineering uncertainties. The evaluation of a mine project under these uncertainties is a complicated job, which may lead to making a wrong decision by managers and stockholders. Therefore, at first, the engineers must recognize the mining uncertainties before carrying out the project evaluation. The economic uncertainties are the most important factors, which may affect the project evaluation. Among the mentioned uncertainties, the operating cost uncertainty is an important and effective factor, which is ignored to a certain extent.

This research uses the binomial tree technique to compute the net present value of the Cayeli copper mine under three scenarios: (1) assuming certainty for both price and operating costs, (2) assuming uncertainty for metal price and certainty for operating costs and (3) assuming uncertainty for both price and operating costs. It is concluded that the mine evaluation suggests greater net present value when uncertainty is considered for both price and operating costs.

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Introduction

Mining projects are complex businesses that demand a constant assessment of risk. This is because the value of a mine project is influenced by many underlying economic and physical uncertainties, such as metal prices, ore grades, costs, schedules and environmental issues. Therefore, evaluating and estimating a mine project without mentioning the risk for future losses (or opportunities) will lead to invalid results. Consequently, managers and stockholders of a mine company make an indiscreet decision based on invalid information.

The main sources of uncertainty arising at the beginning of a mine project can be categorized into three groups: exploration uncertainties, engineering uncertainties and economic uncertainties. Exploration uncertainties will occur in the duration of resource evaluation stages such as geologic uncertainty, data collection, interpretation, modeling, deposit classification, reporting and so forth. Many researchers such as Dowd (1997), Dimitrakopoulos et al., (2002), Dimitrakopoulos et al. (2007), Godoy and Dimitrakopoulos (2004), Leite and Dimitrakopoulos

(2007), Rendu (2007) and Dimitrakopoulos et al., (2009) studied these types of uncertainties.

Engineering uncertainties include bench heights determination, planned grade control, minimum stoping widths, choice of stoping method, dilution factors, geotechnical and hydrological parameters, mining recovery factors and metallurgical recovery. This type of uncertainty will affect the ultimate pit (stope) limit and scheduling period.

Economic uncertainty is another important source of uncertainty, which has a critical impact on mine project evaluation. From the economic point of view, future metal prices and operating costs are the most important factors of uncertainty. The metal price is the real cash-settlement that represents the equilibrium or non-equilibrium of the metal market. Since this market is based on demand, supply and other factors such as speculation, news events and dividend payouts (Fanning and Parekh, 2004; Case and Fair, 1989; Taylor et al., 2000), uncertainty on future metal prices arises because of two main factors (MacAvoy, 1988):

- The lack of exact knowledge of those factors leading to the increase/decrease in metal supply and demand.
- The practices that producers or consumers perform in the face of powerful speculative and political motives.

In the mining industry, metal prices are normally modeled as the average price for the last three years, especially for those

* Corresponding author. Tel.: +989122523159.

E-mail addresses: hesam.dehghan@aut.ac.ir (H. Dehghani), map60@aut.ac.ir (M. Ataee-pour).

¹ Tel.: +989122523159.

commodities whose price is listed on open markets, such as precious and base metals (Rendu, 2006). Even though the use of a single commodity price makes the comparison between companies easy, it prevents the use of excessively optimistic prices. It may be misleading when evaluating mining projects. For example, an overestimated metal price may result in a favorable rate of return for a project, which is otherwise doubtful. Conversely, an underestimated metal price may result in an unfavorable return for the project, which is otherwise profitable.

Cost is another source of uncertainty when evaluating a mine project. The economic evaluation component of the feasibility study is based on the information that provides an answer to the question, ‘what is it going to cost?’ (Gentry and O’Neil, 1984). Since the estimation of capital and operating costs is an important requirement for open pit mine evaluation, uncertainty in costs arises due to the lack of engineering or economic information at the beginning of the mine project. Simply put, current mining companies do not know with absolute certainty how much they will be able to spend tomorrow, let alone next month or next year (Camus, 2002).

Numerous research works have been carried out for price uncertainty (Brennan and Schwartz (1985); Trigeorgis (1993); Moyen et al. (1996); Kelly (1998); Moel and Tufano (2002); Monkhouse and Yeates (2005); Abdel Sabour and Poulin (2006); Samis et al. (2006); Shafiee et al. (2009)). But there is no noticeable research on operating cost uncertainty. Indeed, the operating costs are determined as a certain parameter in the previous research works, mostly. While, some parameters such as market variations, government policy changes, novel technology, management adjustments and so forth may change the operating cost, unpredictably. Thereupon, for determining the real and correct project value, it is necessary to consider the operating costs uncertainty.

In this paper, for determining the effect of operating cost uncertainty on the project value, the project net present value was computed and compared under three scenarios: (1) assuming certainty for both price and operating costs, (2) assuming uncertainty for metal price and certainty for operating costs and (3) assuming uncertainty for both price and operating costs. The binomial tree method was used for studying the operating cost and price uncertainties.

