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# The Value of Alternative Tailings Disposal Technology under Dam Licensing Restrictions: A Real Options Approach

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**Abstract**

In this paper, the value of alternative tailings disposal technology is assessed when there are regulatory restrictions for the licensing of the traditional disposal technology, which relies on the use of dams. The alternative technology requires higher CAPEX for implementation than the traditional technology, but allows the company the possibility of expanding the production volume of its mine. The flexibility embedded in such alternative technology comes from lesser social and environmental impacts. The real options framework is used to assess the value of the option to expand and the results obtained show that, even though the traditional dam technology presents higher naïve NPV than the alternative one, the expanded NPV of the alternative technology indicates its adoption.

**Key words: real options, mining, licensing restrictions.**

## 1) INTRODUCTION

For the mining industry, the last and the next ten years ahead should be noted not only as a period of escalating commodity price volatility, but also by the significant increase in related party restrictions on the socio-environmental impacts of operating activities. To better cope with volatility and the need to adapt to the regulatory environment, companies in the industry will need, in addition to working hard to manage their costs, to introduce more sophisticated techniques to support the decision-making process regarding new investments.

At a global scale, the paradigm that seems to be dominant is that mineral commodities are goods to be conceded to mining companies not only in exchange of royalties and other economic benefits that are considered fair, but also by the explicit agreement of social actors on the externalities of the mining activities and their associated processes. Thus, the combination of these two factors, royalties and acceptable impacts, constitutes the so-called social license to operate, currently considered a critical element for the survival and development of companies that constitute the industry.

In order to highlight the perspective outlined above, Table 1 presents parts of recent reports from renowned consultancy firms and from the Mining and Metals chapter of the Global Transformation agenda of the 2018 World Economic Forum.

Table 1

| Institution | Document Title | Year | Performed Analysis |
|---|---|---|---|
| Delloite | The top 10 trends for mining companies in the coming years. | 2017 | In order to regain social license for operations, mining companies must deepen their focus on environmental sustainability, including: management of water and energy consumed, adaptations to climate change, mine decommissioning plan and recovery of impacted areas. |
| Ernest Young | The top 10 business risks that mining and metals companies are facing. | 2016/ 2017 | In a final analysis, reducing emissions and energy consumption as well as managing scarce inputs such as water and electricity means more than cost reduction. They also represent the reduction of the environmental footprint of mining companies and position them to regain the confidence of the communities and obtain the social license to operate again. |
| World Economic Forum | Central themes of the global agenda - mining and metals. Environmental sustainability. | 2018 | (...) Market volatility and the sharp decline in commodity prices have created a "new normal", where cost reduction, operational efficiency and adaptation to customer needs are imperative. These trends have been exacerbated by industry-specific issues such as regulation, operation in more remote areas, low grade assets, legal and social limitations on land and water use, resource-use nationalism, party activism related issues and acute public scrutiny - and by other points that are transversal to other industries such as disruptive technological innovations and the transition to a low carbon economy. |
| | | | The demands of related parties on land use, water consumption, greenhouse gas emissions, and tailings management are huge and are increasing. The environmental performance of a company increasingly affects its ability to secure and maintain the licenses to explore, build and operate ... |

Source: Deloitte (2017, p. 1 -4), EY (2018) e World Economic Forum (2018).

It is possible to identify several evidences of the increased risk of business discontinuity due to environmental and licensing aspects, either through adverse judicial decisions to mining companies, as detailed by Leotaud (2018), or through recent reports produced and disseminated by players of the sector, such as the Vale and BHP 20-F[1] forms. Such forms highlight the growing licensing requirements as well as the possibility of delays in obtaining them. Among other factors, the greatest regulatory restrictions were motivated by the accidents involving the Fundão dams in Mariana and Dam I of Córrego do Feijão in Brumadinho.

In order to respond more appropriately to the restrictive and challenging context already mentioned, an alternative would be the development of operational and strategic flexibilities to expand the range of available paths in the future. Given the need to embrace these aspects, the investment decision-making process of mining companies has become even more complex, thus requiring deeper analysis and methods that are more sophisticated.

Due to its deterministic nature, the discounted cash flow (DCF) methodology traditionally used to evaluate investment projects can't deal well with volatility and is not appropriate to provide the value of flexibilities that often should be incorporated into the analysis of capital allocation (BRASIL et al., 2007; DIXIT and PINDYCK, 1994).

For environments characterized by high uncertainty, the real options theory plays an important role in the development of a roadmap to guide the process of strategic investment decisions, due to the fact that it allows quantifying flexibilities such as options to expand, options to postpone investments, and more generally, the ability to respond to changes in the business environment (LUERHMAN, 1998; MCERATH, MENDELOW, 2004; SMIT; TRIGEORGIS, 2006).

