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A COMPARISON OF VARIOUS MODELLING TECHNIQUES TO OPTIMISE PRODUCTION RATE ON A PLATINUM MINING PROJECT

Jaco Dreyer

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Masters of Science in Engineering.

Johannesburg, 2021

DECLARATION

I declare that this report is my own, unaided work. I have read the University Policy on Plagiarism and hereby confirm that no plagiarism exists in this report. I also confirm that there is no copying, nor is there any copyright infringement. I willingly submit to any investigation in this regard by the School of Mining Engineering, and I undertake to abide by the decision of any such investigation.



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ABSTRACT

Every business aims to create an optimal economic value for its shareholders. The production rate is one of the critical drivers of value in the mining business. Several approaches have been developed to determine the production rate for mining operations. This study applied three approaches for determining production rate, namely the tonnage-based, microeconomic and marginal-analysis modelling methods. These methods were applied on a platinum project, and the production rate results from the three methods were used to determine the life of mine (LOM) production profiles, capital expenditure (CAPEX) and operational expenditure (OPEX). These results were then used as inputs into a discounted cash flow (DCF) model. The DCF model results were compared and analysed to determine a production rate determination method that results in an optimum production output rate for the project.

The study revealed that the tonnage-based modelling technique resulted in the highest production rate of 410-kilo tonnes per month (ktpm), the highest CAPEX of USD957.24 million, the lowest OPEX of USD75.37 per mined tonne, the highest net present value (NPV) of USD63.12 million and the highest internal rate of return (IRR) of 12.85% over a 40-year LOM. The microeconomic modelling technique ranked second with a production rate of 270 ktpm, CAPEX of USD 726.24 million, OPEX of USD 76.68 per mined tonne, NPV of USD 3.46 million and IRR of 10.17%. The marginal-analysis modelling technique ranked last with a production rate of 230 ktpm, CAPEX of USD 658.76 million, OPEX of USD 77.83 per mined tonne, NPV of USD -10.69 million and the lowest IRR of 9.47%. Mineral Resource tonnage-based modelling may be further investigated in other commodities other than platinum or other multi-element/polymetallic mineral deposits in line with the South African mining industry. This will result in the formulation of industry-specific calibration in the South African mining industry.

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“*You will keep him in perfect peace, Whose mind is stayed on You, Because he trusts in You.*”

Isaiah 26:3

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LIST OF ACRONYMS

AFC	Average Fixed Cost
ATC	Average Total Cost
AVC	Average Variable Cost
CAPEX	Capital expenditures
DCF	Discounted Cash Flow
EBITDA	Earnings Before Interest, Tax, Depreciation and Amortization
GTC	Grade Tonnage Curve
KTPM	Kilo Tonnes Per Month
IRR	Internal Rate of Return
LHD	Load Haul Dumper
LOM	Life of Mine
MCC	Marginal Cost of Capital
NPV	Net Present Value
NSR	Net Smelter Return
PGE	Platinum Group Metals
PVMC	Present Value Marginal Costs
PVMOC	Present Value Marginal Operating Costs
PVMR	Present Value Marginal Revenue
PVR	Present Value Ratio
PWC	Price Waterhouse Coopers
SIB	Stay in Business
SMU	Smallest Mining Unit
TR	Total Revenue
TFC	Total Fixed Cost
TVC	Total Variable Cost
TSR	Total Shareholder Return
OPEX	Operational Expenditure
MC	Marginal Cost
3D	Three dimensional

1 INTRODUCTION

1.1 Chapter overview

This chapter introduces the research. The chapter provides brief background information on mineral project valuation and production rate as one of the key drivers of value. The common trend while determining the production rate of a project is introduced as the primary research problem and discussed along with the research question. The research aim and objectives, research scope and justification for the case study are also discussed in this chapter.

1.2 Background information

Mineral project valuation is a process of determining the economic value of a mining project. There are several methods of determining the value of a mining project, but each method has its strengths and weaknesses. One of the most widely accepted methods is the discounted cash flow (DCF) valuation method. The DCF method determines the net present value (NPV) of a project by applying the modifying factors associated with converting a Mineral Resource to a Mineral Reserve during an economic valuation (Baruti, 2018). This method relies on estimating input parameters such as the production rate, operating costs (OPEX), capital cost (CAPEX), inflation rate, metal price, tax and royalty rates. These parameters must be estimated as accurately as possible to ensure accurate investment decision making.

The nature of the DCF method is such that it values the cash flows generated earlier, more than those generated later in the life of a mine (LOM) because of the time value of money concept. Production rate is one of the critical drivers of value, implying that the determination of an optimum production rate is imperative. Production rate determination is executed at the beginning of a project's life cycle, and various economic factors underpin the period in which the determination is implemented. The optimal production rate or resource depletion rate is subjected to changes in commodity price (i.e. influenced by market supply and demand factors), operational and capital costs, and other physical or production-related aspects (Runge, 1998). One such production-related aspect is the effect of corporate governance on the outcome of the production rate determination (Hutton, 2019). The respective Mineral Resource usually forms part of a more significant portfolio of mineral assets owned by a company and is subjected to the strategic objectives within that

portfolio. This directs the evaluated Mineral Resource to a production rate that fits within an established supply to a concentrator or mill (Hutton, 2015), rather than evaluating the true potential of individual assets within the portfolio.

1.3 Problem statement

The minimum requirement for the conversion of a Mineral Resource to a Mineral Reserve is the application of modifying factors as stipulated in the definition of Mineral Reserve (Hutton, 2015). However, this does not mean that the conversion process must include an optimised Mineral Reserve that presents the best total shareholder return (TSR) and/or the best business case. This only means that it has to prove reasonable economic value. Hutton (2015, p 115) argues that "*... in many instances, optimal economic moments are not considered, and a Mineral Resource is often simply converted into a Mineral Reserve without regard for determining optimal moments to achieve maximum sustainable returns"*. Hutton (2015) further argues that a Mineral Resource cannot be deemed as optimised if microeconomic modelling concepts were not integrated into the Mineral Resource's basic constituents or grade tonnage curve (GTC).

The last platinum price super-cycle (2003 to 2007) left the platinum mining industry predominantly oversized and under-skilled. This is due to the industry applying a production-output-at-all-costs mindset to most operations. This brought about conditions in the mining industry that prioritised production output over simple supply and demand economics (Hutton, 2018a). Subsequently, this caused a market selloff in the mining industry that started in 2010 until 2015. During this period, production costs kept increasing. This was due to the constant demand for the input factors (e.g. skills, stores, power, water and transportation) associated with a mine's production (Hutton, 2018a). Figure 1.1 is a graphical representation of the historical platinum price.



Figure 1.1: Historic Platinum price

(Source: Johnson_Matthey, 2020)

Production rates of operations determined under the super-cycle conditions differ from those determined under normal market operating conditions (Hutton, 2018b). This is due to the volume-over-all-other-factors approach implemented during this period. From 2003 to 2020, some operations were oversized and had to reposition themselves to survive under the current market conditions (Hutton, 2018b). Several methods are used to determine the production rate of a mine. Some methods are based on only the available Mineral Resource tonnage, while some consider various geological, technical, economic and financial factors. With a vast array of production rate determination methods available, determining the optimum production rate for an exhaustible resource can be cumbersome and technically challenging. This raises the question:

> "*What is the best method to use in determining the optimal production rate for the project under analysis*?"

1.4 Research aim and objectives

The research aimed to determine a production rate determination method that best optimises the production output rate of a platinum case study project. Three production rate determination methods, which include: tonnage-based, microeconomic and marginal-analysis methods, were compared. The analysis was done on a platinum mining project that underwent a feasibility study during the 2010 to 2015 period. The objectives of the research were to:

- Review literature on proven production rate determination methods;
- Apply the identified production rate determination methods on a platinum project;
- Compare the results obtained from the identified production rate determination methods to the mining project's feasibility study results;
- Validate the results using the DCF model; and
- Recommend on the best production rate optimisation method.

1.5 Research scope

A specific platinum mining project was chosen as the basis on which the three production rate determination methods were tested. The project was chosen as a case study because it underwent a feasibility study during the 2010 to 2016 period, which coincided with the platinum super-cycle. Production rate determination methods associated with the tonnage-based models (Taylor, 1977), microeconomic modelling (Hutton, 2015) and marginal-analysis (Sabour, 2002) were applied to the mining project. The results obtained from the application of the production rate determination methodologies were compared to the results from the original mining project's feasibility study.

1.6 Research significance

Since production rate is one of the key value drivers in mining operations, it is a fundamental input parameter in the mine design and planning process. Therefore, determining an optimal production rate for an exhaustible resource is essential to create optimal value for mining companies. This research can assist mine planners during the evaluation of mineral projects to realise optimal value.

1.7 Chapter summary and report outline

The report is structured into five chapters. Chapter 1 provides the introduction of the research. The chapter outlines the background information, problem statement, research aim and objectives, research scope, and the research significance. Chapter 2 provides a literature review. It provides an overview of value creation in the mining context leading to production rate as one of the key drivers of value for mining operations. Literature on various production rate determination methods is reviewed, and the intricate details of each of these methods are discussed. Chapter 3 outlines the research methodology undertaken for this study. This includes a description of the data collected and the process of data analysis. The data collected include the Mineral Resource model, cut-off grades, LOM, OPEX, CAPEX and commodity price forecasts. All calculations that are involved in the determination of the optimal production rate are detailed in this chapter. Chapter 3 also outline all the relevant non-disclosure agreements and ethical considerations for this study. Chapter 4 applies the three selected techniques to a platinum project. The obtained production rates were used to determine LOM production schedules, OPEX and CAPEX and the data were then used in the DCF model to determine the optimal method. Chapter 5 concludes the research by stating the best production rate determination method from the three methods applied to the mining project under review. The conclusion is based on the results obtained from the DCF models that were run for each method. Finally, the chapter provides recommendations for further study work based on the conclusions.

2 LITERATURE REVIEW

2.1 Chapter overview

The chapter provides an overview of value and value creation in the mining industry and how value was maintained through the commodity price super-cycle and post the super-cycle. Given the importance of production rate in driving value, literature is reviewed on production rate and the three primary production rate determination methods. These methods include the tonnage-based method, microeconomic modelling method and marginal-analysis modelling technique. Lastly, a discussion is held on the DCF method and how it is used to determine the NPV and internal rate of return (IRR) of a mining project.

2.2 Value creation in the mining business

The mining business is different from most other businesses and can only be analysed differently to most other businesses (Camus & Garcia, 2011). The mining business is broken up into four main or primary activities in the value chain framework, as Porter (1985) proposed. These activities include Mineral Resource management, project management, operations management and lastly, marketing management. Subsequent to Porter (1985)'s work, additional work done by Camus *et al*. (2009) developed a new model that divides mining into five main activities. Figure 2.1 depicts this new proposed model by Camus *et al*. (2009).

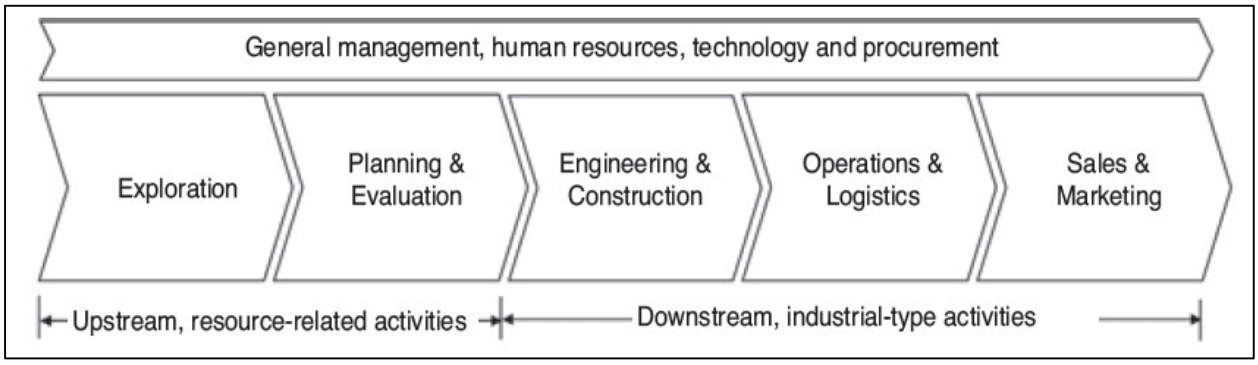

Figure 2.1: Mining value chain

(Source: Camus, *et al*., 2009)

Value can be added or destroyed at each of these various activity levels. The model by Camus *et al*. (2009) is in line with Porter (1985)'s model, but it incorporates an additional activity in the

middle of the value chain, namely engineering and construction. Figure 2.1 shows that the value chain is divided into two broad activities, namely: the upstream and downstream activities. The upstream activities are Mineral Resource related, with the primary function of finding and converting the identified Mineral Resource into a Mineral Reserve (Camus & Garcia, 2011). The main output of the upstream activities is a business plan that identifies the parts of the Mineral Resource that can be economically mined. This business plan is supported by a mine plan that consists of a mine design demonstrating the economic viability of extracting the Mineral Reserves. On the other hand, the downstream activities involve the execution of the business plan as set out during the upstream activities (Camus & Garcia, 2011). These activities are industrial in nature and commence with project management, responsible for the engineering and construction of the business plan. This is followed by the operational management activity, responsible for executing the production facet of the business plan. The final step in the mining value chain model concerns the realisation of the planned revenues through market development and sales of the final mineral product.

As noted by Camus and Garcia (2011), there was a belief in the mining industry that value is only created in the industrial-type downstream activities that directly determine revenue. However, Camus et al. (2009) challenged this view by proposing that value in mining is predominantly created during the upstream activities that focus on Mineral Reserve growth. According to Camus and Garcia (2011, p. 801), "*Mining companies are valued not according to earnings so much as assets, and so factors such as material reserves and production must be taken into account*". Thus, TSR in the mining context equates to dividends paid plus variations in business share price over the production output plus variations in Mineral Reserves. A simplified measure of value in the mining industry was proposed by Moles and O'Regan (2002) and is denoted by Equation 1:

$$Expected\ value = (Expected\ revenue - Expected\ costs) \times Risk\ factor \qquad (1)$$

Several factors affect the overall design and productivity and, in turn, the shareholder perceived value of mining projects. One of these critical factors is corporate governance that has direct input into downstream activities, according to Camus *et al*. (2009)'s model. Investopedia (2019) defines corporate governance as a system of rules, practices and processes by which a firm is directed and controlled. This set of guidelines that steers the firm is created and driven by a company's board of directors. The directors become the indirect proprietors of all the resources under their control

which may instil beliefs of profitability, reliability, integrity, accountability and transparency (Investopedia, 2019). These proprietors have the primary function of balancing the interests of a company's many stakeholders, including shareholders, senior management executives, customers, suppliers, financiers, the government and the community.