Binomial tree

The binomial model is a well-known alternative discrete time, which is developed by Cox et al. (1979). The method of binomial pricing tree is a flexible, powerful and quite a superb method. A binomial pricing tree is a structure that maps all possible trajectories of metal price (or operating cost) through time as are allowed by the model. This structure consists of nodes and branches. Each node in a given layer corresponds to a potential metal price (or operating cost) at a particular point in time. Nodes are identified with traversal probabilities, as well as with metal prices (or operating costs). Nodes and the data items with which they are associated are easily indexed as elements in matrices. A convenient indexing scheme has the layer or time step represented by j (a number between 1 and n , the number of layers or time steps) and the nodes within each layer (the potential metal prices or operating costs) by i (a number between 1 and m , the number of nodes in the layer). Depending on whether or not the tree is recombining, the node count m for any given layer may range from j to twice the number of nodes in the previous layer. Each branch or path in a binomial pricing tree represents a possible transition from one node to another node later in the tree and has a probability and a ratio associated with it. Branches

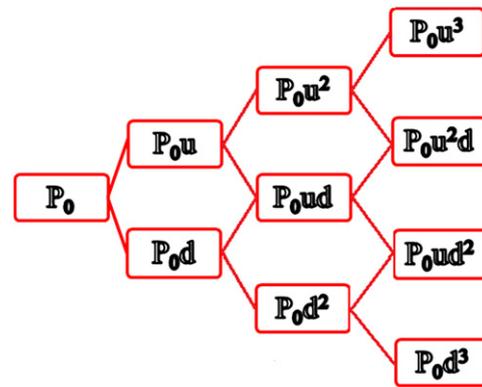


Fig. 1. Three time step binomial tree.

to higher nodes reflect up probabilities (p_r) and multipliers (u), while branches to lower nodes implement the down probabilities ($1-p_r$) and multipliers (d). A schematic binomial tree on the metal price at time zero (P_0) with three steps are shown in Fig. 1. The up (u) and down (d) factors and the probability of occurrence were determined using the following formula:

$$u = e^{\sigma\sqrt{\delta t}} \quad (1)$$

$$d = e^{-\sigma\sqrt{\delta t}} = \frac{1}{u} \quad (2)$$

$$p_r = \frac{(1+rf)-d}{u-d} \quad (3)$$

The basic inputs are the volatility of the metal price or operating cost (σ), the risk-free rate (rf) and stepping time (δt).

Methodology

In this section, three different scenarios were studied to investigate the effect of the uncertainty of the economic parameters such as metal price and operating cost on a mining project:

- Scenario 1: NPV computation under certain metal price and operating cost situation,
- scenario 2: NPV computation under uncertain metal price and certain operating cost situation,
- scenario 3: NPV computation under uncertain metal price and operating cost situation.

Scenario 1: certain metal price and operating cost situation

In this scenario the project NPV was calculated using the traditional DCF technique. For this purpose, at the first step, the free cash flow (FCF) was determined using Eq. (4).

$$FCF_{n,k} = \{[(P_n - C_n)Q_n] - FC_n - D_n(1 - Tax_n)\} + D_n \quad (4)$$

where FCF_n is the free cash flow to the firm at time n , P_n is the mineral commodity price at time n , C_n is the variable cost at time n , Q_n is the production rate at time n , FC_n is the fixed cost at time n , D_n is the depreciation at time n , Tax is the corporative tax and n is the time period.

There are many methods for estimating the future metal price and operating cost such as using the average of the previous metal price and operating cost data and regression analysis. After

calculating the FCF, the NPV will be determined using Eq. (5).

$$NPV = \sum_{n=1}^N \frac{FCF_n}{(1+i)^n} \tag{5}$$

where i is the discount rate for the mining project.

Scenario 2: uncertain metal price and certain operating cost situation

In this scenario, the metal price is considered uncertain but like the previous scenario, the operating cost is assumed certain. A binomial tree, which is constructed using the historical data is utilized for estimating the future metal price changes. Therefore, a new FCF binomial tree is constructed using the metal price binomial tree, annual estimated operating cost and Eq. (4). Finally, the DCF will be estimated using Eq. (6), after building the FCF binomial tree.

$$DCF_{n,k} = FCF_{n,k} + \frac{(pr \times DCF_{n+1,k}) + (1-pr)DCF_{n+1,k+1}}{(1+rf)} \tag{6}$$

where k is the node number at time n .

Scenario 3: uncertain metal price and operating cost situation

In this scenario unlike the previous scenarios, the metal price and operating cost are uncertain. Therefore, the uncertainty of these parameters will be modeled using the binomial tree method. Then, the project free cash flow binomial tree will be constructed using these two trees and Eq. (4). Finally, the project discounted cash flow will be estimated using Eq. (6).

Numerical example

Cayeli copper mine

In this section the role of price and operating cost uncertainties is studied on the project evaluation using the Cayeli mine data. Cayeli mine is located on the Black Sea coast of northeastern

Turkey (Inmet Mining Corporation, 2011). Sub-level stoping with backfill mining method is utilized at the Cayeli mine. The Cayeli deposit is a volcanogenic massive sulfide deposit. Cayeli produces copper and zinc concentrate. The estimated reserve was about 20 million tons of ore grading 3.2% copper. Fig. 2 presents the fluctuations of the copper price and operating costs of Cayeli mine during 2001–2010.

Now, the Cayeli mine project may be evaluated using the mentioned scenarios. For more simplicity, it is assumed that the Cayeli mine produce the copper ore, only.

Scenario 1: evaluation under certain metal price and operating costs situation

Table 1 shows the metal price, operating cost, fixed cost and other fundamental information in 2010. In this scenario, it is assumed the metal price, operating cost and fixed cost are adjusted by the risk free rate for the entire life-of-mine. The effective tax is 30%. The annual depreciation in this mine is equal to 10.8 M\$. The discount rate is 7%.

Table 2 shows the project discounted cash flow. In this table, Eq. (4) is used for computing the FCF. The Cayeli mine project NPV is obtained 81.75 M\$ using Eq. (6).

Table 1
Input data parameters.