## 2) RESEARCH PROBLEM AND GOALS

The main goal of this paper is to evaluate the use of the real options theory in an alternative technology of tailings disposal with reduced social and environmental impacts, namely the storage of slime into exhausted mine pits associated to the stacking of sandy tailings. Furthermore, the results obtained with the real options theory are compared with those obtained with the discounted cash flow methodology, traditionally used by mining companies to evaluate capital projects.

Recent papers on the field of real options call for the development of new studies that focus on case of individual projects and business units (Trigeorgis and Reuer, 2017). Additionally, Whitten, Hertzler and Strunz (2012) defend the adoption of such theoretical lens as an instrument for valuing forms of protection against the risk of business discontinuity due to environmental restrictions (stakeholders). At the best knowledge of the authors, previous research using real options analysis to evaluate mining projects has not taken into consideration the restrictions on use of dams. This paper is justified by considering these perspectives, thus contributing to fill gaps in the literature.

## 3) LITERATURE REVIEW

In this section a literature review on real options and stochastic processes is presented.

### 3.1) Real Options

Dias (2014) argues that the real options theory translates the freedom of choice of an agent in a decision-making process about a real asset, since they constitute a right and not an obligation. According to him, this concept is broader than the mere application of techniques of valuation of financial options to real assets and implicitly refers to the epistemological basis used for the development of the theory of real options, that is, the perspective of flexibility vis-à-vis irreversibility, originated in the field of environmental economics.

A similar position was also expressed by other authors. Mcgrath, Ferrier, and Mendelow (2004) have argued that the distinctive feature of option theory is the consideration that firms make investments that give them the ability to move in one direction only if it is favorable. For Smit and Trigeorgis (2006), this optionality characterizes strategies that are flexible, thus allowing companies to adjust or change development routes in the sectors in which they operate.

## 3.2) Stochastic Processes

Mun (2010) points out that a stochastic process is a sequence of events or paths generated by probabilistic laws. In this sense, random events are determined by probabilistic or statistical rules over time.

Dias (2015) argues that probabilistic analyses allow the uncertainties present in a project or asset to be treated in depth, allowing the use of the real options theory. According to him, a stochastic process is a set of random variables in a probability space that is indexed by t, that is, that occur at a given moment of time. Moreover, given that stochastic processes can capture stylized facts about a time series of prices, they can be used to forecast uncertainty variables, allowing one to understand the risk of a forecast. The estimation of the parameters of stochastic processes is detailed by Dias (2015, p. 23-28):

> "The choice of the best stochastic process for a given stochastic variable should meet some desired properties, such as data adherence (but not overfitting), economic logic, and consistency with stylized facts of price behavior. Econometric tests to indicate which stochastic processes are suitable for a specific series are useful but have important limitations, especially for series of few datapoints or series of short time periods. Economic intuition and the stylized facts of similar price series are often needed to supplement (or even replace, in extreme cases) the econometric analyses in the indication of the best stochastic model and on the estimation of the parameters of these models. In addition, the simplicity of the model (parsimony principle, where "less is better") should be considered as a desired property, since very complex stochastic models are difficult to interpret and require more parameters to be estimated, introducing additional errors in simpler models (less parameters to be estimated).
>
> Intuitively, the stochastic process is a sequence of probability distributions over time (or indexed by time) of the same phenomenon. [...] In this sense, what is the best probability distribution for the future prices of an asset? As (the majority of) asset prices in the market cannot be negative, it is natural (in most cases) to use distributions that do not allow negative prices. In this sense, the lognormal distribution is by far the most widely used distribution in finance and economics (and in other disciplines). [...].
>
> In econometrics (in the estimation of parameters of stochastic models) it is desirable to assume that the data sampled are considered i.i.d (independent and identically distributed), otherwise any estimation would be very complex. Working with logarithmic (rather than discrete) returns, facilitates the i.i.d. Therefore, in the discussion related to the estimation of parameters of stochastic processes using regressions, logarithmic (and not discrete) returns are used".
>
> Translated by the authors.

According to Mun (2010) and Dias (2015), the geometric Brownian motion and the mean reversion model are the main stochastic processes used in finance. A brief overview of these processes is provided in the next section.

### 3.2.1) Geometric Brownian Motion (GBM)

The random walk or Brownian motion is a Markov process. Therefore, the forecast of any variable that follows a random walk depends only on its current value: the value of a specific variable in the next period is equal to its value today plus a random shock (HULL, 2009). Although such a process is non-stationary, with shocks being incorporated permanently over time, the time series of differences (the increments) are stationary (DIAS 2015; GUJARATI AND PORTER, 2011).