Nieponice *et al*. (2019) reported that industry circumstances have greatly improved since the last commodity price super-cycle slump that occurred in 2008 and 2009. These prevailing conditions should inspire mining companies to develop value creation strategies that create positive TSR throughout the entire mining value chain, independent from commodity prices. These strategies include:

- Securing long-term value creation through profit margin expansions to ensure profitable growth;
- Increasing productivity through the application of new technologies, ensuring the sustainability of current cashflows by offsetting expected cost increases with efficiency increases;
- Securing future growth options by favourable positioning of mining projects and funding capacity that targets constant growth (organic or inorganic), even in countercyclical environments;
- Taking a value-driven approach (Lean project design / "*Fit for Purpose*" – CAPEX; improved construction planning; implementation of newest and latest available technologies) to project evaluation, selection and execution; and
- Considering various new approaches to social and policy challenges.

Hutton (2018b) noted that production rates of mining projects differ under different market conditions. This can be attributed to the strategies implemented by the directors of a mining company, such as the value creation strategies (Nieponice *et al*., 2019). Hutton (2015) observed this during the commodity price super-cycle when mining companies "…*responded rapidly by prioritising capacity expansions to capture greater market share*." (Hutton, 2015, p. 115). One such example was when Anglo American Platinum decided to increase their metal output capacity by 75% in seven years, from 2 million ounces to 3.5 million ounces (Hutton, 2015). This increase in volume was driven by the belief that increased production levels would result in greater profitability and efficiency through the effects of economies of scale (Hutton, 2015). Corporate

governance, therefore, does influence the determination of the production rate of a mining project and, ultimately, TSR through the implemented strategies.

2.3 Production rate and factors that affect production rate

Mining projects are commonly valuated by determining their NPV through DCF modelling (Neingo *et al.*, 2018). Revenue is one of the significant input factors that determine the NPV of a mining project and is significantly driven by production rate, among other factors. Dalheimer *et al*. (2007) emphasised the need to incorporate the optimal production rate during the valuation of a mining project, considering it as a key driver of revenue generation in a mining company. The production rate of an operating mine and its capacity to produce is affected by various factors (i.e. upstream and downstream) in the mining value chain (Neingo *et al.*, 2018). These include the implemented mining method, development infrastructure placement, equipment selection and utilisation, access method and the ore handling systems in place. For example, a mine will only be able to produce its planned production when the ore handling system is executed as per design intention.

Cavender (1992) defines an optimal production rate as the rate where NPV or IRR is maximised. Mining companies are price takers (Neingo *et al.*, 2018); hence the only way they can maximise profits is by controlling production output and costs. Production output may be a downstream value chain activity along with cost control. However, it is determined during the upstream activities when the initial business plan is established. Production output during the downstream activities can only be manipulated to a marginal extent during the operational phases before falling outside the original design intent. This causes incorrect sizing of underground and surface infrastructure (Smith, 1997), resulting in additional capital expenditure to expand the mining operations. Hence, it is critical to determine an optimum production rate during the upstream activities in the mining value chain. This will ensure accurate evaluation of the orebody during the initial stages of the mining project through maximising project NPV and IRR. Additionally, it will also inform the decision-making associated with the orebody during the upstream and downstream activities (Smith, 1997). The optimum production rate will lower unit operating costs by translating the project costs into economies of scale, which improves the overall profitability of the mining project (Neingo *et al.*, 2018).

2.4 Production rate determination methods

There are various accepted production rate determination methods used to estimate the production rates of mining operations. Tatman (2001) grouped these methods into three main categories. These categories are empirical formulae, economic optimisation and general input requirements. This research categorises the methods into three categories: tonnage-based modelling, microeconomic modelling, and marginal-analysis modelling. These methods have been widely used in the mining industry, and they present unique solutions for unique characteristics associated with different Mineral Resources, commodities and mining methods. However, not all of the aforementioned methods apply to each mining project or Mineral Resource. This is due to differences in physical characteristics of mining deposits in relation to the original orebodies used during the establishment of the formulae (Neingo, *et al.*, 2018). This is especially prevalent in tonnage-based modelling methods. The different methods are discussed in the following subsections.

2.4.1 Production rate determination by total Mineral Resource tonnage only

Taylor's method

Models used to determine the production rate by utilising the total Mineral Resource tonnage only (although limited to one parameter) have proven useful. Taylor (1977, p. 203) developed a rule of thumb after noticing that "*supposedly optimum mining rate has long been estimated by elementary economic theory, usually by present-value methods, but it has been observed that many such exercises show a bias towards high rates of working that are unachievable or undesirable in practice*". The original Taylor's formula is denoted by Equation 2 (Taylor, 1977):

$$Mining\ rate\ \left(\frac{Mt}{day}\right) = a\ x\ Tonnage^{(b)} \qquad (2)$$

Where *a* and *b* are constants and (tonnage) is the total expected Mineral Resource tonnes. The formula was derived by utilising data obtained from several operating mines.

The original Taylor's formula circumvents the high production rate challenge associated with present value production rate determination methods. However, one of the significant limitations of this method is that it was derived from expansive, mostly young mines and a database consisting of mines with differing orebody and mining conditions (Baruti, 2018). McSpadden and Schaap (1984) noted some deviations in industry practice after applying the original Taylor's formula to

porphyry copper deposits being mined. They attributed the deviations to variations in Mineral Resource grades, infrastructural requirements and differences in the taxation models applied.

Tatman (2001) gave three reasons for deviations from the original Taylor's formula. The first factor concerns the type of support units installed as primary and secondary support as well as the intervals at which they are installed. The type of support is dictated by the in-situ rock mass conditions. The second factor involves access to Mineral Resource. Some Mineral Resources outcrop on the surface, enabling immediate access to revenue-generating mineral ore that can be exploited as part of the initial development activities. Other Mineral Resource orebodies are deposited deeper underground, making access to the revenue-generating mineral ore more complex with costly infrastructure requirements. The third factor concerns the production capacity constraints faced by mines. These include ore handling systems' ability to bring the mined ore to the surface, mining method efficiencies, and production face availability, to name a few. These factors result in different magnitudes of cost, making the comparison between different mining commodities and individual mines less accurate in applying the original Taylor's formula. Long (2009) attributed the deviation between industry actuals and Taylor's formula to dissimilar technologies required to extract different Mineral Resources. Dalheimer *et al*. (2007) argued that rule of thumb estimation models used for production rate determination did not consider the market influence on the outcome of a mining project. The rules of thumb methods just assumed that there will always be a demand in the market for the mineral product and capital for implementing these projects (Neingo *et al.*, 2018).

Modifications to Taylor's method

Since its development, Taylor's formula was adjusted for several Mineral Resource characteristics by incorporating data obtained from the respective Mineral deposits and mining operations. Table 2.1 shows the chronological modifications of Taylor's formula.

Table 2.1: Summary of the chronological development of tonnage-based models

(Source: Baruti, 2018)

S/N	Source or scholar	Mine Type	No. of Mines	a	b	Model
1	(Taylor, 1977)	Mining projects	30	0.0143	0.7500	Production $(\frac{Mt}{day}) = 0.0143\ x\ Tonnage^{(0.75)}$
2	(Long, et al., 1998)	Open Pit gold/ silver	41	0.4160	0.5874	Production $(\frac{Mt}{day}) = 0.416\ x\ Tonnage^{(0.5874)}$
3	(Long, et al., 2000)	Underground – massive sulfide	28	0.0248	0.7040	Production $(\frac{Mt}{day}) = 0.0248\ x\ Tonnage^{(0.704)}$
4	(Long & Singer, 2001)	Open-pit copper mine	45	0.0236	0.7400	Production $(\frac{Mt}{day}) = 0.0236\ x\ Tonnage^{(0.74)}$
5	(Long & Singer, 2001)	Open-pit/block caving-other	342	0.1230	0.6490	Production $(\frac{Mt}{day}) = 0.123\ x\ Tonnage^{(0.649)}$
6	(Long & Singer, 2001)	Underground –other	197	0.2970	0.5620	Production $(\frac{Mt}{day}) = 0.297\ x\ Tonnage^{(0.562)}$

In addition to the modified versions of Taylor's rule of thumb, Tatman (2001)'s formula makes provision for mining production rates on a vertical drop-down basis. Tatman (2001)'s formula is based on applying different formulae developed by different authors on the same steeply Mineral Resource. Figure 2.2 shows the annual production rate per respective formula. Notably,, the applied formulae did not yield a correlated outcome, which emphasised the necessity for revising the formula.

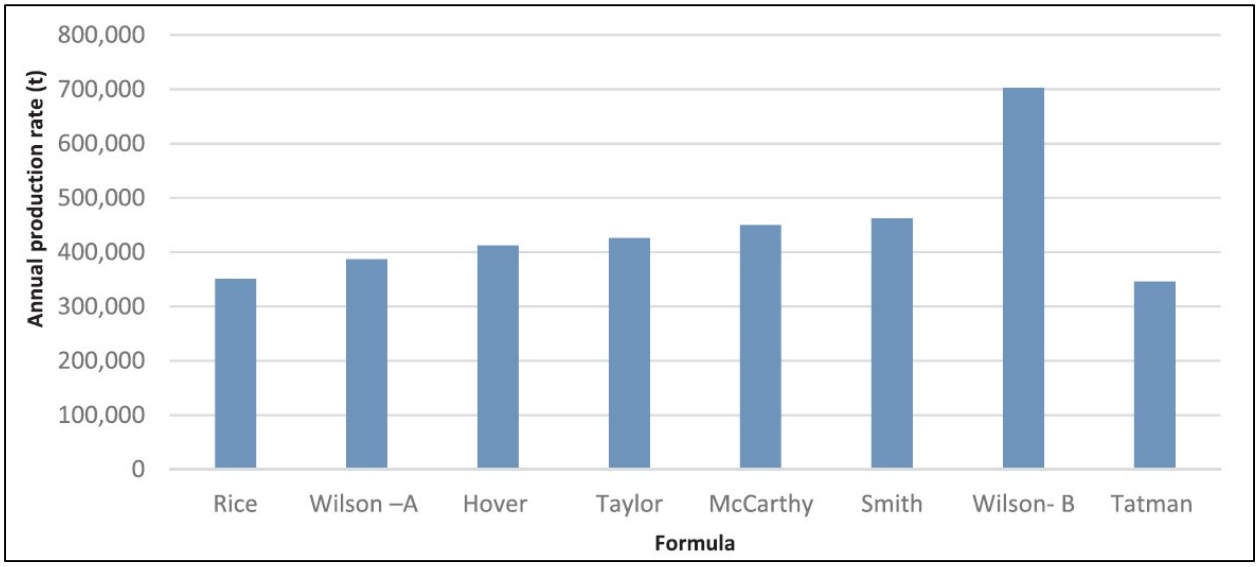

Figure 2.2: Variation in production rate by empirical formula

(Source: Tatman, 2001)

The modification by Tatman (2001) is shown in Equations 3 and 4:

$$Mining\ rate\ \left(\frac{Tonnes}{Anum}\right) = Rate\ factor\ \times\ rate\ multiplier \qquad (3)$$

$$Mining\ rate = \frac{1}{2}\ x\ \frac{Tonnage}{Depth\ (ft)} \qquad (4)$$

Equation 4 is a half vertical tonnage-based model used to determine the production rate for a steeply dipping, mechanised mine. Geometry based production rate determination formulae were not used in this research because the orebody utilsed in the case study is not steeply dipping.

Neingo *et al*. (2018) compared the results obtained from applying three production rate determination formulae or rules of thumb on actual Southern African platinum producing mines. The three rules of thumb formulae applied during Neingo *et al*. (2018) are the economic rents, minimum life of mine and the tonnage-based formulae. Their study found deviances of up to 218% when applying the three rules of thumb in relation to the investigated mining operations' actual production rate. They also established that weak correlations exist between the results obtained from formulae and actual production outputs declared by mining companies for their respective mining operations. Neingo *et al*. (2018) concluded that the characteristics of a Mineral Resource could not be used in isolation when applying the rules of thumb in estimating production rate. This is because several factors need consideration when determining the optimum production rate.

These factors include, but are not limited to, Mineral Resource grades, infrastructural requirements, taxation models applied, geotechnical considerations, access method – surface and underground, production capacity constraints, applied technologies, market conditions and access to capital. The study also concluded that the analysed mines did not utilise these rules of thumb in the sizing of the supporting infrastructure for the mines included in the dataset.

According to Neingo *et al.* (2018, p. 119), "*Optimisation, in general, involves either maximising or minimising an objective function against a given set of constraints*". The rule of thumb formulae, as applied by Neingo *et al*. (2018), did not correlate any linkages to any objective function. The formulae only determine a production rate based on the limited input criteria utilised with no optimisation process. Based on this premise, the rule of thumb formulae cannot be used for optimising the production rate of any mining project. However, they can be used in conceptual level studies where there is a lower level of confidence and engineering.

2.4.2 Production rate determination by Microeconomic modelling

Minnitt's economics of exhaustible resource

Minnitt (2007) reviewed the work done by Hotelling (1931) and realised that Hotelling (1931)'s work, albeit being ahead of its time, was more from an economist's perspective. The work was based on a set of assumptions that concluded into a model for the extraction of natural resources. The model did not represent the true reality of the minerals industry; therefore, it cannot be applied with accuracy in practice. Hotelling (1931) made seven main assumptions that did not represent the true reality of the minerals industry. The assumptions are listed below:

- The mining operation's owner aims to maximize the present value of profits;
- The mining operation operates in a competitive environment that is free from any influence on the commodity price obtained for produce;
- The mining operation's production capacity is not constrained in any way whatsoever;
- The mining operation's Mineral Resource has a capitalised value. Also, the Mineral Resources will be subjected to a function of scarcity through the notion of depletion. This will enable conferment of value on low graded Mineral Resources;
- The mining operation's Mineral Resource is homogeneously deposited, with no variance in grade expected throughout the LOM;

- The mining operation's costs incurred during production will stay constant throughout the LOM; and
- The mining operation's extraction method will stay constant with no technological advancements bringing forth efficiency improvements throughout the LOM.