Input data	Amount	Unit
Metal price	3.55	(\$/lb)
Operating cost	2.83	(\$/lb)
Copper production	67.2	(Mlb)
Fixed cost	40	(M\$)
Deprecation	10.8	(M\$)
Tax	30	%
Discount rate	7	%

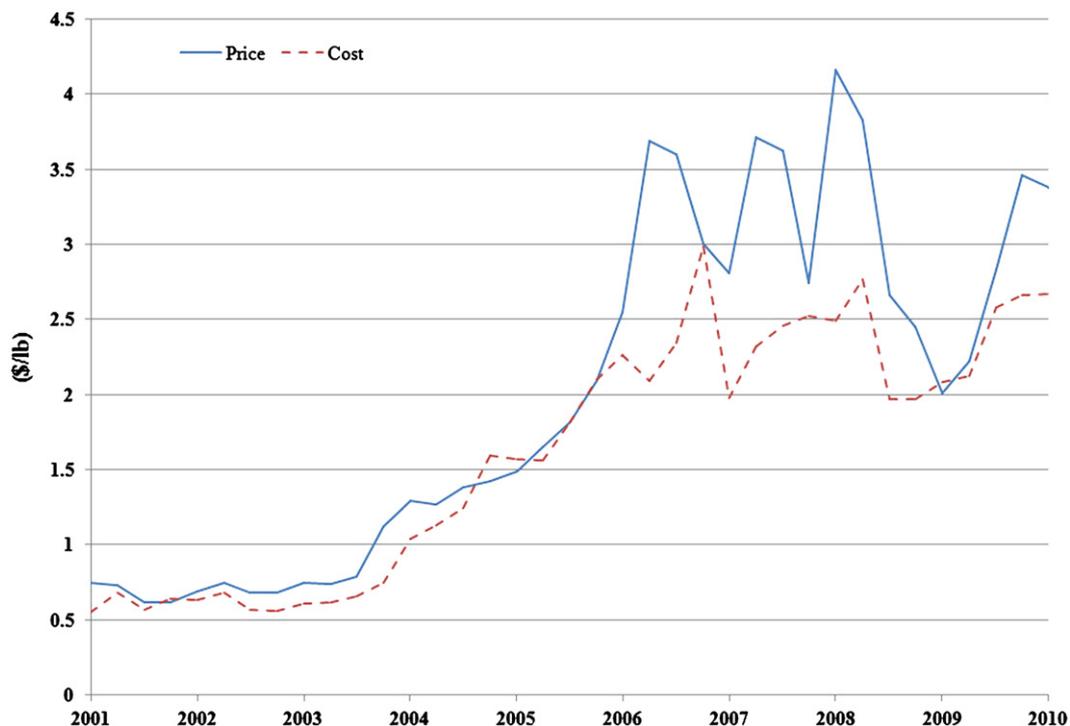


Fig. 2. Copper price and operating cost from 2001 to 2010 (Inmet Mining Corporation, 2011).

Table 2
The project cash flow.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Price (\$/lb)	3.55	3.80	4.06	4.35	4.65	4.98	5.33	5.70	6.10	6.53	6.98
Operating cost (\$/lb)	2.83	3.03	3.24	3.47	3.71	3.97	4.25	4.54	4.86	5.20	5.57
Production (M lb)	67.24	67.24	67.24	67.24	67.24	67.24	67.24	67.24	67.24	67.24	67.24
Fixed cost (MS)	40.00	42.80	45.80	49.00	52.43	56.10	60.03	64.23	68.73	73.54	78.69
Deprecation (MS)	10.76	10.76	10.76	10.76	10.76	10.76	10.76	10.76	10.76	10.76	10.76
Free cash flow (MS)	7.71	8.47	9.29	10.17	10.95	11.49	12.07	12.68	13.35	14.05	14.81
Discounted cash flow (MS)	7.20	7.40	7.59	7.76	7.81	7.65	7.51	7.38	7.26	7.14	7.04

Table 3
Fundamental data for copper price binomial tree.

Input data	Volatility (σ)	Up (u)	Down (d)	Risk free rate (rf)	Probability (p_u)
Metal price	33.72%	1.40	0.71	0.07	0.52