According to Dias (2015), the geometric Brownian motion is a version of the random walk process and is defined by equation (1):

$$\frac{dS}{S} = \mu dt + \sigma dz \quad \textbf{(1)}$$

where $\mu$ is the trend or drift of the variable $S$ and $\sigma > 0$ represents its volatility. Finally, he observes that although the variable of interest follows a lognormal distribution, its rate of change follows a normal distribution with mean $\mu dt$ and variance $\sigma^2 dt$, as presented in equation (2):

$$\frac{dS}{S} \sim N(\mu dt, \sigma^2 dt) \quad \textbf{(2)}$$

### 3.2.2) Mean Reversion Model (MRM)

According to Dias (2015) and Gujarati and Porter (2011), when a time series of a given variable is autoregressive, that is, mean reverting, the fluctuations around the mean present has constant amplitude, meaning that the series is stationary. These authors also observe that the rate of reversion to the mean is dependent on the autocovariance: reversion rate is high when the autocovariance is small and low when the autocovariance is large.

According to Bastian-Pinto (2009), the mean reversion model of stochastic variables can be classified with respect to the number of structural factors in the model, e.g., single factor models to describe a single source of uncertainty and two factors when the modelled variable is governed by two drivers. He argues that a second classification should be analyzed: the arithmetic or geometric nature of the models. While the former can accommodate negative values, the latter cannot.

In this paper, the single factor Schwartz model was chosen. The model can be used to generate simulated values based on an exact discretization equation, allowing the use of high values[2] of $\Delta t$. Moreover, the Schwartz model is based on the well-known Ornstein-Uhlenbeck model (Bastian-Pinto, 2009) and is defined by equation (3):

$$\frac{dS}{S} = \eta[ln(\bar{S}) - ln(S)]dt + \sigma dz \quad \textbf{(3)}$$

where $ln(\bar{S})$ represents the expected value of $ln(S)$ in the long term[3] and $\eta$ is the mean reversion rate. The intuition of the model is that if the value of $ln(S)$ is higher (lower) than $ln(\bar{S})$, a negative (positive) return is expected in the following period.

### 3.2.3) Econometric Test for the Selection of Stochastic Processes

According to Dias (2015), the standard test to identify whether the series of a given variable behaves as GBM or MRM is the Dickey-Fuller test (augmented, in cases of autocorrelated series). However, such author stresses that the reliability of this test is low, given the lack of availability of very long series, which would necessary to detect the weak mean reversion. As an alternative, one can resort to the variance ratio test, which consists of calculating the ratio of the variance of the returns calculated for longer time periods divided by the variance of returns calculated considering a small time period. The variance ratio is calculated according to equation (4):

$$R_k = \frac{1}{k}\frac{Var(p_{t+k} - p_t)}{Var(p_{t+1} - p_t)} \quad \textbf{(4)}$$

If the studied series is a GBM, the variance of the numerator tends to grow linearly as $k$ increases and, consequently, $R_k$ tends to 1. On the other hand, if the series is autoregressive (MRM), the variance of the numerator grows only to a certain and limited level as $k$ increases, which causes $R_k$ to fall with increasing $k$ (tending to infinity).

## 4) METHODOLOGY

In this section, the real options valuation approach used in this paper is presented.

### 4.1) Real Options Valuation

The object of the case study is a firm that owns a mine originally developed to operate with a tailing disposal technology that makes use of dam. New regulations in the mining sector are about to be published and might restrict the use of dams, requiring the implementation of alternative disposal technologies. Besides that, it is expected that mining companies will be subject to formal endorsement of communities located around their sites, which puts at risk mining rights previously registered or acquired from third parties. One of such alternative technologies consists in disposing thickened slime into exhausted pits (nature-confined reservoir) associated to the filtering of sandy tailing and subsequent stacking process. The adoption of such alternative requires higher investment than dams and brings additional costs to the production process.

The company's operations, located in Brazil, involve the following stages: i) iron ore extraction; ii) beneficiation and production of pellets; iii) port operation. The cash flows generated from the operations are subject to a number of volatile drivers of revenues and costs: i) quantity of pellets produced; ii) iron ore price risk (Platts 62% CFR China); iii) BF[4] Pellet Premium; iv) Baltic C3 freight cost and v) foreign exchange rate (US$/BRL).

The volatile nature of the company's cash flows calls for the assessment of flexibilities embedded in its operations and projects. The firm has identified that the adoption in 2018 of the alternative technology described above for tailing disposal would allow it to get licenses to increase its production from 2020 onwards. To expand the production from a rhythm of 7.5 Mt/year to 17.4 Mton/year, a total investment of US$ 384.5 million would be required during the period 2019-2025. Besides that, such investment would extend the life of the mine in two years.