Hotelling (1931)'s model ultimately assumed that the selling price of a mined mineral commodity must be based on the scarcity of that mineral commodity. In addition, the selling price should be equal to the interest rate for the mining project. Thus, a Mineral Resource can only yield a return to the owner, if it appreciates its value in future (Solow & Wan, 1976). This relationship is denoted by Equation 5 (Hotelling, 1931):

$$p = p_0 e^{\gamma t} \tag{5}$$

Where p represents the final price, p_0 represents starting price, t represents time, and γ represents the interest rate applied. From Equation 5, Hotelling (1931) defined the relationship between net profit, the initial selling price of mineral commodity and interest rate. Hotelling (1931) then determined the production rate at a specific time as a function of the selling price of the mineral commodity being mined and time. This is denoted by Equation 6 (Hotelling, 1931):

$$\int_0^T q\, dt = \int_0^T f(p_0 e^{\gamma t}, t) dt = a \tag{6}$$

Where q represents the production rate, and f represents the function required to calculate q. This method only considers economic factors with little appreciation for the capability or capacity of the Mineral Resource as well as changing input costs and market environments.

Minnitt (2007) identified seven factors on an industry level basis in the quest to determine the optimal production rate. Firstly, Solow (1976) established that the selling price of an exhaustible resource deposit would have to grow at a minimum rate of interest to appreciate in value. This implies that the current value of the Mineral Resource is equal to the present value of all future revenues minus all costs incurred associated with the extraction process thereof. Secondly, Minnitt (2007) noted that Solow (1976) identified that when the selling price of a mineral commodity rises at the rate of interest, the production rate for that Mineral Resource will remain constant. Thirdly, Minnitt (2007) observed that when the demand for the mineral commodity stays stable, the production rate steadily declines to a final point of zero. This is defined by Equation 7 (Minnitt, 2007):

$$Selling\ price\ =\ marginal\ cost\ -\ opportunity\ cost\ of\ depletion \quad (7)$$

The concept of scarcity and its impact on the production rate through dictation of the selling price is introduced at this point. The fourth factor by Minnitt (2007) is that in a monopolistic market environment, production rate will be retarded (Devarajan & Fisher, 1982). Hotelling (1931) held the view that the monopolist that raises the selling price of its product to create a demand for the said produce artificially will inadvertently slow the production rate. This is in direct opposition to a competitive market environment, where the owner of the Mineral Resource will take advantage of market conditions by depleting the Mineral Resource rapidly. Fifthly, Minnitt (2007) noted the consequences of aggregated production output on the selling price and the associated production costs (Solow & Wan, 1976). The cost of production increases as the cumulative production output increase. The oversupply at higher production costs will negatively affect the demand for the mineral product, and in turn, the selling price of the product will decrease. However, when this product is subjected to depreciation, the mineral commodity selling price will follow a U-shaped trajectory (Levhari & Pindyck, 1979).

The sixth factor that Minnitt (2007) identified was the effect that positive and negative uncertainty had on Mineral Resource estimates. A Mineral Resource owner who knows the extent of the owned Mineral Resource will be able to control the production rate more effectively. The owner will take advantage of the favourable market conditions by increasing the production rate and vice versa. Additionally, the owner will also be aware when the Mineral Resource is close to depletion and that its capacity is to fulfil market demand at such a time. Contrary, an owner who is not knowledgeable about the extent of the Mineral Resource will act more conservatively in the same market conditions. In addition, hereto, Devarajan and Fisher (1982) named three conditions that would impede consistent market demand and create additional market uncertainty. These three are advancements in the technologies utilised in the extraction, replacement, and expropriation of the Mineral Resource.

The seventh factor that Minnitt (2007) noted was the effect that the optimal production rate of Mineral Resources has on intergenerational equity. According to Minnitt (2007, p. 545), "*the main issue at stake is the rate at which mine owners and society would want to discount future consumer surpluses*". Sustainability in the mining industry is one of the contentions which emphasises the

divergence between social interests and Mineral Resource exploitation and, consequently, depletion. This is expressed in the form of discount rates that are applied to mining projects. If social discount rates are lower than private discount rates, it will lead to premature depletion of Mineral Resources. On the maximisation factors for an individual mine basis, Minnitt (2007) established that Hotelling (1931) took a different approach. The mineral selling prices were kept constant, resulting in a steadily declining production rate over time. Apart from this deviance, all other factors were common between the industry level and individual mine basis.

Minnitt (2007) also mentioned ways in which mining operations are affected during the optimisation of production rate. The first way is ignoring the fact that mines exploit finite capital assets. It, therefore, means that maximising the production rate requires marginal profit to be kept constant throughout each of the assessed periods. Secondly, there is a need to realise that the production rate of an exhaustible Mineral Resource is an investment challenge that is subjected to the investors' expected rate of return. This implies that a mining project or a Mineral Resource's perceived value is equal to or better than other investment opportunities. This requires that the economic rent obtained from the Mineral Resource be equal to or greater than the interest rate to make it a competitive investment opportunity. Economic rent should also not be much higher than the interest rate. This, in turn, will incentivise non-extraction based on having the Mineral Resource as an asset being more valuable in the ground than exploited. Thirdly, the condition of optimising production rate is affected by the availability of a Mineral Reserve. Ultimately, mining only becomes attractive when the mineral selling price exceeds the marginal cost by an amount equal to or greater than the scarcity rent or Hotelling rent (Hotelling, 1931). Equations 8 and 9 depict this premise (Minnitt, 2007):

$$p = MC\ (q_t)\ +\ \lambda \quad or \quad \lambda = p -\ MC\ (q_t) \tag{8}$$

Where p is Hotelling rent, λ is scarcity rent, *MC* represents marginal cost and q_t represents the quantity mined in time period *t.*

$$r = \frac{(p - MCq_{t+1}) - (p - MCq_t)}{(p - MCq_t)} \tag{9}$$

Where *r* is Hotelling's r-percent rule, *p* is scarcity rent, *MC* represents marginal cost and q_t represents the quantity mined in time period *t***.** Minnitt (2007) proposed an integrated modelling technique in which economies of scale would be reached at some point. After reaching economies

of scale, diseconomies of scale would be encountered once progressing beyond an optimal point of production. Minnitt's (2007) integrated modelling technique considers micro and macro-economic factors when determining the optimum production rate. This is depicted by a U-shaped cost curve. The cost curve depicts the essential operational concepts closely linked to the efficiency and competitiveness of a business, namely the economies of scale. It represents the relationship of the unit cost of a business as the production output of the operation increases (Hutton, 2015). Figure 2.3 shows the U-shaped cost curve of an operation.

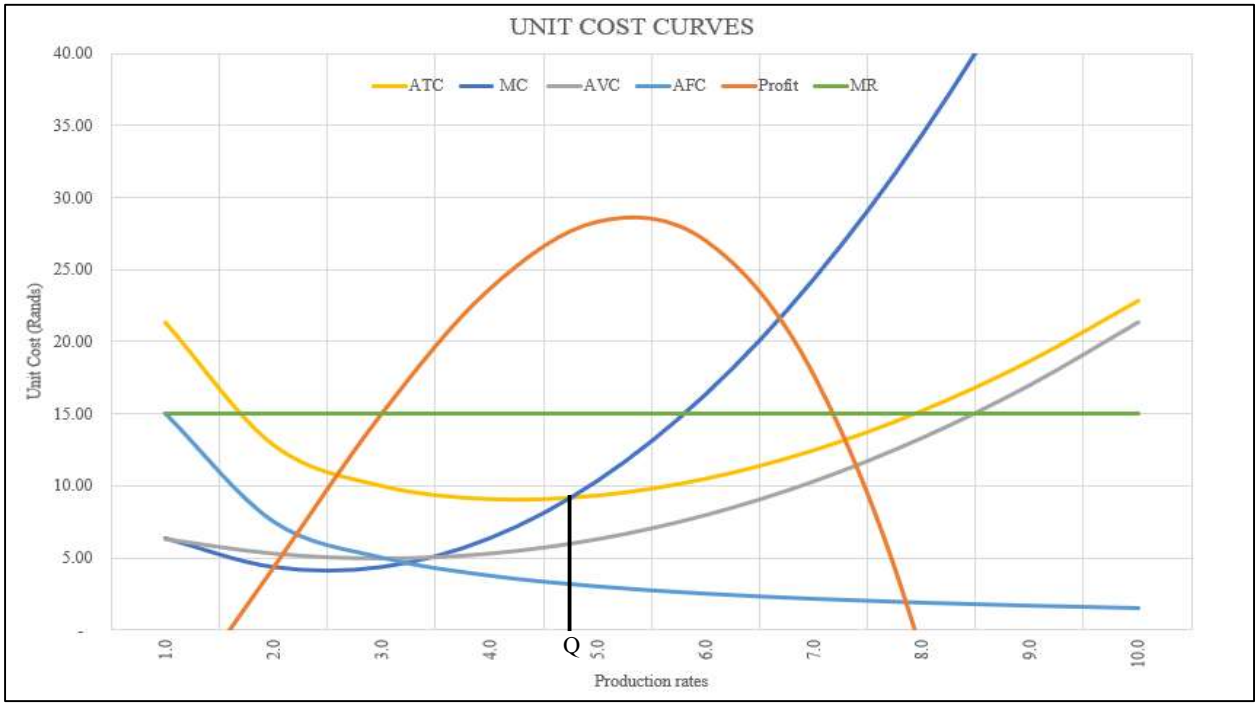

Figure 2.3: Basic economies of scale

(Source: Minnitt, 2007)

Figure 2.3 shows that the average fixed cost (AFC) decreases as production output and the average variable cost (AVC) increases. Marginal cost (MC) is the change in the total costs from increasing output by one unit and is linked to the marginal productivity associated with the increase in production output. The average total cost (ATC) decreases as the production output increases until it reaches point *Q*, where economies of scale are reached. After point *Q*, the ATC increases and, in turn, signals that a dis-economies of scale is reached for the associated production rate. Equation 10 denotes Minnitt (2007)'s alternative hypothesis of cost response, where *FC* represents fixed costs, and *q* is the production rate:

$$TC = FC + 8q - 2q^2 + 1/3q^3 \quad (10)$$

Figure 2.4 shows an example of Minnitt (2007)'s proposed model done by Hutton (2015), where the *FC* was made to be ZAR15 with the revenue at ZAR15. Equation 11 is used to calculate total revenue (TR):

$$TR = 15 \times q \quad (11)$$

When extrapolating the equations for various production rates, in Figure 2.4, the total cost curve does not follow a linear but rather a concave path. Another point that is noted is that beyond 8.5 production units, profits become negative. Therefore, no economic benefit is yielded beyond this point.

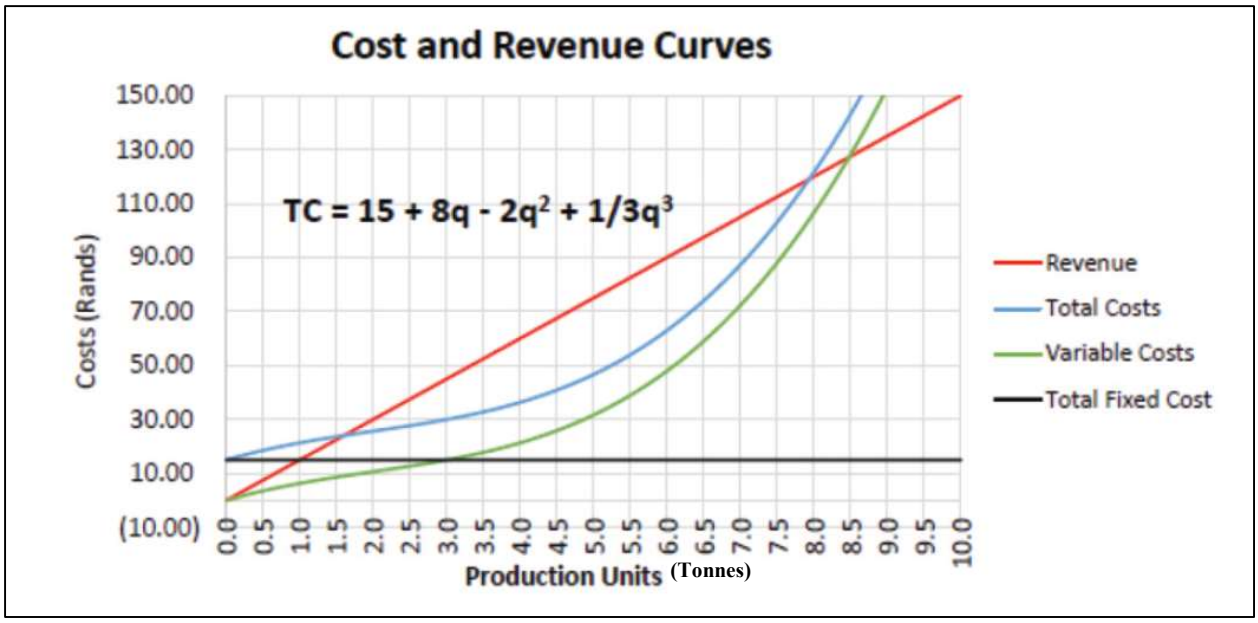

Figure 2.4: Absolute cost and revenue curves

(Source: Minnitt, 2007)

Working this same example back to unit costs and displaying it on a unit cost curve is depicted in Figure 2.5.