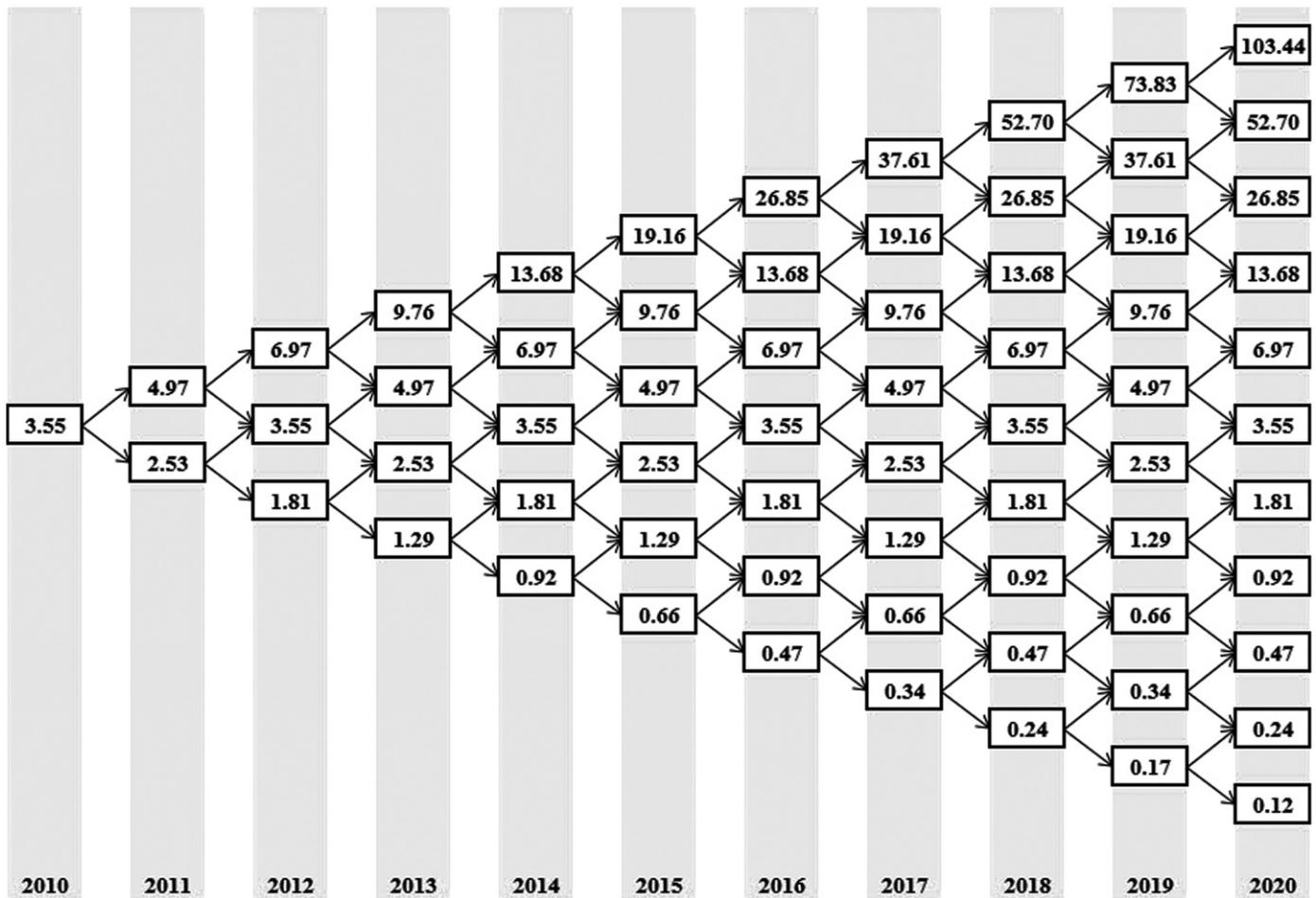


Fig. 3. Binomial tree of copper price from 2010 to 2020 (\$/lb).

Scenario 2: evaluation under uncertain metal price and certain operating costs situation

In this scenario, the copper price fluctuations are modeled using the binomial tree method. For this purpose, the volatility of the metal price was calculated using the historical data. Table 3 shows the fundamental information for building the copper price

binomial tree. Up, down and probability factors are calculated using Eqs. (1)–(3), respectively.

Fig. 3 illustrates the binomial tree of copper prices for 10 years. To calculate the upside node copper price in 2011, the copper price in 2010 should be multiplied by the upside factor ($3.55 \times 1.40 = 4.97$) and for downside node, the copper price in 2010 should be multiplied by the downside factor ($3.55 \times 0.71 = 2.53$). Consequently, a similar

approach has been utilized, to work out the range of copper prices up to 2020.

The operating cost and the rest of input data are the same as that of Scenario 1. Table 4 shows these data from 2010 to 2020.

Therefore, the FCF binomial tree is calculated using the Eq. (4). For example, FCF for the first node of 2011 is calculated as bellow:

$$FCF_{2011-1} = (((4.97 - 3.03) \times 67.24] - 42.80 - 10.76) \cdot (1 - 0.3)) + 10.76 = 64.84 \text{ M\$}$$

Fig. 4 demonstrates FCF binomial tree for the Cayeli mine.

In this scenario, the project discounted cash flow binomial tree is calculated from project free cash flow binomial tree. The last column in Fig. 5 is the same as the last column in Fig. 4. Eq. (6) is used to calculate the project DCF for the remaining years. For example, DCF of the first node of 2009 is calculated as bellow:

$$DCF_{2011-1} = 64.84 + \frac{0.52 \times 1167.94 + (1 - 0.52) \times (-565.47)}{(1 + 0.07)} = 376.08 \text{ M\$}$$

According to this approach, the NPV is -327.2 M\$.

Scenario 3: evaluation under uncertain metal price and uncertain operating costs situation

In this scenario, the NPV of the Cayeli mine is determined by considering the uncertainty of both the price and operating costs. For this purpose, the binomial tree is built for the operating costs (Fig. 6). The volatility of the operating cost data was calculated using the historical data. Table 5 shows the fundamental information for building the operating cost binomial tree. Up, down and probability factors are calculated using Eqs. (1)–(3), respectively.

The free cash flow is calculated using Eq. (4). P_n and C_n in this formula are replaced by Figs. 3 and 6, respectively. For example, FCF for the first node of 2011 is calculated as bellow:

$$FCF_{2011-1} = (((4.97 - 3.78) \times 67.24] - 42.80 - 10.76) \cdot (1 - 0.3)) + 10.76 = 29.34 \text{ M\$}$$

Fig. 7 presents the FCF binomial tree.