The first stage of the work was the traditional economic-financial evaluation. Thus, the deterministic cash flows of the dam scenario and the one regarding to slime thickened disposal into exhausted pit associated with filtering of sandy tailing were discounted at a risk-adjusted discount rate, resulting in the present value of the benefit regarding to each alternative. The present value of the project (PV) is used as the underlying asset of the option, in line with the methodology proposed by Copeland and Antikarov (2003). The PV and NPV of the investment opportunity are given by the formulas below:

$$PV_0 = \sum_{t=1}^{T} \frac{CF_t}{(1+WACC)^t} \quad \mathbf{(5)}$$

$$NPV = PV - I \quad \mathbf{(6)}$$

where
$PV_0$ = present value, at time $t = 0$, of operating cash flows;
$CF_t$ = operating cash flow generated at time t;
$WACC$ = weighted average cost of capital;
NPV = net present value of the project;
I = present value of the investment needed to implement the alternative waste disposal technology;
T = final year of operating cash flow generation of the project.

In the second step, the stochastic modeling of the endogenous and exogenous sources of uncertainty of the project and the estimation of the parameters of the model adopted for each source were developed.

In the third step, Monte Carlo simulations of the stochastic operating cash flows of the project were carried out, as recommended by Copeland and Antikarov (2003). The aggregate volatility of the project was estimated using the procedure proposed by Brandão, Dyer and Hanh (2012). The volatility is then obtained by calculating the standard deviation of the project returns between periods zero and one, which are calculated according to equation (7):

$$return = ln\left(\frac{PV_1 + CF_1}{PV_0}\right) \quad \textbf{(7)}$$

Following the estimation of the volatility, the last step of the method, which consists of valuing the individual and composite real options of the project. The options identified were calculated using the binomial model proposed by Cox, Ross and Rubinstein (1979). At each period, a cash flow yield – analogous to the dividend yield used in financial option pricing – is calculated according to equation (8):

$$dividend\ yield_t = \frac{CF_t}{PV_t + CF_t} \quad \textbf{(8)}$$

A summary of the research methodology is provided on Figure 1:

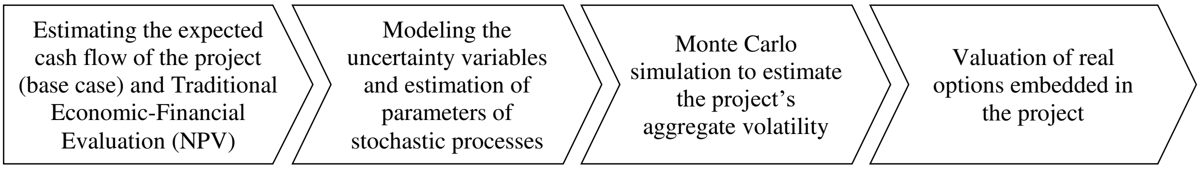


Figure 1 – Stages of the research methodology
Source: Adapted from Sousa Neto, Oliveira and Bergamini Junior (2008, p.60).

## 5) RESULTS

### 5.1) (Net) Present Value

Table 2 illustrates the deterministic forecast of free cash flows for continuing using dam:

Table 2 – Expected Cash Flows: traditional technology (using dams)

| Item | Unity | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
|---|---|---|---|---|---|---|---|---|---|---|
| Net Revenue | USD' 000 | 0 | 686.219 | 661.781 | 690.359 | 645.713 | 679.797 | 676.615 | 670.500 | 331.896 |
| (-) Operating Costs | USD' 000 | 0 | -298.114 | -303.538 | -310.223 | -311.644 | -314.422 | -319.438 | -313.391 | -242.604 |
| (-) Royalties | USD' 000 | | -24.018 | -23.162 | -24.163 | -22.600 | -23.793 | -23.682 | -23.467 | -11.616 |
| (-) Taxes | USD' 000 | 0 | -26.590 | -27.081 | -27.638 | -27.699 | -27.962 | -28.374 | -27.875 | -20.943 |
| (-) Other Expenses | USD' 000 | 0 | -1.372 | -5.936 | -5.526 | -5.721 | -5.175 | -5.586 | -5.451 | -4.785 |
| (=) EBITDA | USD' 000 | 0 | 336.125 | 302.064 | 322.811 | 278.048 | 308.446 | 299.536 | 300.315 | 51.948 |
| (-) Depreciation | USD' 000 | 0 | -176.226 | -184.075 | -186.419 | -189.214 | -191.373 | -194.938 | -199.010 | -203.811 |
| (=) EBIT | USD' 000 | 0 | 159.899 | 117.989 | 136.392 | 88.834 | 117.073 | 104.598 | 101.306 | -151.862 |
| (-) Income Tax | USD' 000 | 0 | -43.173 | -31.857 | -36.826 | -23.985 | -31.610 | -28.241 | -27.352 | 0 |
| (=) NOPAT | USD' 000 | 0 | 116.726 | 86.132 | 99.566 | 64.849 | 85.463 | 76.356 | 73.953 | -151.862 |
| (+) Depreciation | USD' 000 | 0 | 176.226 | 184.075 | 186.419 | 189.214 | 191.373 | 194.938 | 199.010 | 203.811 |
| (-) Change in Working Capital | USD' 000 | 0 | 89.918 | -2.979 | 3.665 | -5.561 | 4.299 | -328 | -848 | -88.165 |
| (=) OPERATING CASH FLOW | USD' 000 | 0 | 203.034 | 273.186 | 282.320 | 259.624 | 272.537 | 271.623 | 273.811 | 140.113 |
| (-) CAPEX Project + Sustaining | USD' 000 | -97.772 | -48.609 | -31.256 | -36.265 | -35.029 | -42.801 | -48.877 | -57.632 | -35.651 |
| (=) FCFF | USD' 000 | -97.772 | 154.425 | 241.930 | 246.056 | 224.596 | 229.735 | 222.746 | 216.179 | 104.463 |