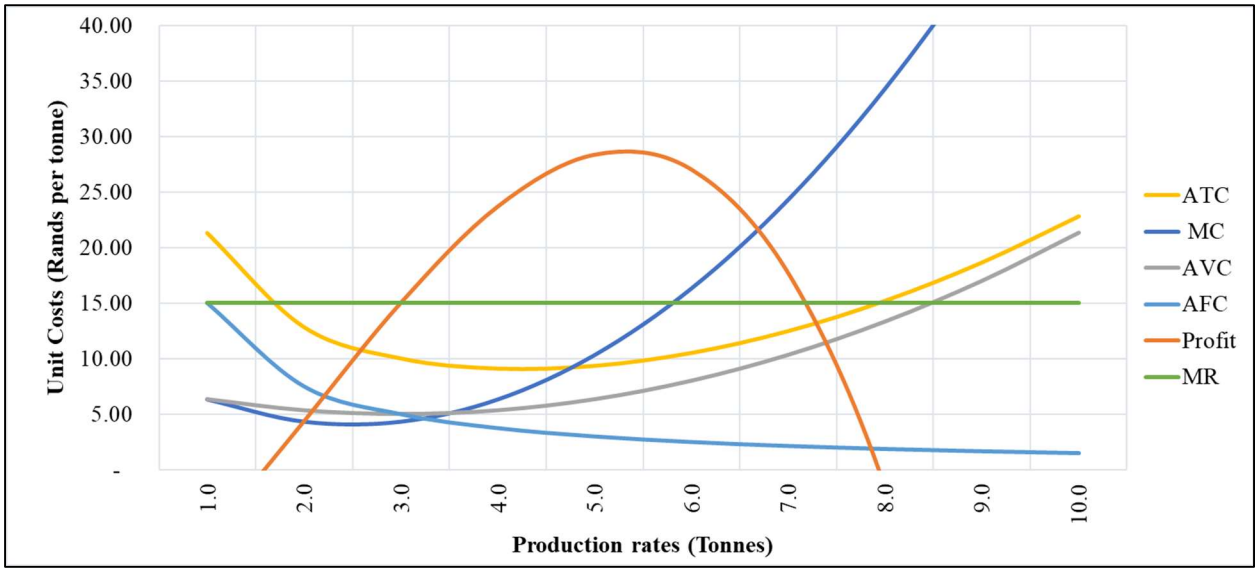

Figure 2.5: Microeconomic U-shaped unit cost curve

(Source: Minnitt, 2007)

Hutton's optimisation of the extraction of an exhaustible resource (Hutton, 2015)

During the commodities price super-cycle from 2003 to 2011, the mining industry focused more towards a production-volume-at-any-cost business model (Hutton, 2015). This production over efficiency business model was tested beyond breaking point when the commodity price slump was encountered in 2009. According to Hutton (2015), this demoted the global mining industry to a demeaned, low valued, poor producing sector that had to find the correct balance between existing operations and future opportunities. However, during the price boom, the same investors pushing for high production outputs and cost controls with disciplined capital allocation, also rewarded producers with the most attractive project expansion (Hutton, 2015).

Hutton (2015) considered an alternative approach by analysing the main issues that affect the industry. This was done by revisiting the micro-economics of the mining business and the established concepts to consider for the optimal economics of exhaustible Mineral Resource. The main point highlighted by Hutton (2015) underscored the short-term gains made by cost reduction programs. These cost reduction programs managed in controlling the cash cost incurred during the production phase of the mining value chain. This practice was a display of corporate governance to create value in the downstream mining value chain activities at their disposal. However, long-term sustainability is dependent on the improvement of efficiency in the current mining operations. By prioritising production output, Hutton (2015) demonstrated that the fatal flaw lay in exceeding

the minimal gains in mineral rents to be made by surpassing the production rate equivalent. Hutton (2015) achieved this demonstration through the microeconomic modelling of the cost curves technique. On the curve, the optimal production rate is reached when the MC curve intersects the ATC curve. This means that when the MC incurred for an additional production unit becomes greater than the ATC, no marginal gain can be made (Minnitt, 2007). Hutton (2015) reviewed and broke down the work done by Minnitt (2007) into three components. These are:

- Part 1 - Prioritising of production rate;
- Part 2 – Modelling of production rate; and
- Part 3 - Integrating production rate with microeconomic Mineral Resource modelling.

Part 1 focuses on prioritising production rate and how it is affected by the commodity price super-cycle or commodity price slump. Hutton (2015) looked at how investors rewarded the mining company with the most appealing expansion projects during the commodity price super-cycle. Hutton (2015) also identified that during the commodity price slump followed by the super-cycle, the same investor reduced their risk aversiveness by demanding a better return on investment. The commodity price super-cycle created an environment where companies pursued amplified profitability through escalated production rates. This ignored the premise of diseconomies of scale in the pursuit of economies of scale, which ultimately resulted in the increase of unit operating cost way beyond the prospects of any gains to be made (Hutton, 2015). Hutton (2015) looked at methods supporting the prioritisation of production at all costs, which included the regression curves developed by Rudenno (2009) during the commodity prices super-cycle. Rudenno (2009)'s microeconomic curves support the premise of continued economies of scale through increased production rate. The curves entail the microeconomic theory concepts of MC, AVC, AFC as well as ATC. Figure 2.6 depicts Rudenno (2009)'s cost curve or power curve.

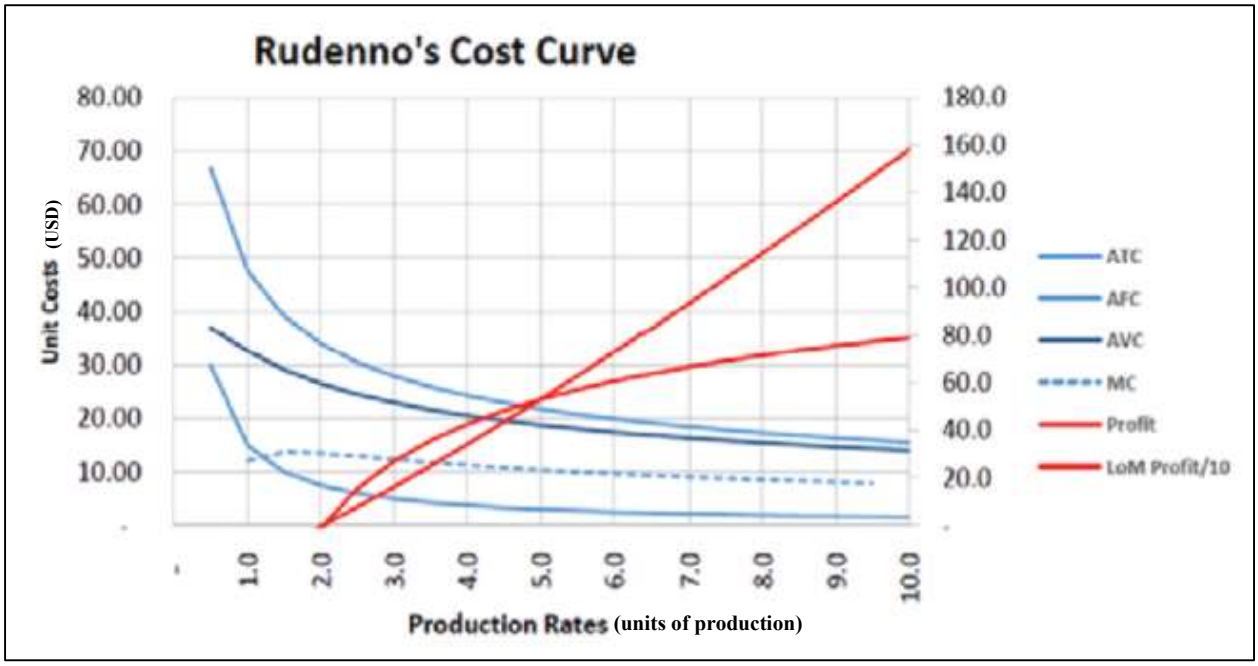

Figure 2.6: Rudenno's power curve

(Source: Hutton, 2015)

Figure 2.6 shows that the ATC, AFC and AVC decrease as the production rate increases, which shows that companies prioritised production at all costs during the commodity super-cycle. The second part of Hutton (2015)'s work focuses on production rate modelling and the possible econometric techniques from which the U-shaped cost curves can be derived. According to Hutton (2015), Minnitt (2007)'s work was not readily adopted by the industry because of the complex mathematics involved. This, however, is not such a significant obstacle to overcome based on today's computing capacity brought on by technological advancements. With Minnitt (2007)'s complex mathematics hidden in graphical representations, today's computers can easily be applied to support this hypothesis. According to Kohler (1992), three micro-economic functional forms are encountered when applying microeconomics.

The first form is the continuous economies of scale (Figure 2.6). The second form is the economies/diseconomies of scale (Figure 2.5). The third form, which was not considered in Hutton (2015)'s work, is the constant economies of scale. Hutton (2015) proved Minnitt (2007)'s method on a real-world case study by applying the standard single-equation linear regression analysis technique. This resulted in the cost curves, as depicted in Figure 2.7. Hutton (2015) also derived an optimal production rate of 265 ktpm, at the point where the MC curve intersects the AC curve.

In the context of the work done by Minnitt (2007) and Hutton (2015), any production rate above 265 ktpm will yield increased unit costs.

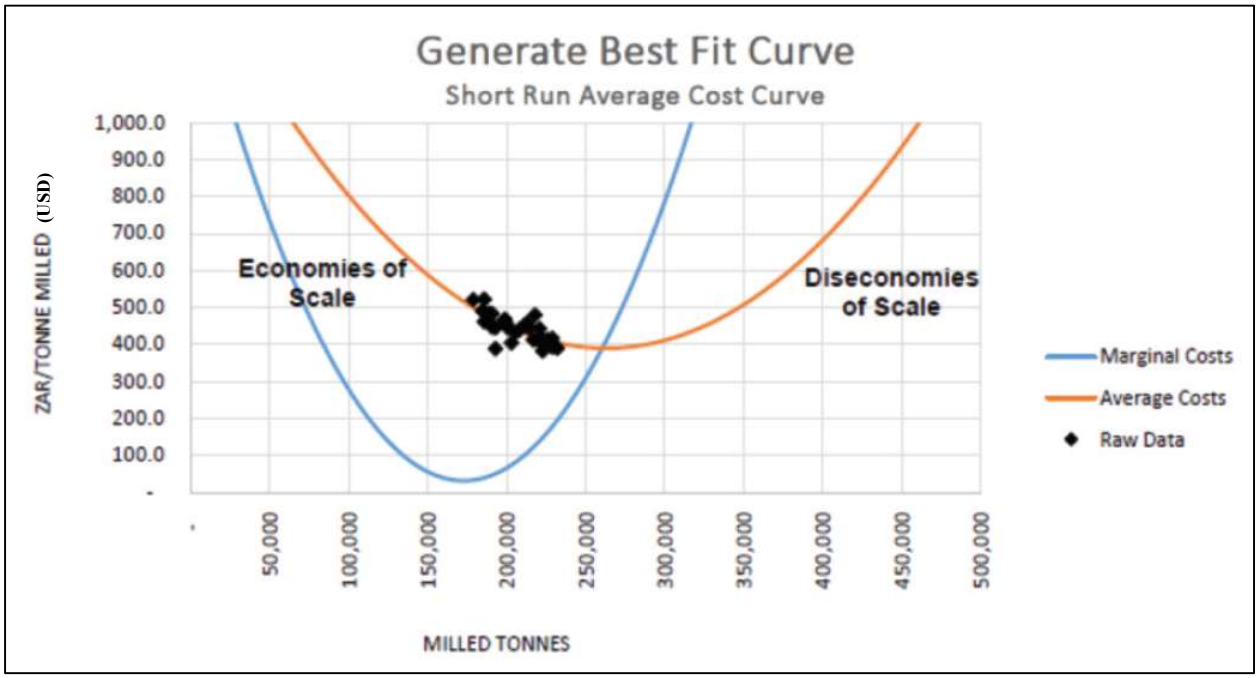

Figure 2.7: Generated best-fit curve of real-world example

(Source: Hutton, 2015)

The third part of Hutton (2015)'s work focused on integrating production rate with economic Mineral Resource modelling. Minnit (2007)'s work defined the optimal rate of extraction isolated from the economics associated with an exhaustible resource. Hutton (2015) addressed this by integrating Minnit (2007)'s work with the cut-off grade for an exhaustible resource and, in so doing, determined the maximum grade and NPV for that Mineral Resource. This is done by applying a three-dimensional (3D) optimisation technique incorporating the (GTC) that calculates the optimal cut-off grade for that respective Mineral Resource. A GTC is a unique signature or fingerprint of a Mineral Resource. Figure 2.8 depicts a typical GTC.

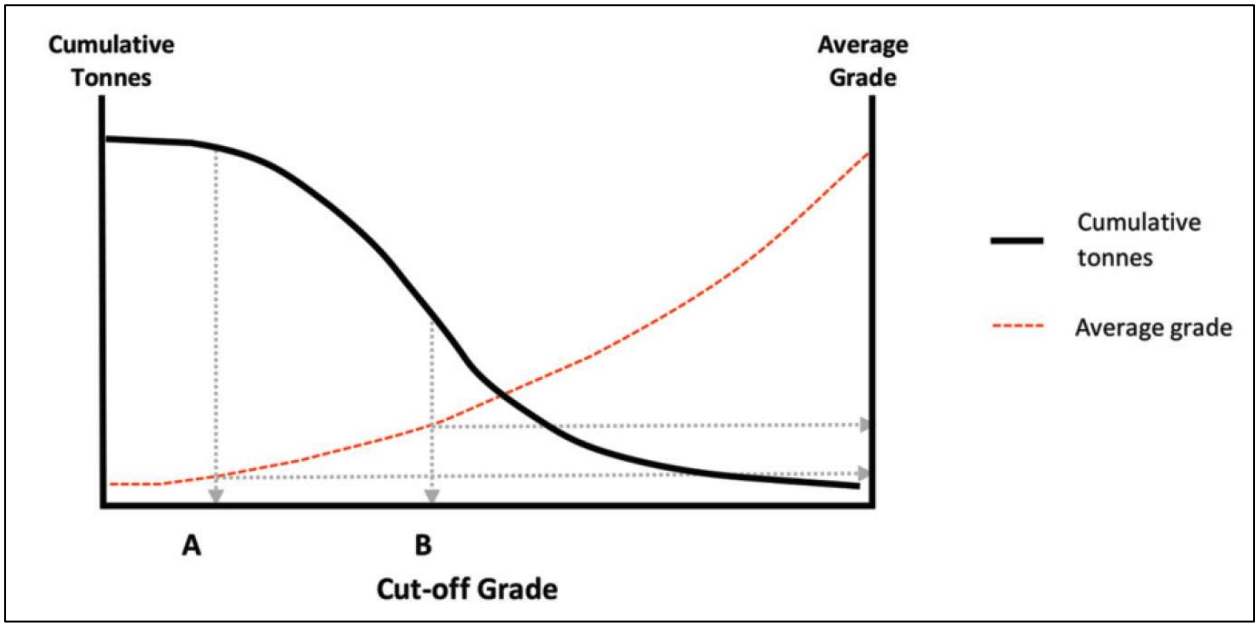

Figure 2.8: A Typical Grade Tonnage Curve

(Source: Hutton, 2015)

According to (Hutton, 2015, p. 1092), "*A GTC graphically profiles the cumulative distribution of grade to tonnage and shows at lower cut-offs (Point A) that utilisation of an exhaustible resource is high with a corresponding high payability and by implication rates of development are low as selectivity is low, but the opposite is true at high cut-off grades (Point B)"*. Figure 2.9 depicts the integration of microeconomic principles into the GTC for a real-world project. This was done to obtain the cut-off grade where maximum profit is realised under the applied constraints, which is at 2.1 grams per tonne (g/t) for this case study.