After calculating the FCF binomial tree, the DCF binomial tree will be determined using Eq. (6). Fig. 8 shows the DCF binomial

Table 4
Fundamental information.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Operating cost (\$/lb)	2.83	3.03	3.24	3.47	3.71	3.97	4.25	4.54	4.86	5.20	5.57
Production (M lb)	67.24	67.24	67.24	67.24	67.24	67.24	67.24	67.24	67.24	67.24	67.24
Fixed cost (M\$)	40.00	42.80	45.80	49.00	52.43	56.10	60.03	64.23	68.73	73.54	78.69
Deprecation (M\$)	10.76	10.76	10.76	10.76	10.76	10.76	10.76	10.76	10.76	10.76	10.76

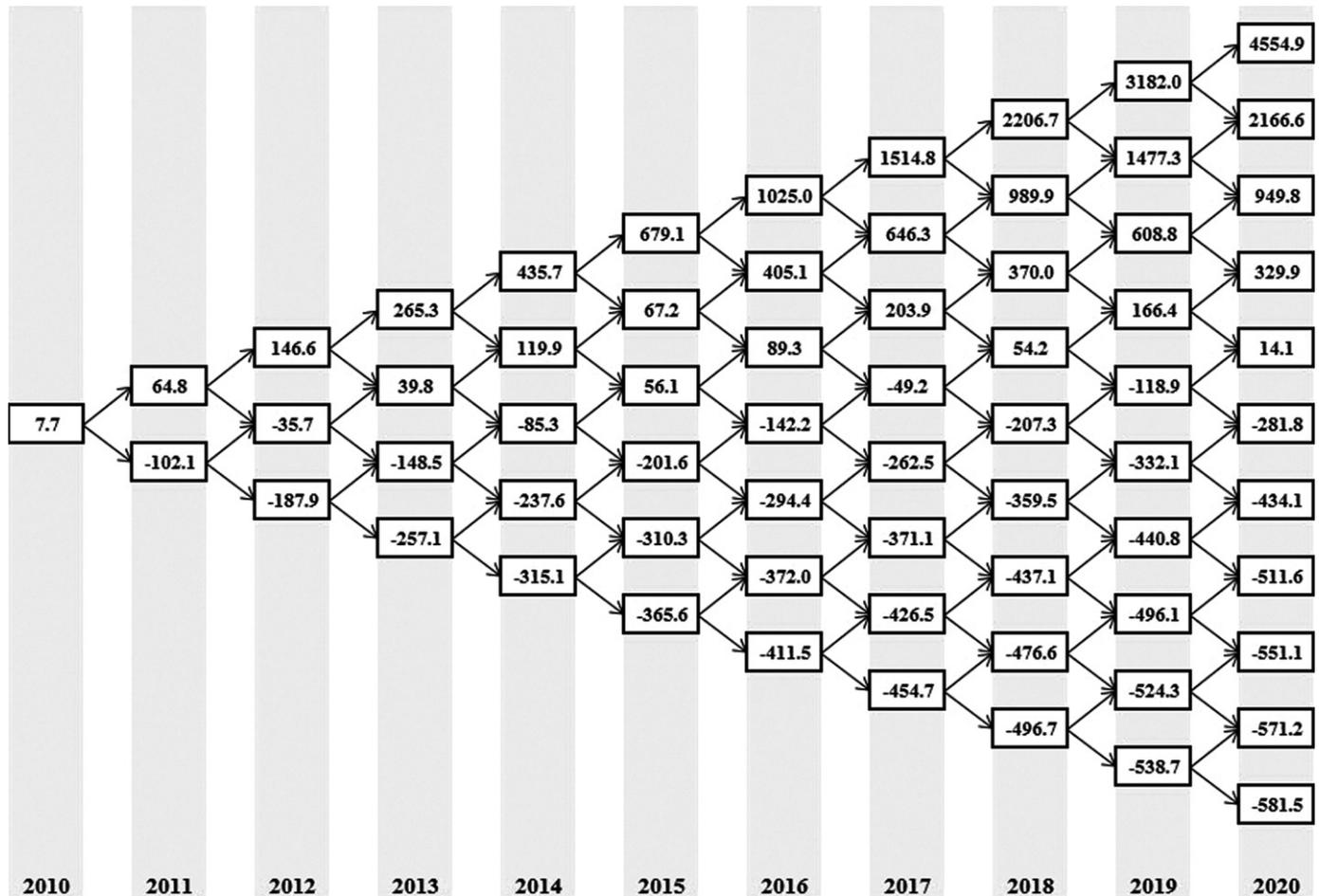


Fig. 4. Binomial tree of FCF (M\$) for scenario 2.