Source: Prepared by the authors.

The expected free cash flows of the scenario in which the firm adopts the alternative tailings disposal technology (slime into exhausted pit and filtering of sand tailing) for the current production level are presented on Table 3:

Table 3 – Expected Cash Flows: alternative technology (exhausted pit + filtering)

| Item | Unity | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
|---|---|---|---|---|---|---|---|---|---|---|
| Net Revenue | USD' 000 | 0 | 686.219 | 661.781 | 690.359 | 645.713 | 679.797 | 676.615 | 670.500 | 331.896 |
| (-) Operating Costs | USD' 000 | 0 | -323.020 | -328.827 | -335.745 | -336.632 | -339.757 | -344.841 | -338.406 | -254.864 |
| (-) Royalties | USD' 000 |  | -24.018 | -23.162 | -24.163 | -22.600 | -23.793 | -23.682 | -23.467 | -11.616 |
| (-) Taxes | USD' 000 | 0 | -28.621 | -29.143 | -29.719 | -29.737 | -30.028 | -30.446 | -29.915 | -21.943 |
| (-) Other Expenses | USD' 000 | 0 | -1.372 | -5.566 | -5.155 | -5.347 | -4.809 | -5.215 | -5.079 | -4.419 |
| (=) EBITDA | USD' 000 | 0 | 309.187 | 275.082 | 295.577 | 251.397 | 281.410 | 272.432 | 273.632 | 39.054 |
| (-) Depreciation | USD' 000 | 0 | -176.556 | -190.539 | -195.002 | -197.787 | -199.912 | -203.477 | -207.548 | -212.349 |
| (=) EBIT | USD' 000 | 0 | 132.631 | 84.543 | 100.576 | 53.610 | 81.499 | 68.955 | 66.084 | -173.295 |
| (-) Income Taxes | USD' 000 | 0 | -35.810 | -22.827 | -27.155 | -14.475 | -22.005 | -18.618 | -17.843 | 0 |
| (=) NOPAT | USD' 000 | 0 | 96.821 | 61.717 | 73.420 | 39.135 | 59.494 | 50.337 | 48.241 | -173.295 |
| (+) Depreciation | USD' 000 | 0 | 176.556 | 190.539 | 195.002 | 197.787 | 199.912 | 203.477 | 207.548 | 212.349 |
| (-) Change in Working Capital | USD' 000 | 0 | 90.264 | -2.974 | 3.668 | -5.568 | 4.304 | -327 | -854 | -88.513 |
| (=) OPERATING CASH FLOW | USD' 000 | 0 | 183.113 | 255.230 | 264.754 | 242.490 | 255.102 | 254.141 | 256.644 | 127.567 |
| (-) CAPEX (Project + Sustaining) | USD' 000 | -101.538 | -120.646 | -56.834 | -36.265 | -35.029 | -42.801 | -48.877 | -57.632 | -35.651 |
| (=) FCFF | USD' 000 | -101.538 | 62.467 | 198.396 | 228.489 | 207.462 | 212.300 | 205.264 | 199.011 | 91.916 |

Source: Prepared by the authors.

Table 4 presents the forecast of free cash flows regarding only the incremental production volume from 2020 onwards if the firm decides to invest a total of US$ 384.5 million during the period 2019-2025:

Table 4 – Expected Cash Flows: incremental volume through alternative technology (exhausted pit + filtering)

| Item | Unity | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Net Revenue | USD' 000 | 0 | 833.475 | 856.949 | 835.595 | 884.059 | 847.491 | 858.468 | 1.138.229 | 1.221.973 | 822.160 |
| (-) Operating Costs | USD' 000 | 0 | -320.552 | -325.365 | -335.354 | -342.313 | -340.468 | -336.915 | -430.250 | -594.245 | -490.916 |
| (-) Royalties | USD' 000 | 0 | -29.172 | -29.993 | -29.246 | -30.942 | -29.662 | -30.046 | -39.838 | -42.769 | -28.776 |
| (-) Taxes | USD' 000 | 0 | -29.074 | -29.441 | -30.310 | -30.932 | -30.682 | -30.440 | -39.009 | -52.681 | -42.873 |
| (-) Other Expenses | USD' 000 | 0 | -1.667 | -7.930 | -8.041 | -7.705 | -8.174 | -7.734 | -8.497 | -10.960 | -8.798 |
| (=) EBITDA | USD' 000 | 0 | 453.011 | 464.220 | 432.644 | 472.167 | 438.505 | 453.333 | 620.635 | 521.318 | 250.798 |
| (-) Depreciation | USD' 000 | 0 | -185.715 | -197.120 | -205.155 | -212.616 | -219.584 | -224.947 | -232.219 | -238.570 | -245.073 |
| (=) EBIT | USD' 000 | 0 | 267.296 | 267.100 | 227.489 | 259.551 | 218.921 | 228.386 | 388.416 | 282.748 | 5.725 |
| (-) Income Tax | USD' 000 | 0 | -72.170 | -72.117 | -61.422 | -70.079 | -59.109 | -61.664 | -104.872 | -76.342 | -1.546 |
| (=) NOPAT | USD' 000 | 0 | 195.126 | 194.983 | 166.067 | 189.472 | 159.812 | 166.722 | 283.544 | 206.406 | 4.179 |
| (+) Depreciation | USD' 000 | 0 | 185.715 | 197.120 | 205.155 | 212.616 | 219.584 | 224.947 | 232.219 | 238.570 | 245.073 |
| (-) Change in Working Capital | USD' 000 | 0 | 108.636 | 3.001 | -2.531 | 6.155 | -4.597 | 1.323 | 36.266 | 12.746 | -161.000 |
| (=) OPERATING CASH FLOW | USD' 000 | 0 | 272.204 | 389.101 | 373.753 | 395.933 | 383.993 | 390.346 | 479.496 | 432.230 | 410.252 |
| (-) CAPEX (Project + Sustaining) | USD' 000 | -170.722 | -140.209 | -99.403 | -99.689 | -83.653 | -64.378 | -87.303 | -76.238 | -78.073 | -75.833 |
| (=) FCFF | USD' 000 | -170.722 | 131.995 | 289.698 | 274.063 | 312.281 | 319.615 | 303.043 | 403.258 | 354.157 | 334.420 |

Source: Prepared by the authors.

Table 5 presents the calculation of the Company's WACC required to discount the forecasted cash flows.

Table 5 – Calculation of the Company's WACC .

| Item | Value | Source/Comments |
|---|---|---|
| Unlevered Beta (1) | 1.29 | Reference adopted by PWC in a valuation report of a similar company in 2017. |
| Debt/Equity Ratio Target (2) | 51% | Based on the latest company´s financial statement. |
| Risk Free Rate - T Bond 10 years (3) | 2.8% p.a. | Bloomberg – 2018, June. |
| Risk Country (4) | 3.6% p.a. | |
| US Long Term Inflation (5) | 2.0% p.a. | CPI (*Consumer Price Index*) from Factset – 2018, June. |
| Cost of Debt in Nominal Terms (6) | 7.5% p.a. | Company's Treasury. |
| Income State Tax (7) | 27% p.a. | Company's Financial Statement |
| Cost of Debt in Real Terms = [1+(6)x(1-(7))]/[(1+(5))] | 3.4% p.a. | Calculations performed by the authors. |
| Leverage beta (9) = [(1)x[1+[1-(7)]x[(2)/[1-(2)] | 2.28 | |
| Market Risk Premium (10) | 5.37% p.a. | Damodaran Online (www.damodaran.com – access in 2018, June). |
| Equity Cost in Real Terms (11) = [1+((3)+(4))+[((9)x(10))] /(1+(5))]-1 | 16.3% p.a. | Calculations performed by the authors. |
| WACC in Real Terms (12) = [(8)x(2)+[(1-(2)x(11)] | 9.69% p.a. | |

Source: Prepared by the authors.

The results of the analyses based on the deterministic free cash flows of the two alternatives, considering a WACC of 9.69% in real terms, are presented on Table 6.

Table 6 – DCF Results of Deterministic Analyses

| Scenario | NPV (USD'000) | PV (USD'000) | PV of Project CAPEX, excludes sustaining (USD'000) |
|---|---|---|---|
| **Traditional Technology (Dam)** | 1,034,729 | 1,134,580 | 99,851 |
| **Alternative Technology (Exhausted Pit + Filtering)- Current Production Level** | 849,806 | 1,040,356 | 190,550 |
| **Possibility of Incremental Volume (Expansion) using Alternative Technology** | 1,516,740 | 1,860,645 | 343,905 |

Source: Prepared by the authors.