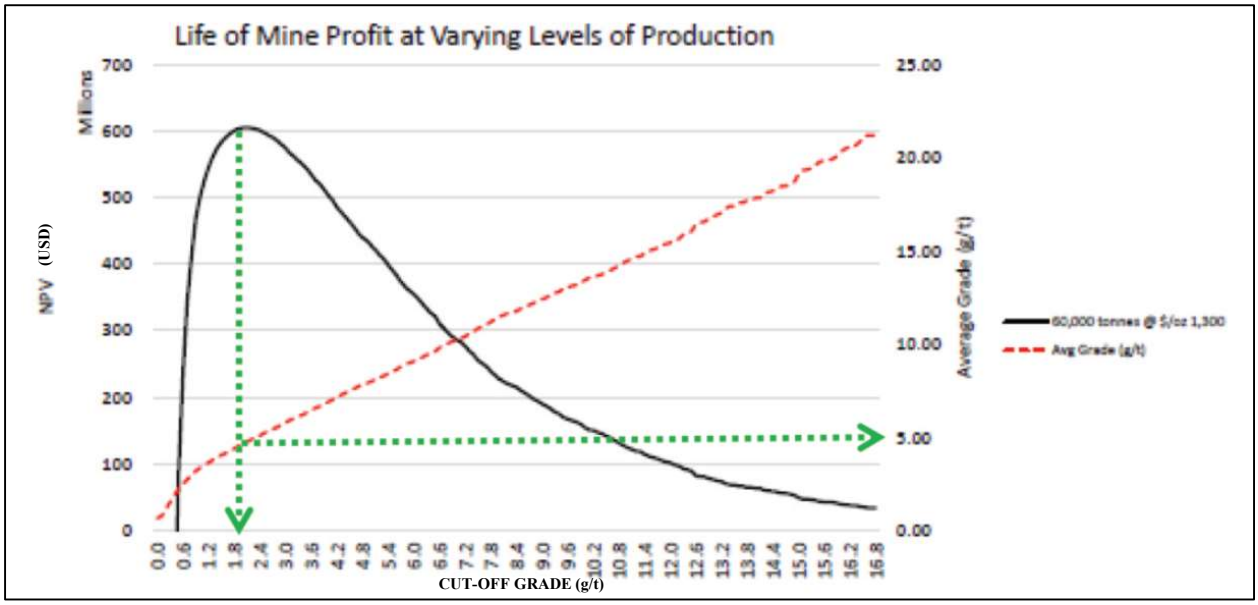

Figure 2.9: Graphical representation of LOM profit

(Source: Hutton, 2015)

Hutton (2015) excluded the cost of capital during his analysis of the optimal cut-off grade. Incorporating the cost of capital when determining an optimal cut-off grade may disproportionately escalate the cut-off grade by reducing the Mineral Resource's payability. Capital and economic factors in a mining project are only subtracted from the obtained NPV in a process that uses this model outputs as inputs. This will, in turn, result in the maximum NPV for the project as a whole. Hutton (2015)'s model can be used to run sensitivity analyses on production rate, the unit cost of production, mineral selling price and even mining methods with different extraction ratios. The results obtained are subjected to the U-shaped cost curves outputs and finally related back to the Mineral Resource. Hutton (2015)'s model considers the effects of the economies of scale and that of the economies of an exhaustible resource. All these various input variables can then be incorporated into one model, with the results obtained depicted on a 3D graph depicted in Figure 2.10.

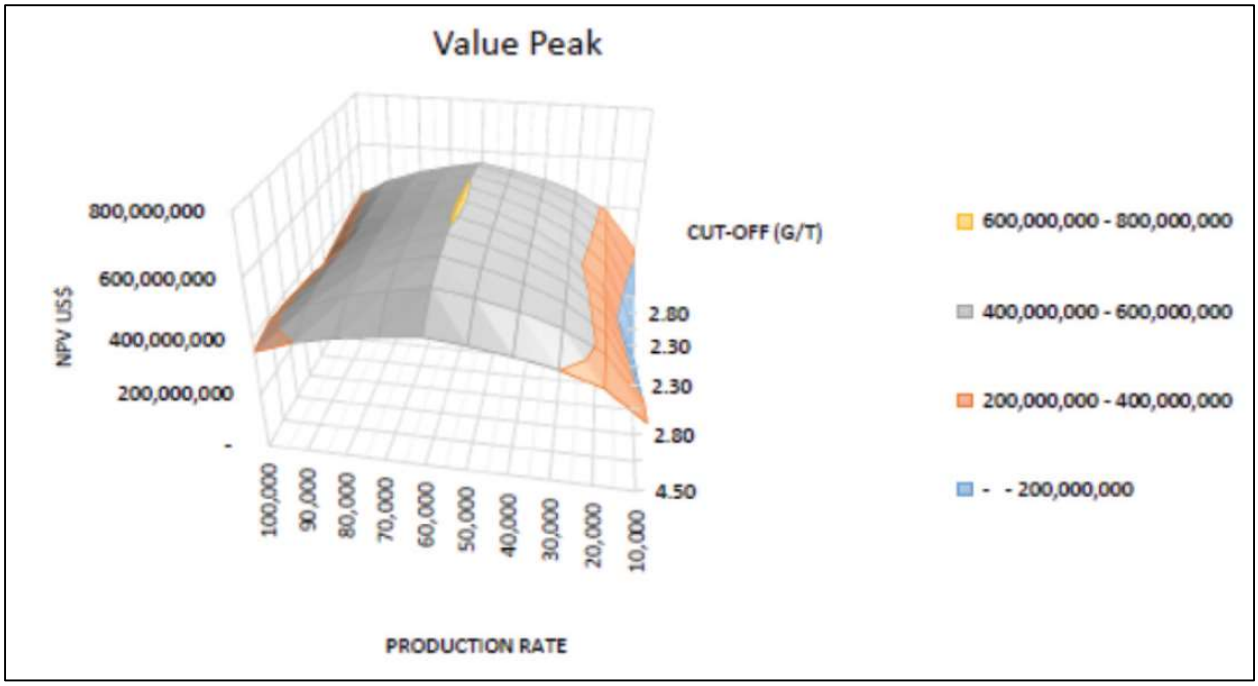

Figure 2.10: Three-dimensional modelling

(Source: Hutton, 2015)

The 3D graph is the culmination of the process of integrating the effects of the U-shaped cost curve on the overall outcome of the mining project. In conclusion, Hutton (2015) derived the premise that ignoring the U-shaped cost curve during mine design and operation leads to overcapitalisation and higher costing operating mines during steady-state production. This was further supported by a study done by Price Waterhouse Coopers (PWC) (2014). This study utilised Hutton (2015)'s model in determining the optimal production rate for the reviewed mining. Hutton (2015)'s work is an evolution of Minnitt (2007)'s work considering that it utilises the economies/diseconomies concept through the incorporation of Equations 10 and 11 into his work. Hutton (2015)'s work advanced the economies/diseconomies concept through 3D integration of the findings from unit cost curves obtained with the Mineral Resource's GTC.

2.4.3 Marginal-analysis modelling technique

The size of a Mineral deposit determines the production rate, which in turn determines the ability to generate revenue and create value in the mining project (Sabour, 2002). The production rate also influences the initial capital layout, annual revenues and annual operational expenditure, along with determining the LOM (Wells, 1978). If the production rate is lower, less infrastructure required to mine the deposit. This will result in a smaller initial capital investment required for the smaller

mine. The smaller mine, in turn, will bring about a lesser ability to generate revenue and, ultimately, a lower expected return over a more extended period. Contrary, the higher the production rate, the more the infrastructure required for the bigger mining operation. The bigger mine will require a higher initial capital spend to fund the start-up of the mine. It will have a longer build-up to steady-state production and a more prominent ability to generate revenue in a shorter period than that of a smaller mine for any given mineral deposit. If the production rate is too low, it may impede the mining operation's ability to repay the initial capital investment at a higher discount rate. Contrary, if the production rate is too high, it may undermine the mining operation's overall economics with a high risk of not achieving the business plan when a delayed start is encountered (Sabour, 2002). Thus, there exists more than one production rate that can be applied to a mining project. Smith (1997) determined that the optimal production rate of any mining project lies within an optimum range of production rate. The lower limit of the range is dictated by the point at which the cash flow of the mining project can repay double the amount of the initial capital investment. The upper limit of the range is dictated when maximum NPV is achieved from the cash flow.

Sabour (2002) developed a marginal-analysis model based on the assumption that the production rate of a mine is optimised when the present value of marginal cost (PVMC) value is equal to the present value of the marginal revenue (PVMR). According to the microeconomic theory, the point at which the PVMR equals the PVMC is the point where the production rate will maximise NPV of a mining project investment. The marginal-analysis equation is denoted by Equation 12 (Sabour, 2002):

$$PVMC = PVMR \tag{12}$$

Equation 13 is used to calculate PVMR (Sabour, 2002):

$$PVMR = e^{-\alpha \times d} \times \frac{N \times P \times G_r \times R}{\alpha} \times \left(1 - e^{\frac{-\alpha \times R_e}{N \times P_r}} \left(1 + \frac{\alpha \times R_e}{N \times P_r}\right)\right) \tag{13}$$

Where N is the number of working days per year, P is the metal selling price, Gr is the average ore grade, R is the processing recovery, d is the pre-production construction period, Re is the reserve tonnage. Pr is the tonnes per day production rate, and α is the difference between the risk-adjusted nominal discount rate and the expected growth rate of the mineral price. Equation 14 is used to calculate PVMC (Sabour, 2002):

$$PVMC = MCC + e^{-\delta \times d} PVMOC \quad (14)$$

Where *MCC* is the marginal cost of capital, δ is the difference between the risk-adjusted nominal discount rate (μ) and the expected annual increase of operating cost (*gc), d* is the pre-production construction period and *PVMOC* is the present value marginal operating cost.

When PVMR is higher than PVMC, then the mine's production rate is undersized, and the mine's production rate has to be increased. This means that at all production rates where PVMR is more than PVMC, the incremental increase in production rate will still yield a profit equal to the difference. This profit will be realised up to the point where PVMR equals PVMC. When PVMR is lower than PVMC, the mine's production rate is oversized and must be reduced accordingly. Consequently, it means that for all production rates where PVMC is higher than PVMR, a loss is recorded equal to the difference. Figure 2.11 is a graphical representation of PVMR and PVMC behaviour.

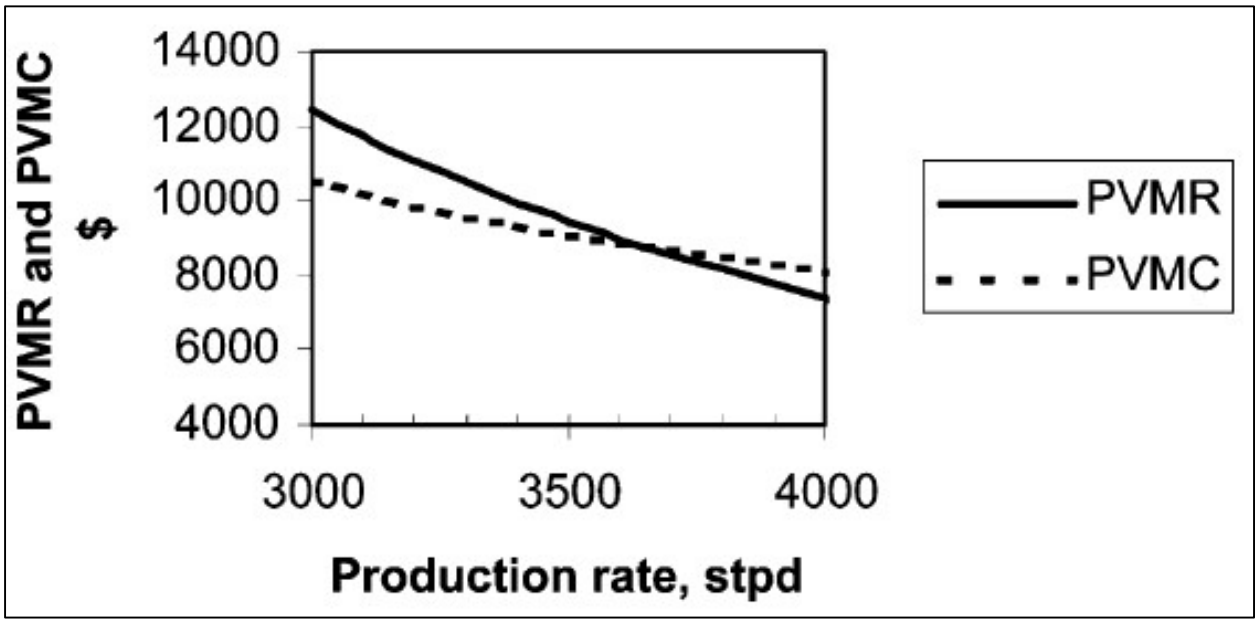

Figure 2.11: The optimum production rate at PVMR = PVMC

(Source: Sabour, 2002)

Sabour (2002)'s microeconomic theory considers the following factors associated with mining projects:

- Physical characteristics associated with the Mineral Resource;
- Economic factors; and
- Financial factors.