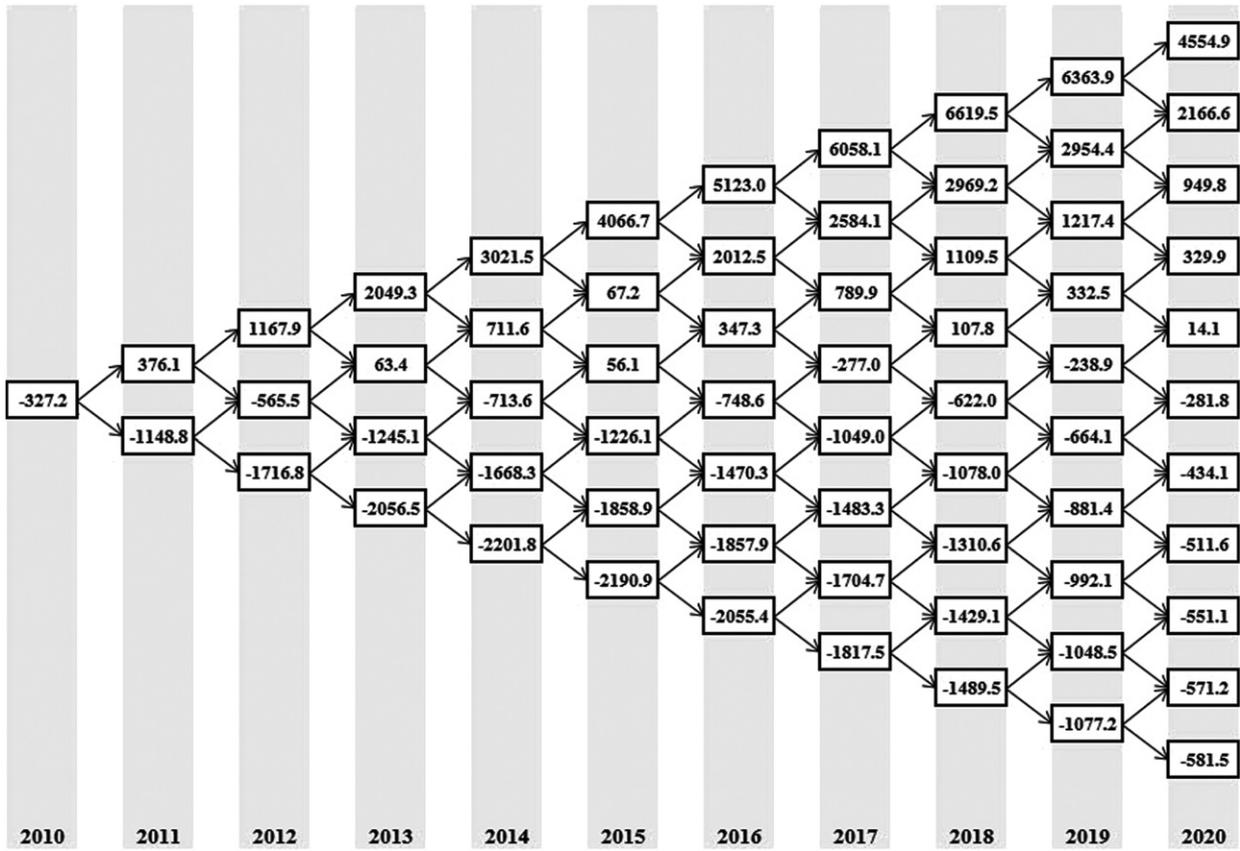


Fig. 5. Binomial tree of DCF (M\$) for scenario 2.

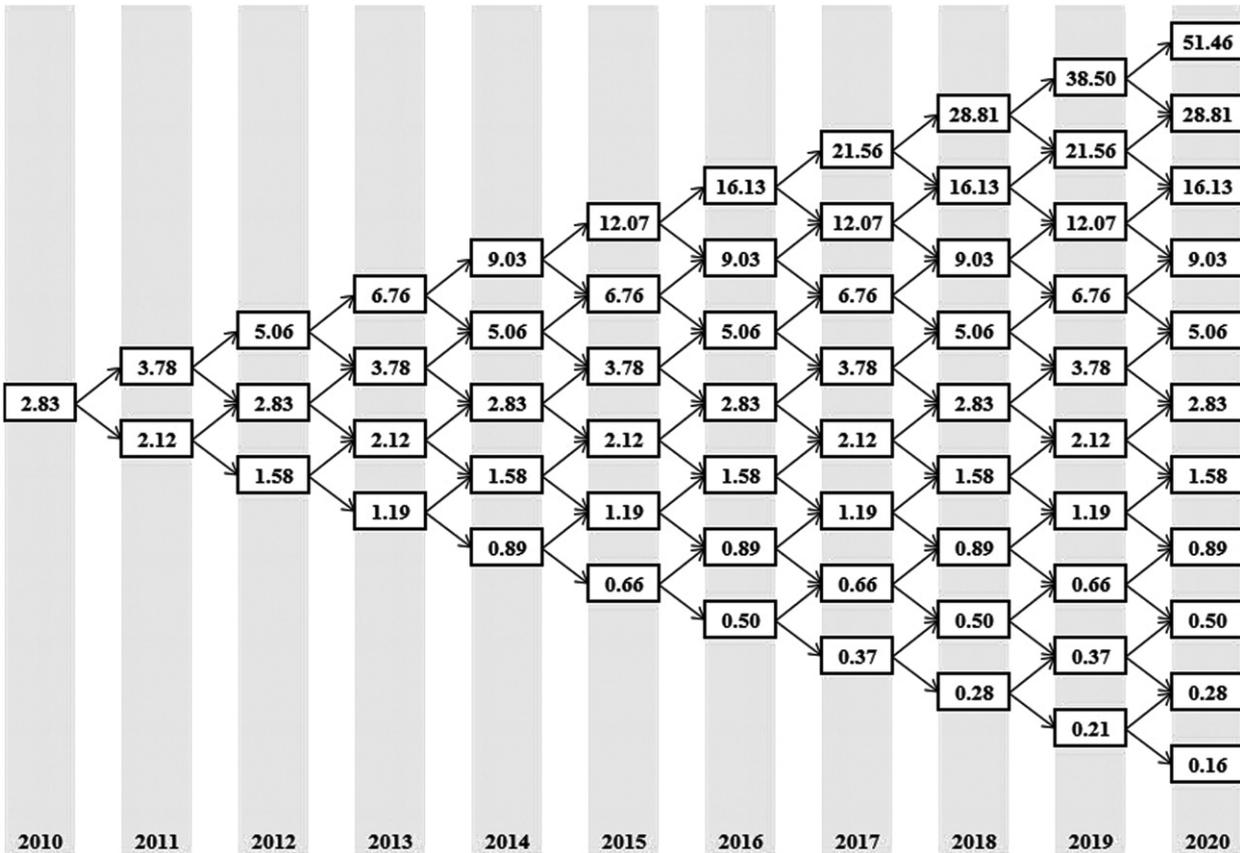


Fig. 6. Binomial tree of operating costs from 2010 to 2020 (\$/lb) for scenario 3.

tree. Using this method, the NPV of the project is obtained 106.0 M\$.