If one does not take into consideration the possibility of expanding the production volume with the adoption of alternative technology, the DCF methodology indicates that the firm should choose the alternative that uses dam to dispose tailings.

### 5.2) Estimation of Parameters of Stochastic Processes

The choice of the stochastic processes for the Platts 62% CFR China BF Pellet Premium and the Baltic C3 freight cost was conducted according to the variance ratio test described in section 3.2.3). Figure 2 presents the results of the variance ratio test for the three time series:

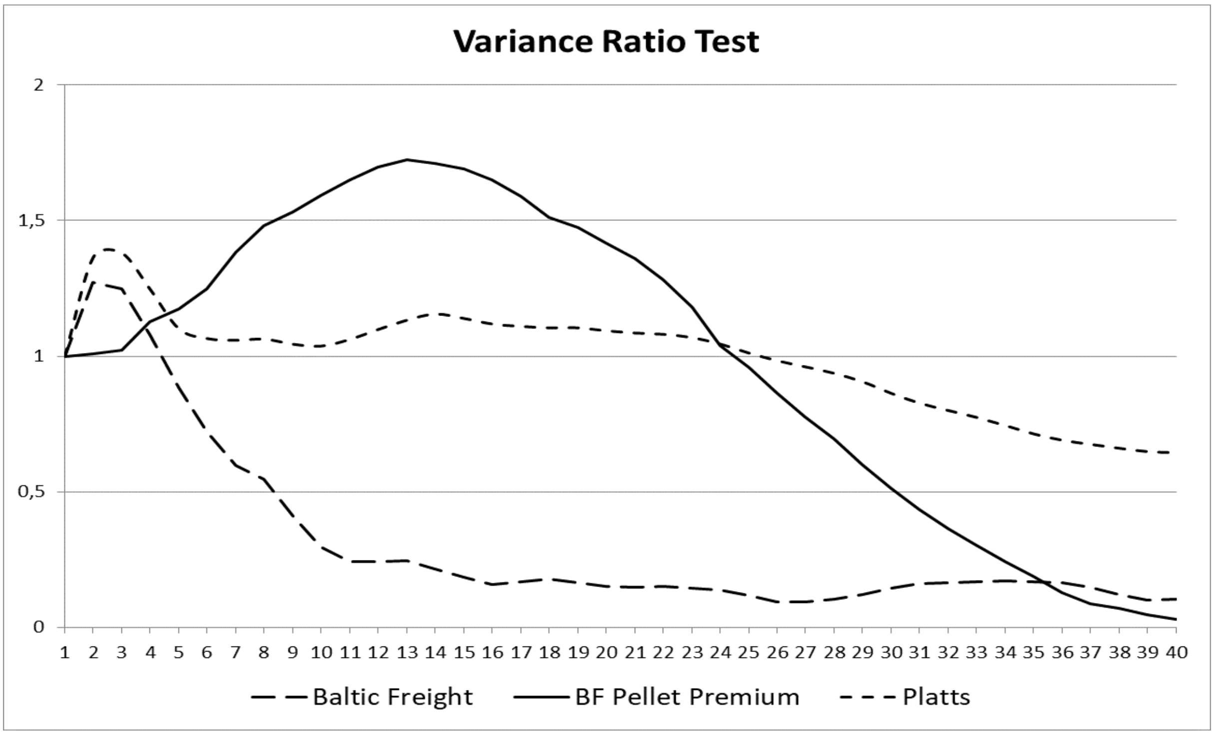


Figure 2 – Results of the Variance Ratio Test

Source: Prepared by the authors.

The results of the test suggest that the three series exhibit mean reverting behavior, as the tests converge to zero as the number of lags increase. Parameters of the Schwartz model were estimated using ordinary least squares, following the procedure presented by Bastian-Pinto (2009).

The foreign exchange rate (BRL/US$) has been modeled as a GBM, following authors Brasil and Aronne (2015). Parameters were estimated using ordinary least squares.

The quantity of pellets produced each year has been modelled as a triangular distribution with minimum, maximum and most likely values of 85%, 95% and 100% of the nominal capacity, respectively. Due to the absence of a time series, these assumptions were provided by the technical operating team of the mining company.

Table 7 presents the parameters[5] used in the Monte Carlo Simulation:[6]

Table 7 – Parameters Used in the Monte Carlo Simulation

| Parameter | Platts (MRM) | BF Pellet Premium (MRM) | Baltic Freight (MRM) | Exchange Rate (MGB) |
|---|---|---|---|---|
| **Volatility ($\sigma$)** | 38,9% | 18,7% | 80,7% | 20,5% |
| **Mean Reversion Rate ($\eta$)** | 0,45 | 0,60 | 1,79 | - |
| **Half-Life (H)** | 1,54 years | 1,16 years | 0,39 years | - |
| **Long Term Prices ($\bar{S}$)** | 88,1 | 41,6 | 19,3 | - |
| **Growth Rate ($\mu$)** | - | - | - | 0,0% |

Source: Prepared by the authors.