The physical characteristics that are considered include the reserve tonnage and the ore grade of the Mineral Reserve. The Mineral Reserve tonnage increase as the production rate increases. This is in line with work done by Wells (1978) and Smith (1997), and the conclusion is reached that the production rate has a direct relationship with the Mineral Reserve size. The second physical characteristic that is considered by Sabour (2002) is the Mineral Reserve grade. As the overall grade increases, the ability to generate more revenue per unit mined also increase. This indicates that grade also has a direct relationship with the production rate of a mine. This conclusion, however, does contradict the work of Wells (1978), who claims that the optimum production rate is independent of the grade and profit generation per unit of extraction. This deviance is attributed to applied optimisation criteria. Wells (1978) assumed that the profit per unit is independent of the production rate and used the present value ratio (PVR) as the optimisation criterion. The PVR method is defined by Equation 15 (Wells, 1978):

$$PVR = PVOUT/PVIN \tag{15}$$

Where *PVOUT* is the present value of positive cash flow, *PVIN* is the present value of negative cash flow. For a *PVR* of less than one, it specifies a substandard return on investment condition. For a *PVR* equal to one, a moderate or acceptable return on investment condition exists. For all *PVR* results greater than one, a condition greater than the minimum acceptable requirement exists.

The first economic factor that Sabour (2002)'s model considers is commodity price. As with the increase of Mineral Reserve grade per unit extracted, the increase in commodity price increases the revenue generated per single unit extracted. Hence, production rate also has a direct relationship with commodity price. The second economic factor is the expected rate of change associated with commodity price of the mined commodity. As the mineral commodity price is subjected to supply and demand, it is anticipated that the price will change throughout the LOM. The expected commodity price growth rate has an inverse relationship with the optimum production rate (Sabour,

2002). This is because the opportunity cost associated with mining a Mineral Reserve at a later stage is higher or lower than mining it at present. This opportunity cost is subjected to a discount rate associated with the mining project, decreasing as the discount rate increases and vice versa. The third economic factor is the expected rate of change associated with the cost of mining a Mineral Reserve due to inflation and other expected factors. It is expected that the cost of mining a Mineral Reserve will increase on a year to year basis. If the expected rate of change is high, the optimal production rate tends to be higher to avoid the rapid increase in costs in the future. This will favour a shorter LOM, whereas a lesser increase will favour a lower production rate and consequently a longer LOM.

The third factor that Sabour (2002)'s model considers are the financial factors associated with a mining project. Mining companies access capital to finance projects through various ways, including internal financing, debt and equity. A company's corporate governance dictates the financing methods, capital structures and cost of capital to be pursued (Sabour, 2002). Cash flows generated from a project are used to repay the accessed capital funds and the interests incurred before a net profit is declared, if a debt financing option is chosen. There exists a concave relationship between the optimum production rate and the cost of capital (Sabour, 2002). Production rate increases as the cost of capital increases, but decreases at a certain point as the cost of capital keeps on increasing (Sabour, 2002). This is due to PVMR, PVMC and differences in the relative change and/or sensitivities between them as the cost of capital increases (Sabour, 2002). The following are the two main attributing factors that cause the difference in sensitivities between PVMR and PVMC (Sabour, 2002):

- The expected rate of change in the mineral commodity price is greater than the expected rate of change from the associated mining costs; and
- The PVMC, which is the summation of the marginal capital cost (MCC) and the present value of marginal operating cost (PVMOC)

Equation 16 is used to determine the MCC (Sabour, 2002):

$$MCC = A_m \times B_m \times {P_r}^{B_m - 1} + A_p \times B_p \times {P_r}^{B_p - 1} \quad (16)$$

Where *MCC* is the marginal cost of capital, *Pr* is the tonnes per day production rate, *Am* and *Ap* is the capital investment required for mining and processing, respectively. *Bm* and *Bp* are constants

that depend on the applied mining and processing methods. Equation 17 is used to calculate PVMOC (Sabour, 2002):

$$PVMOC = \frac{N}{\delta} C_m \times {P_r}^{-D_m} \left[(1 - D_m) - e^{\frac{-\delta \times R_e}{N \times P_r}} \left((1 - D_m) + \frac{\delta \times R_e}{N \times P_r} \right) \right] + \frac{N}{\delta} C_p \times {P_r}^{-D_p} \left[\left(1 - D_p\right) - e^{\frac{-\delta \times R_e}{N \times P_r}} \left(\left(1 - D_p\right) + \frac{\delta \times R_e}{N \times P_r} \right) \right] \quad (17)$$

Where *PVMOC* is the present value marginal operating cost, *N* is the number of working days per year, δ is the difference between the risk-adjusted nominal discount rate (μ) and the expected annual increase of operating cost (*gc*), *Cm* and *Cp* are the operational expenditure incurred during production by mining and processing, respectively, *Pr* is the tonnes per day production rate, *Dm* and *Dp* are constants that depend on the applied mining and processing methods, and *Re* is the reserve tonnage.

2.5 Optimisation criteria

Optimisation aims to maximise and or minimise a set of inputs and or outputs (e.g. NPV, production output, Mineral Reserve, waste generation and production costs) against a given set of constraints (Neingo *et al*., 2018). The aim is to derive economic benefits from the Mineral Reserve by utilising minimal input resources required to extract the Mineral Reserve. These economic benefits are measured in several ways, including revenue generation, which is driven by the production rate achieved during the extraction process, among other factors.

2.5.1 Net present value

One of the most used measures of value obtained from a Mineral Resource is NPV. NPV is defined as the sum of all future cash flows expressed as a monetary value in real terms (Moles & O'Regan, 2002). This is done by discounting all future cash flows by the project-specific discount rate. The discount rate is defined as the expected rate of return in the context of the percentage return required to realised expected economic return for an investment project (Grabowski & Pratt, 2008). The determination of a project-specific risk premium to be used for each project is generally subjective, with projects being assigned a risk class for which the premium has been established.

Bhappu and Guzman (1995) noted that NPV and IRR are the primary investment decision-making criteria used in the mining industry, with the payback period being secondary. A project is considered viable if the NPV is positive and vice versa. Projects with higher NPV and IRR are more attractive to investors and are more likely to be executed (Bhappu & Guzman, 1995).

2.5.2 Internal rate of return

IRR is defined as the interest rate at which project capital has to be invested at to generate the same value from the invested project (Mahmoodzadeh *et al*., 2007). It is also the point at which the NPV is equal to zero (Mahmoodzadeh *et al*., 2007). The cost of capital is the minimum expected rate of return that is required from an investment project to warrant funds being invested in that project as supposed to another investment opportunity (Grabowski & Pratt, 2008). Hence, the cost of capital in economic terms refers to the opportunity cost foregone in investing in one investment project over another less attractive project (Grabowski & Pratt, 2008). As the discount rate reflects the risk associated with the project as well as time value of money, it is deemed as the cost of capital or the required rate of return. The greater the IRR, the faster the capital invested is retrieved making the business more lucrative and desirable. Using this criteria, a project is considered viable if the IRR is greater than the discount rate and vice versa. When the IRR is more than the discount rate, the investment project exceeds the cost of capital by the delta between the discount rate and the IRR and adds value. When the IRR of a project is less than the discount rate, it destroys value and the project is not worth pursuing.

2.5.3 Payback period

Along with NPV and IRR, payback period is one of the main decision-making criteria used in mineral projects valuation (Bhappu & Guzman, 1995). The payback period in isolation does not assess the profitability of that project (Mahmoodzadeh *et al*., 2007). The payback period of a project equates to the time taken by that project to recover the initial capital investment incurred by breaking even on a cumulative cashflow basis (Mahmoodzadeh *et al*., 2007). When the payback period is less than the payback rule as prescribed by the project valuator, the project should be accepted. Projects with shorter payback periods are more attractive than projects with longer payback periods.

2.5.4 Discounted cash flow

There are three main approaches used to valuate Mineral projects which include the market, cost and income valuation approach (Ellis, 2016). Each approach has its respective strengths and weaknesses, but the income valuation approach was used in this study. Three main income valuation techniques fall under the income valuation approach. These techniques include the real option pricing, DCF, and tail margin analysis (Lilford & Minnitt, 2005). Considering that the outputs obtained from a DCF analysis are NPV, IRR and payback period the DCF method was chosen for this study.

Lilford and Minnitt (2005) defined the DCF as a valuation of all future net cash flows. The future net cash flows are obtained by calculating all future generated revenues minus all costs. These costs include, but may not be limited to, operational costs, initial and working capital estimations, as well as royalties and taxation of sales or produce. Extraction of the underground mineral ore-bearing material forms one of the primary revenue-generating activities of a mining operation. By increasing the production rate, the revenue generated by the mining operation increases proportionally in that period. The DCF valuation method is used to calculate NPV, IRR and payback period of a project using modifying factors, which presents a maximised NPV when the production rate is optimised (Baruti, 2018).

Smith (2002) evaluated a single mining project using the DCF valuation model. During this valuation, Smith (2002) made a case for a "*Bare Bones*" (Smith, 2002, p. 101) base case based on an analysis that saw the same mining project being manipulated to attain varying NPV and IRR outcomes by adjusting only the input parameters in the DCF model. Smith (2002) established that the input factors into a DCF that has the most significant impact are the Mineral Reserves, commodity price, and the chosen discount rate. The "*Bare Bones*" base case, as proposed by Smith (2002), reasons that in the establishment of such a case, a common reference point is created that allows all projects evaluated to be seen on an equal basis. This creates a layer-less (input assumptions layers) view that renders all evaluated projects on an equal basis of which investment opportunities can be compared to see the true potential of each project. The "*Bare Bones*" base case DCF model is established by utilising a constant metal price input, 0% inflation, 0% debt and that royalties and tax calculations are to be on the same detail level as operational and capital expenditures (Smith, 2002).

2.6 Chapter summary

There are many methods utilised in the mining industry to determine the value obtained from a Mineral Resource. One of the most commonly used measures of value in the mining industry is NPV (i.e. determined using the DCF valuation method), which states the monetary value of a project in nominal or real terms (Smith, 2002). NPV is defined as the sum of all future cash flows that are expressed in real terms (Moles & O'Regan, 2002). This is done by discounting all future cash flows by the project-specific discount rate. Many factors drive NPV of a mining business that is spread over five broad activities on the mining value chain (Camus, *et al.*, 2009). One of the factors considered in this study is the production rate. Production rate is, in effect, one of the factors that enable a mining project to produce and generate revenue, which is obtained from the sale of the run of mine product.

Many production rate determination approaches were developed throughout the mining industry. Some approaches are more effective in optimising production rate than others. Three approaches for determining production rate were reviewed in this study, including the tonnage-based, microeconomic and marginal-analysis modelling techniques. The tonnage-based modelling technique includes Taylor (1977)'s method, which was subsequently modified by Long and Singer (2001). The tonnage-based modelling techniques consider only two parameters, the size of the Mineral Resource and the commodity being mined, during the determination of production rate. The microeconomic modelling technique applies microeconomic principals (e.g. economies/diseconomies of scale principal), during production rate determination. These principals were applied in this study. The microeconomic modelling technique takes several factors (e.g. the fixed mining cost, commodity price and average grade of the Mineral Resource mined) into consideration. These factors are used to determine unit cost curves from which the production rate is determined. The microeconomic modelling technique integrates the obtained production rate with the Mineral Resource GTC, from which NPV is determined. The marginal-analysis modelling technique assumes an optimal production rate when PVMC equals PVMR. This modelling technique considers the following factors: (i) number of working days per year, (ii) commodity selling price, (iii) the average ore grade, (iv) processing recovery, (v) pre-production construction period, (vi) the reserve tonnage, (vii) the difference between risk-adjusted nominal discount rate, (viii) the expected growth rate of the mineral price, (ix) marginal cost of capital, and (x) the expected annual increase of the OPEX.

3 RESEARCH METHODOLOGY

3.1 Chapter overview

In this chapter, the research method and analytical techniques that were applied in this study are described. The data that was required to apply the optimal production rate determination methods includes the Mineral Resource model, resource structural model, mining extraction strategy, cut-off grades, OPEX, CAPEX and lastly, all financial data associated with the project analysed. This chapter also describes how the collected data was analysed to answer the research question.

3.2 Data collection and data sources

The data utilised in this study were sourced from a consulting company's database for the selected project. Permission to access the database was obtained from the consulting company. An ethical clearance certificate was sought from the University of the Witwatersrand. The certificate is attached in APPENDICES Appendix A.

3.3 Data analysis

The data required to model the three production rate determination modelling techniques include the Mineral Resource model, resource structural model, mining extraction strategy, cut-off grades, OPEX, CAPEX and all financial data. The following subsections outline how the data was analysed.