By comparing the NPVs of the mentioned scenarios, it is found that when uncertainty is taken into account for both metal price and operating cost, the maximum NPV is obtained.

Sensitivity analysis

In this section a sensitivity analysis was carried out using the input data. For this purpose, the NPV of each scenario was computed by changing the input data. The NPV, obtained previously, was assumed as the base NPV for comparison. Then each kind of input data was changed ±10% (or ±20%) while other kinds of input data were constant. Using new input data, the task was performed under all scenarios and the corresponding NPVs were obtained. Table 6 shows the sensitivity analysis.

Table 6 shows that even by changing in input economic parameters, the project NPV, which is calculated in uncertain metal price and uncertain operating cost situation is the greatest. The main reason is the metal price and operating cost fluctuations

have a same behavior in the project life. For example, in Fig. 2, in 70% of cases, when the price goes up (down) the cost goes up (down) too. In the case of volatility, in scenario 3, the effect of changes is low-impact, because the volatility changes are applied on the metal price and operating cost, simultaneously.

Conclusion

The NPV of the Cayeli copper mine production project was determined under three scenarios, i.e. using: certain metal price and certain operating costs, uncertain metal price and certain operating costs and uncertain metal price and uncertain operating costs. The following results were concluded:

The binomial tree method is a suitable and applicable technique for forecasting the economic uncertainties in mining projects.

The conventional approach (Scenario 1) provided \$81.75 M\$ for the NPV, while the NPV in uncertain metal price and certain operating costs situation was obtained for –327.2 M\$.

The NPV in uncertain metal price and uncertain operating costs situation was obtained for 106.0 M\$.

The sensitivity analysis shown that even by changing in input economic parameters, the NPV, which was computed in uncertain metal price and uncertain operating cost situation, was the greatest.

Table 5
Fundamental data for operating cost binomial tree.

Input data	Volatility (σ)	Up (u)	Down (d)	Risk free rate (rf)
Operating cost	29.01%	1.34	0.75	0.07

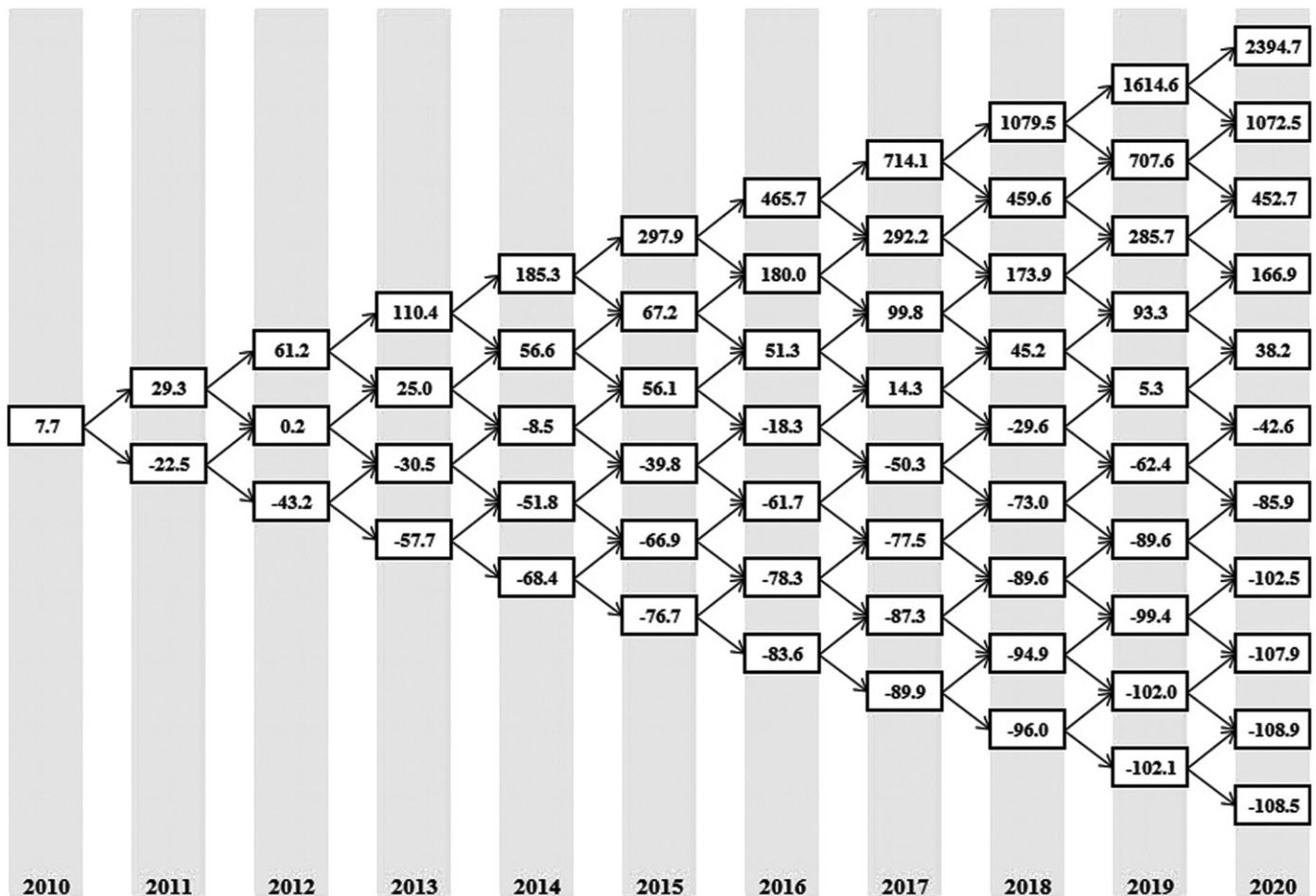


Fig. 7. Binomial tree of FCF (M\$) for scenario 3.