## 5.3) Project Volatility

Based on the cash flow waterfall of the project illustrated on Table 4 and on the parameters defined for the risk factors, 10,000 iterations of Monte Carlo simulations were run, in order to estimate the project volatility. Considering the result of such simulations the project volatility to be considered is 44.35% p.a.

## 5.4) Option to Expand

Considering a continuously compounded risk-free rate equal to 6.2% per annum, binomial lattice of the option to expand is developed, as presented in Figure 3:

**Call Expansion: Binomial Lattice**

**Parameters**

| | |
|---|---|
| **σ =** | 44,35% |
| **u =** | 1,5582 |
| **d =** | 0,6418 |
| Risk Free Rate-r | 6,2% |
| **q=** | 0,46053022 |
| **1-q=** | 0,53946978 |

Incremental Production Value

Expansion Option Value

Optimal Decision

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 0 |
| | | | | | | | | | 0 |
| | | | | | | | | 5.054.911 | defer |
| | | | | | | | | 4.490.860 | |
| | | | | | | | 7.012.687 | expand | 0 |
| | | | | | | | 6.482.463 | | 0 |
| | | | | | | 7.521.356 | expand | 2.082.065 | defer |
| | | | | | | 7.022.932 | | 1.518.014 | |
| | | | | | 6.483.148 | expand | 2.888.452 | expand | 0 |
| | | | | | 6.014.617 | | 2.358.229 | | 0 |
| | | | | 5.349.274 | expand | 3.097.968 | expand | 857.581 | defer |
| | | | | 4.908.842 | | 2.599.544 | | 293.529 | |
| | | | 4.314.961 | expand | 2.670.341 | expand | 1.189.723 | expand | 0 |
| | | | 3.900.944 | | 2.201.810 | | 659.500 | | 0 |
| | | 3.368.556 | expand | 2.203.310 | expand | 1.276.021 | expand | 353.229 | defer |
| | | 2.979.368 | | 1.762.878 | | 777.597 | | 0 | |
| | 2.604.077 | expand | 1.777.288 | expand | 1.099.886 | expand | 490.035 | defer | 0 |
| | 2.238.230 | | 1.363.270 | | 631.354 | | 0 | | 0 |
| 1.860.645 | expand | 1.387.473 | expand | 907.521 | expand | 525.580 | defer | 145.491 | defer |
| 1.516.740 | | 998.285 | | 467.089 | | 27.156 | | 0 | |
| expand | 1.072.592 | expand | 732.046 | expand | 453.031 | expand | 201.840 | defer | 0 |
| | 706.746 | | 318.029 | | 11.756 | | 0 | | 0 |
| | expand | 571.486 | expand | 373.798 | defer | 216.481 | defer | 59.926 | defer |
| | | 182.298 | | 5.089 | | 0 | | 0 | |
| | | expand | 301.522 | defer | 186.599 | defer | 83.136 | defer | 0 |
| | | | 2.203 | | 0 | | 0 | | 0 |
| | | | defer | 153.964 | defer | 89.166 | defer | 24.683 | defer |
| | | | | 0 | | 0 | | 0 | |
| | | | | defer | 76.858 | defer | 34.243 | defer | 0 |
| | | | | | 0 | | 0 | | 0 |
| | | | | | defer | 36.727 | defer | 10.167 | defer |
| | | | | | | 0 | | 0 | |
| | | | | | | defer | 14.104 | defer | 0 |
| | | | | | | | 0 | | 0 |
| | | | | | | | defer | 4.188 | defer |
| | | | | | | | | 0 | |
| | | | | | | | | defer | 0 |
| | | | | | | | | | 0 |
| | | | | | | | | | defer |
| CAPEX | 365.846 | 389.187 | 414.018 | 440.432 | 468.532 | 498.424 | 530.223 | 564.052 | 600.038 |
| Dividend Yield | 10% | 17% | 18% | 20% | 22% | 26% | 40% | 54% | 100% |
| **2019** | **2020** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** |

Figure 3 – Binomial Lattice

Source: Prepared by the authors.

## 5.5) Expanded Net Present for Using Alternative Tailing Disposal

Considering that the chance of getting the social license to expand in case of using exhausted pit associated to filtering of sand tailing is 50%, the expanded NPV results are presented on Table 8:

Table 8 – Results of the Real Options Analysis

| **Metric** | **Values (USD'000)** |
|---|---|
| **Basic (Naive) NPV** | 849,806 |
| **PV of the option to expand in the second year (50% odds)** | 712,888 |
| **Expanded NPV** | 1,562,694 |

Source: Prepared by the authors.