3.3.1 Production rate determination using tonnage-based modelling

According to the tonnage-based modelling technique, the first step in determining the production rate was reviewing the Mineral Resource block model from which the GTC was drawn. The second step was to apply a cut-off grade to the resource model. The original mining project's feasibility study cut-off grade was calculated on a net smelter revenue (NSR) basis. The NSR is the net revenue that the owner of a mining project receives from the sale of the metal/non-metal products, less transportation and refining costs. This was done to ascertain what portion of the Mineral

Resource could be economically extracted. Equation 18 was used to calculate cut-off grade using input parameters as per the original mining project's feasibility study shown in Table 3.1.

$$Cut - off\ grade\ = Total\ cost\ /\ (Metal\ price\ x\ 4E\ Recovery\ x\ Net\ smelter\ return\ x\ Mine\ call\ factor) \quad (18)$$

Table 3.1: Input parameters to calculate cut-off grade for the Original mining project's feasibility study

Item	Quantity
Mining cost (USD)	50.00
Processing cost (USD)	11.56
Royalty Tax (USD)	3.00
Total overheads cost (USD)	5.00
Total Cost (USD)	**69.56**
Metal price - Basket price (USD/g)	42.22
4E Recovery (%)	84.00
Net Smelter Return (%)	85.00
Mine Call Factor (%)	100.00

The third step in determining production rate, according to the tonnage-based modelling technique, was to apply the modified Taylor's rule-of-thumb formula. As the mining project under review is a platinum mine, it falls under the "*Underground – Other"* classification. Long and Singer (2001)'s formula for "*Underground – other*" mine type in Table 2.1 was used to calculate production rate. Equation 19 shows the formula.

$$Production\ (\frac{Mt}{day}) = 0.297\ x\ Tonnage^{(0.562)} \quad (19)$$

3.3.2 Production rate determination through microeconomic modelling

Firstly, TFC, TVC and TC for the case study project were calculated. The costs were then used to determine the TC, TR, unit cost and unit revenue curves according to Equation 10. From the curves, the optimal production rate was determined at the point where the marginal cost intersected the ATC line. Table 3.2 shows the input parameters that were used to determine the optimal production rate.

Table 3.2: Input parameters to determine optimal production rate using Microeconomic modelling

Item	Quantity
Fixed Cost (USD/month)	12 583 333.00
Variable cost (USD/t)	20.02
Production rate (Tonne)	1 000.00
Commodity price (USD/oz)	1 173.00
Cut-off grade (g/t)	2.31
Average grade (g/t)	2.92
Troy oz (g/oz)	31.10
Recovery rate (%)	83.90
Net Smelter return (%)	100.00
Mine Call Factor (%)	100.00
Revenue per gram (USD/g)	29.72
Revenue per tonne (USD/t)	86.70

The determined cost curve data and subsequent production rate were then used in Hutton (2015)'s 3D integration method, integrating the obtained data back to the Mineral Resource. Through this integration process, NPV was calculated at the relevant cut-off grade for the determined cost curve data and production rate. Table 3.3 displays the input parameters used in the integration process, based on the original mining project's feasibility study data.

Table 3.3: Input parameters for the Integration of production rate with Mineral Resource modelling

Item	Quantity
Commodity price (USD/oz)	1 173.00
Recovery rate (%)	83.92
Royalty rate (%)	1.90
Dilution (%)	10.00
Production rate (tpm)	270 000.00
Cost (USD/ton)	76.15
Discount rate (%)	10.00
Troy oz	31.10
Expected CAPEX (USD)	593 993 687.00

3.3.3 Production rate determination through marginal-analysis modelling

Equations 12, 13, and 14 were used to determine optimal production rate as explained in Section 2.4.3. Table 3.4 depicts the input parameters used to calculate the optimal production rate through the marginal-analysis technique.

Table 3.4: Input parameters to determine the optimal production rate using Marginal-analysis modelling

Item	Quantity
Commodity Price - 4E basket price (USD/oz)	1 173.00
Troy oz (g/oz)	31.10
Net smelter return (%)	100.00
Number of working days per year	353.00
Number of working days per month	29.00
4E Basket price per mined tonne – Average (USD/tonne)	103.32
Average ore grade (g/t)	2.92
Processing recovery (%)	83.90
Expected LOM (Years)	37.50
Risk adjusted nominal discount rate (%)	10.00
Expected growth rate of mineral price (%)	0.00
Reserve tonnage (Million tonnes)	126.10
Construction (pre-production) period (Years)	1.50
Mining capital (Million USD)	377.10
Processing capital (Million USD)	216.90
Mining unit cost (USD/tonne)	48.62
Processing unit cost (USD/tonne)	27.54
Expected annual increase of operating cost (%)	6.40

3.3.4 Cost estimation data

Relevant data collected for this study was reviewed and escalated for the purpose of this study. Since the collected data was determined and published in 2016, there was a need to bring all relevant data into 2021 terms. This was done by escalating annual inflation up until the year 2021. Table 3.5 depicts the inflation rates used to escalate the OPEX and CAPEX data.

Table 3.5: Inflation rates for the normalisation process

(Source: STATISA, 2020)

Year	Inflation %	Factor
2021	0.00	100.00
2020	2.43	102.43
2019	4.13	106.66
2018	4.62	111.59
2017	5.27	117.47
2016	6.34	124.92
2015	5.23	131.45
2014	5.32	138.44
2013	5.30	145.78
2012	5.71	154.10
2011	6.41	163.98
2010	3.37	169.51
2009	6.04	179.75
2008	9.35	196.55
2007	7.57	211.43
2006	4.82	221.62

3.3.5 Revenue generation data

The production rate and the associated average ore grade, among other factors, determines the revenue in a mining operation. The reviewed mining project is a platinum project that has a 4E grade. The 4E grade is a weighted average grade field determined by adding the content of the four most precious elements of platinum, palladium, rhodium and gold together. Once the total content is determined, it can be worked back to a grade field by dividing it by the respective tonnes containing the added content. The 4E grade and the prill split was determined from the Mineral Resource block model analysis, which was then used to calculate the 4E basket price using Equation 20. Table 3.6 shows the metal prices from the original mining project's feasibility study.

$$\begin{aligned} \textit{4E Basket Price} = &\textit{(Platinum Price*Platinum prill split \%) + (Palladium Price*} \\ &\textit{Palladium prill split \%) + (Rhodium Price* Rhodium prill split \%) + (Gold} \\ &\textit{Price* Gold prill split \%)} \end{aligned} \tag{20}$$

Table 3.6: Metal price data according to the original mining project's feasibility study

Metal prices				
Description	**Price**	**Units**	**Price**	**Units**
Platinum	1 350	USD/oz	43.40	USD/g
Palladium	900	USD/oz	28.94	USD/g
Rhodium	1 050	USD/oz	33.76	USD/g
Gold	1 248	USD/oz	40.12	USD/g

3.3.6 Validation of results through DCF

The production rate results obtained from the three modelling techniques were validated using the DCF model. This required the three different rates of production obtained from the respective modelling techniques to be scheduled over the LOM of the reviewed mining project. This was done by utilising the collected data and rerunning the excel-based production schedule at the rates obtained from the respective modelling techniques. The collected data used as input into the DCF also included the OPEX, CAPEX, Stay-In-Business (SIB) CAPEX, and the royalty tax rate that was amended for the respective production schedules. This included reviewing and changing the normalised capital budget estimate to suit the rescheduled production rates. It also included the amendment of the OPEX model from the original mining project's feasibility study to suit production rates as rescheduled. The SIB CAPEX was calculated from the data collected as well as when the SIB CAPEX started. The SIB CAPEX was then applied in the DCF model as a percentage, starting in the financial year as applied in the original mining project's feasibility study. The royalty tax rate was also calculated as per the "*Mineral and Petroleum Resource Royalty Act 28 of 2008*" for an unrefined Mineral Resource. The other input parameters used for the DCF model were based on either the collected data or from Smith (2002)'s recommendations obtained through the literature review. Table 3.7 shows the input parameters that were used in the DCF models.

Table 3.7: DCF input parameters

Financial inputs	Quantity
Royalty - 4E Calculation (%)	Y=0.5+(X/12.5)
Project Metal Price increase (%)	0.00
Project OPEX Inflation (%)	0.00
Project CAPEX inflation (%)	0.00
Discount Rate (%)	10.00
Companies Tax (%)	0.00

For the purpose of this study, the "*Bare Bones*" base case (Smith, 2002, p. 1) approach was adopted in the DCF analysis of each respective production rate determination technique. The DCF analysis was done on an Earnings Before Tax, depreciation and amortization (EBITDA) basis as per Smith (2002)'s "*Bare Bones*" (Smith, 2002, p. 1) base case. This means that no company's tax, depreciation or amortization calculations were considered in NPV and IRR calculations. The results from the DCF validated the three production rate determination modelling techniques by distinguishing which modelling technique yields the best NPV and IRR results. The NPVs obtained

from the DCF runs, was then compared with NPVs obtained from other production rate determination techniques. The best method was determined on maximum NPV and IRR.

3.4 Chapter summary

This chapter lists the data that was collected and describes the processes of data collection and analysis. Geological data collected include reserve tonnage, average grade. Economic data include CAPEX, OPEX, 4E price and inflation rates. The steps involved in analysing the collected data are described in this chapter. These steps included normalising the collected data, production rate determination by respective modelling techniques, and, lastly, financially valuating all the obtained production rates using the DCF valuation technique.

4 ANALYSIS OF RESULTS FROM THE THREE PRODUCTION DETERMINATION TECHNIQUES

4.1 Chapter overview

This chapter applies the collected data on the three production rate determination methods. The three selected production rate determination techniques were analysed individually to obtain the respective rates of production. In addition, hereto, the LOM production schedules, OPEX and CAPEX for the project were updated accordingly for each modelling technique. This data coupled with the stay-in-business (SIB) CAPEX, the royalty tax rate as well as other parameters as per Table 3.7, were then used as input parameters in the DCF. NPV and IRR results from the DCF were then analysed and compared to the other two modelling techniques.

4.2 Analysis of original mining project's feasibility study data

The original mining project's feasibility study data was analysed to better understand the resource characteristics, mining extraction strategy, scheduling constraints and the general data employed. Aspects of the data analysed during this section were required to arrive at a logical application of the constraints associated with the original mining project. This enhanced the practicality of the input parameters to validate the obtained production rates for each modelling technique.

4.2.1 General data

Table 4.1 shows the data that forms the basis for all of the production rate calculation techniques.

Table 4.1: General information

General information	Quantity
Days per annum	365.00
Public holidays	12.00
Working days per annum	353.00
Working days per month	30.00
Operating shifts per day	2.00
Hours per shift	12.00
Shifts per Month	60.00

4.2.2 Orebody characteristics

After calculating the grade and tonnage of the Mineral Resource, the physical characteristics of the orebody were reviewed. These include the thickness, dip, and the major geological structures within the orebody. It was revealed that the orebody is narrow and tabular, and its structure consists of an open syncline that plunges gently to the south and dipping inwards generally at dips of less than 10°. The dip of the orebody is uniform with a localised dip of up to 25°. The orebody is sub-divided into five major mining areas by major geological discontinuities, with throws varying from 10m to 100m. Minor geological discontinuities are also encountered with throws ranging from 1m to 3m. The main economic concentrations of platinum group elements (PGE) mineralisation occur in the main reef horizon. For this study, only the primary reef mineralisation was considered. The mining height was calculated through a process whereby the mineralised stratigraphy was subdivided into 0.25m slices. This process was then used to determine whether it is economical or not. This resulted in an average height of between 2.5m and 2.75m. Figure 4.1 shows the depth to seam plot of the orebody. A maximum depth of 350m below the surface is encountered, with the primary reef mineralisation outcropping on the surface.

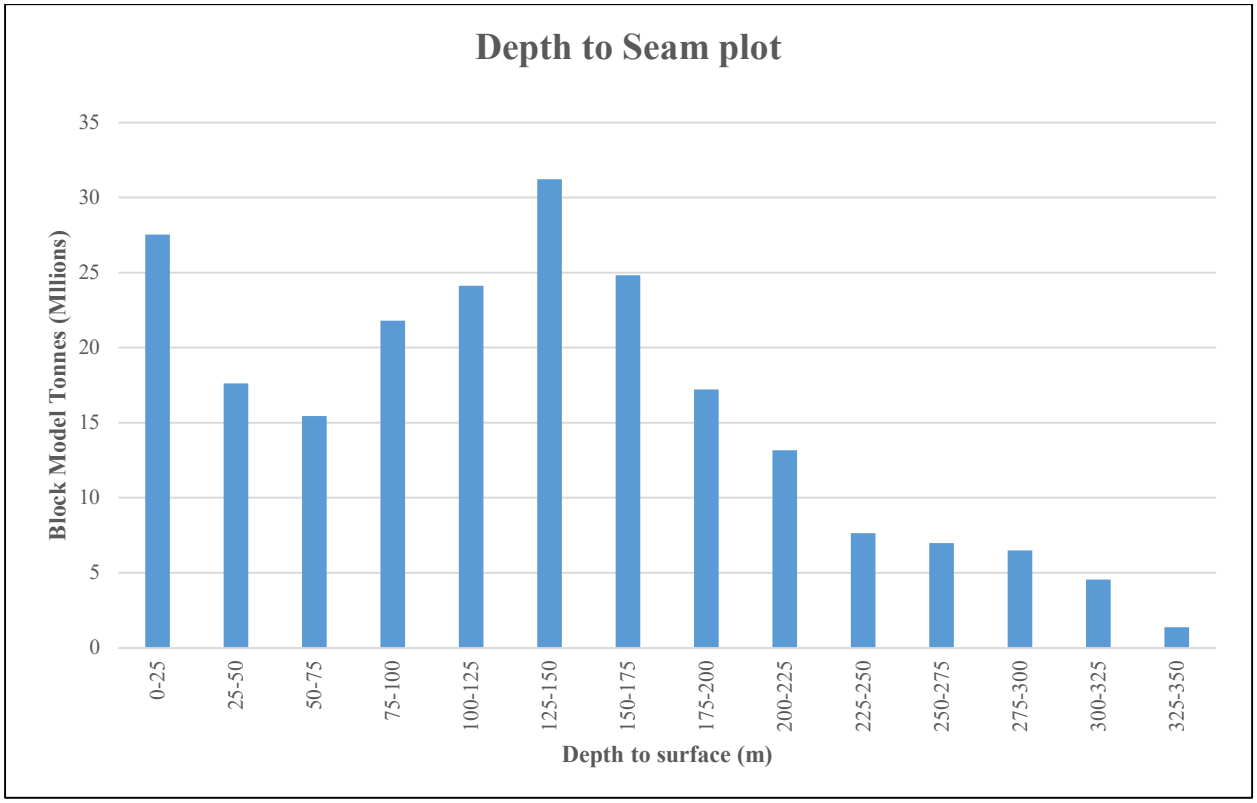

Figure 4.1: Depth to seam plot of the orebody

The five mining areas of the orebody formed the five mines as utilised during the LOM production schedules that were generated. The Mineral Resource was converted to a Mineral Reserve by applying modifying factors such as weathering losses, irregular geological zones, known and unknown geological losses, mining pillar losses and mining dilution incurred. The resultant Mineral Reserve amounted to 126.6 million tonnes at an average 4E grade of 2.78 g/t. This was derived from the Mineral Resource, which was subjected to a cut-off grade, of 201.5 million tonnes at an average grade of 2.92 g/t. The resultant Mineral Reserve was scheduled for each of the respective production rate calculation techniques used as input into the DCF analysis.