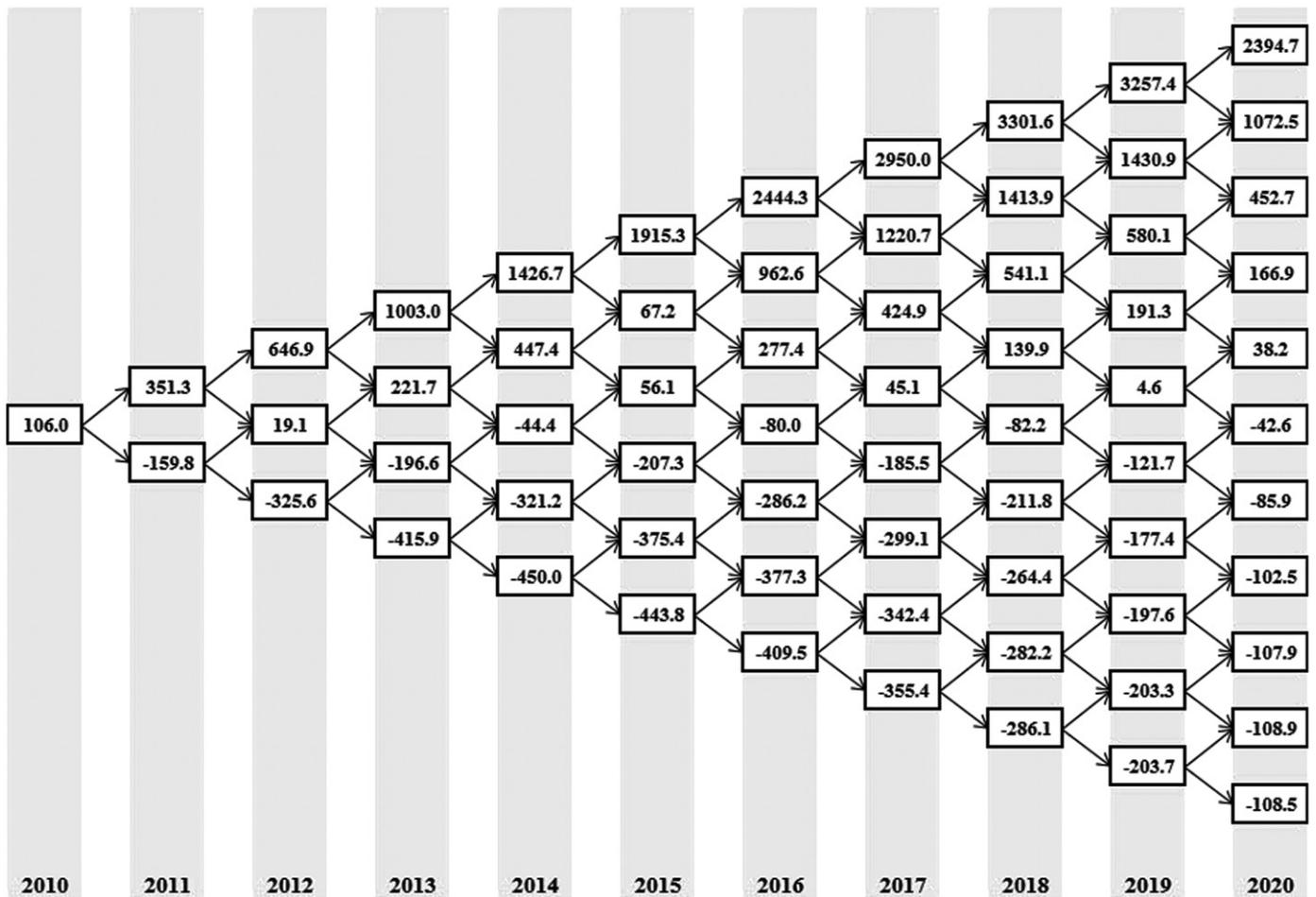


Fig. 8. Binomial tree of DCF (M\$) for scenario 3.

Table 6
Sensitivity analysis.

Input data	Change (%)	Scenario	Calculated NPV (M\$)
Metal price (<i>p</i>)	10	1	256.52
		2	85.15
		3	266.98
	-10	1	-230.79
		2	-409.20
		3	-216.56
Operating cost (<i>C</i>)	10	1	-166.08
		2	-375.85
		3	-79.87
	-10	1	221.68
		2	55.57
		3	271.64
Volatility (σ)	10	2	-369.09
		3	105.07
		3	106.14
	-10	2	-286.75
		3	106.14
		3	106.14
Risk free rate (<i>rf</i>)	20	2	-200.95
		3	137.32
		3	57.85
	-20	2	-523.89
		3	57.85
		3	57.85

Applying the metal price and cost uncertainties cause the net present value to be calculated more realistically than certain conditions.

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