4.2.3 Mining extraction strategy

During the review of the mine extraction strategy, it was essential to understand the strategy intended for the extraction of the underground Mineral Resource. This understanding would facilitate the determination of the LOM production profiles and the capital requirement used as input into the DCF. As the Mineral Resource outcrops on surface, a decline cluster system was selected as the method to access the underground workings. This option was found to be the optimal option as the decline cluster would be immediately on the reef horizon at the starting point from the boxcut highwall. Bord and pillar was selected as the optimal mining method for the original mining project's feasibility study based on the characteristics of the orebody. The smallest mining unit (SMU) for this mining operation is the bord and pillar mining crew which consists of a low-profile drill rig, a roof bolter and two small load haul dumpers (LHD). The crew efficiency for each of these SMUs was determined to be 20 ktpm.

The decline option as the access method would also determine the primary ore handling philosophy system to use. Trade-off analysis was conducted to determine the best method would be for handling material from the underground workings. The analysed methods are trucking and belt conveying. Ultimately the belt conveyor option proved to be the cheapest option for moving material from underground to surface. Thus, blasted material would be moved by LHDs from the panels to two sections or strike belt conveyor that service each bord and pillar section, consisting of 15 bords. Having two section belts in each of the mining sections would reduce the overall tramming distance travelled by the LHDs. These strike section belt conveyors would connect back to the main dip belt conveyor situated in the decline cluster. This belt conveyor would convey all material supplied by the respective mining sections to surface. This main belt conveyor is

specifically sized to accommodate all of the generated material from the respective sections. Each of the decline clusters or underground portals has a maximum design capacity of 140 ktpm.

4.2.4 Scheduling constraints

All production rates scheduled for the respective modelling techniques were generated in a Microsoft Excel model. The model considered the effect of variable grade distribution of the Mineral Resource throughout the LOM. The model also made provision for mining ramp-up, steady-state mining and end of mine ramp-down for each respective mining area or mining portal scheduled. The ramp-up and ramp-down was a function of the production rate at which the individual mine was depleted.

Four of the five respective mines was accessed by their own mining portal and decline cluster, and one mine (Mine 4) was accessed from Mine 3's surface infrastructure. Having the orebody divided up into the separate mines created the need for two or more mines being mined at any particular point to attain the required overall mining project's production target. The individual production rates for each respective mine were determined according to its Mineral Resource size and its capability to conform to the overall required production target. Mine 1 and Mine 2 are the two mining areas with the highest average Mineral Resource grades. Therefore, the two mines were mined first to maximise NPV due to the time value of money principle. This would also enable early paying back of capital. Mine 3 or Mine 5 was being mined third overall. Mine 4 was only able to start producing a minimum of twelve months after Mine 3 has started, due to its reliance on Mine 3's surface and underground infrastructure.

The subdivision of the orebody into smaller mines resulted in these smaller mines having different production rates and grades. The difference in production rates and grade had to be balanced to obtain the optimal overall LOM production rate and grade for the orebody as a whole. This caused each individual mine's production rate to be adjusted to conform most optimally within the overall production and grade yield. As the original mining project feasibility study's production rate was 280 ktpm, it was designed to have a minimum of two operational underground mines at any one stage. The resultant design required a maximum production yield per underground mine of 140 ktpm. Mine 1 makes up 20.6% of the overall Mineral Resource with an average reserve grade of 3.03 g/t. Mine 2 makes up 22.2% of the overall Mineral Resource with an average reserve grade of 2.88 g/t. Mine 3 and Mine 4 make up 8.3% and 15.9% of the overall Mineral Resource with

average grades of 2.82 g/t and 2.74 g/t, respectively. Lastly, Mine 5, the biggest portion of the Mineral Resource, makes for 33.0% of the total Mineral Resource at an average grade of 2.56 g/t. The 2.56 g/t from Mine 5 is by far the lowest grade and was managed accordingly to reduce the expected impact from this lower graded material.

The last point of consideration during the LOM production scheduling is stockpiling. Stockpiles are built when the underground production exceeds the milling capacity, with the excess tonnage being stockpiled. This stockpile material will only be processed when the mill has the capacity to process the additional stockpiled material. The mining, transportation and storage costs are incurred whilst building the stockpile, but the revenue is realised only when the stockpile material is processed, refined and sold. Stockpiles negatively affect cash flow during the initial stages of the LOM when only costs are incurred, but no revenue is realised.

4.2.5 Project operational expenditure

The operating cost model from the original mining project's feasibility study was developed from first principles using the activity-based cost costing approach. Costs were obtained from tenders received during the procurement phase of the original mining project's feasibility study. These costs were then scheduled in the DCF model according to linkages to the mining activities associated with the mining production profile. The operational expenditure was divided into direct mining, engineering, concentrator and concentrate costs shown in Appendix B, Appendix C, Appendix D and Appendix E, respectively.

The total OPEX for the original mining project's feasibility study amounts to USD60.97 per tonne of Mineral Reserve mined or USD642.91 per 4E ounce mined, as summarised in Table 4.2. This includes the SIB capital expenditure, which, according to the owner of the Mineral Resource's policy on the basis of estimation, is included as OPEX. It is also noted that the total Mineral Reserve tonnage utilised for the cost model results in 60.4 million tonnes. This is due to the financial model only taking the first twenty years of the LOM into account and not the entire forty-one point seven-years LOM.

Table 4.2: Operation expenditure summary

Cost Component	Total Mined Tonnes	Total Cost (USD)	Cost per Mined Tonne (USD/t)	Total Mined Oz	Cost per Mined Oz (USD/oz)
Total Underground Mining Cost	59.61	2 044.75	34.30	5.72	357.17
Contractor Mining Cost - Underground	0.76	12.28	16.14	5.72	2.15
Concentrate Costs	60.37	500.14	8.28	5.72	87.36
Concentrator	60.37	830.63	13.76	5.72	145.09
SIB	60.37	292.75	4.85	5.72	51.14
Total Operational Expenditure Costs	**60.37**	**3 680.56**	**60.97**	**5.72**	**642.91**

Figure 4.2 shows, the original mining project's feasibility study's position (as indicated by the green arrows) on the Southern African platinum industry's cost curve.

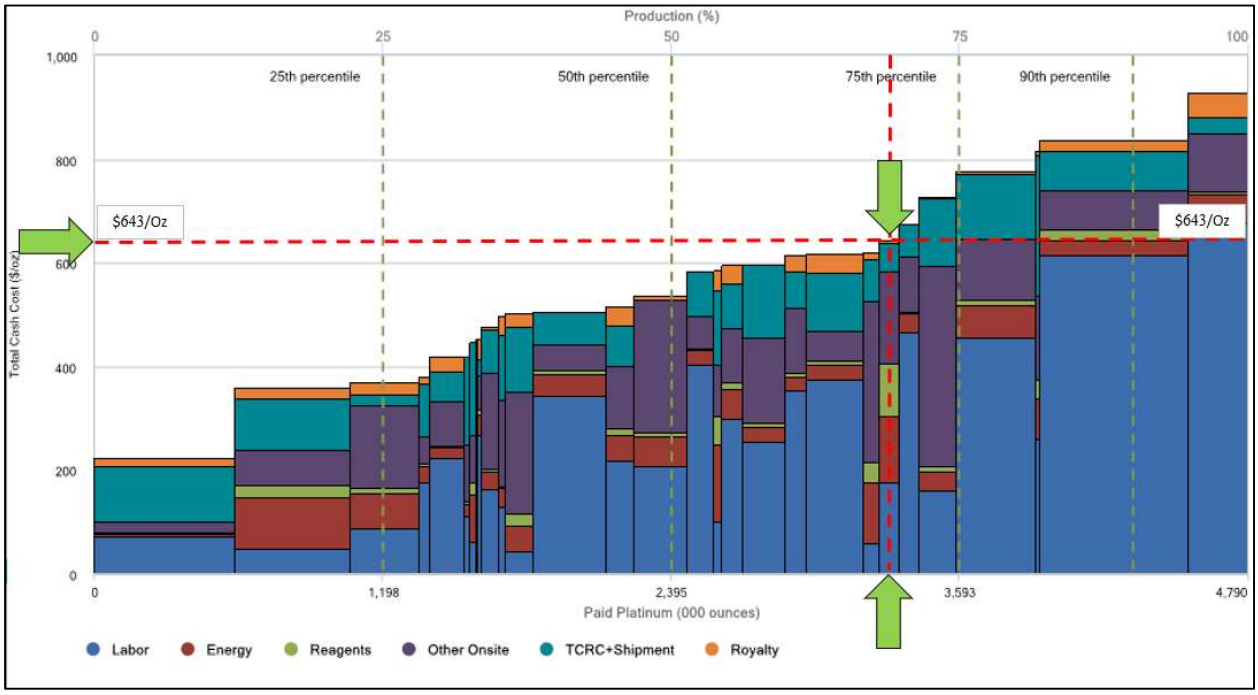

Figure 4.2: Southern African platinum Industry cost curve

(Source: S&P Global, 2020)

The original mining project's feasibility study is located within the 75th percentile on the platinum industry's cost curve. This position on the platinum industry's cost curve was revisited after applying the production rate methods. This was done to record any movement in position on the industry cost curve.

4.2.6 Project capital expenditure

The capital budget estimate for the original mining project's feasibility study was broken down into several work breakdown structures. CAPEX costs were obtained from the vendor's tendered quotations and the mining consultant's in-house data. The capital budget estimate was based strictly on the equipment, material and specifications described within the documentation for the feasibility study. The capital budget estimate also conformed to the levels of accuracy required for the level of study the original mining project. Table 4.3 shows the summarized capital budget estimate.

Table 4.3: Capital budget estimate

Cost Component	Total Mined Tonnes - Mil	Total Cost - (USDMil)	Cost per Mined Tonne (USD/t)	Total Mined Oz	Cost per Mined OZ (USD/oz)
Surface Mining	60.37	-	-	7.15	-
Underground Mining	60.37	260.82	4.32	7.15	45.56
Concentrator	60.37	153.13	2.54	7.15	26.75
Infrastructure	60.37	63.79	1.06	7.15	11.14
Indirect Cost	60.37	116.25	1.93	7.15	20.31
Capital Budget Estimate	**60.37**	**593.99**	**9.84**	**7.15**	**103.76**

The total CAPEX for the original mining project's feasibility study amounts to USD593.99 million or USD9.84 per tonne mined after normalisation. Figure 4.3 show the CAPEX schedule according to the expected date of expenditure derived from the LOM production profile from the original mining projects' feasibility study.

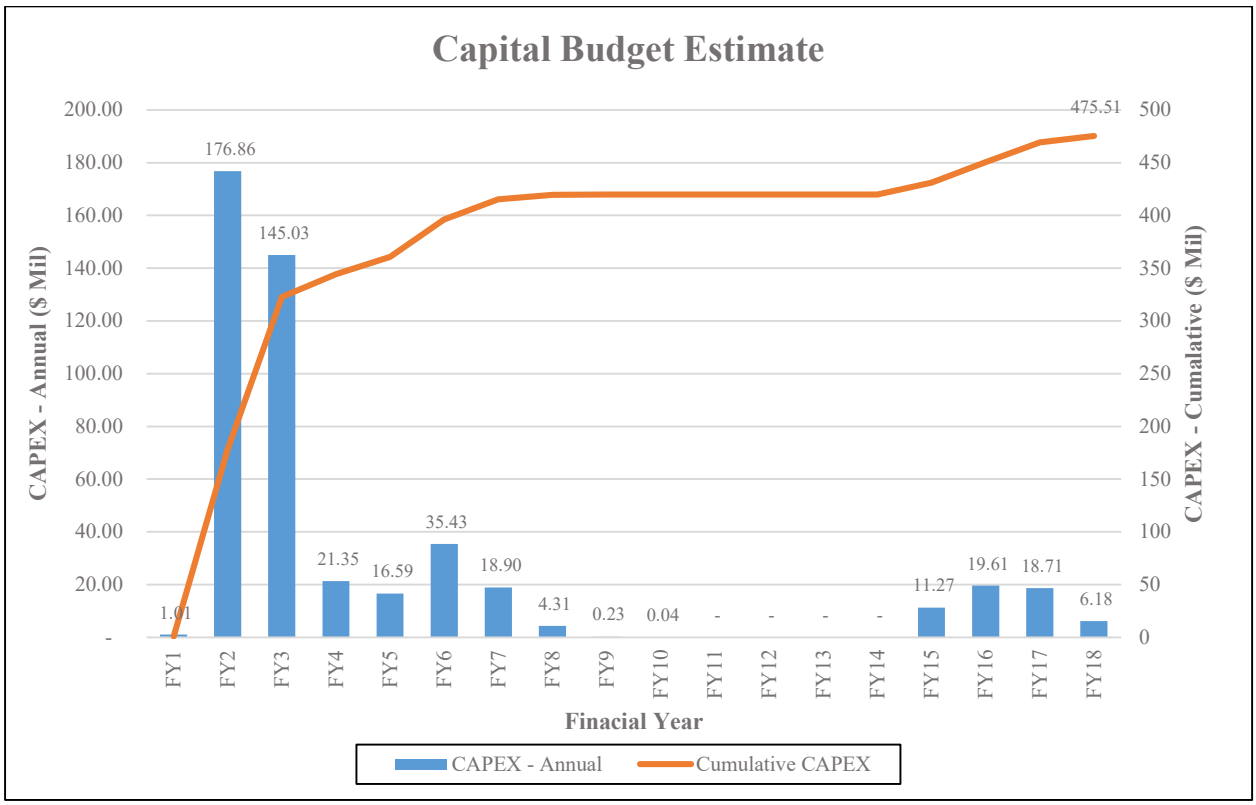

Figure 4.3: Capital budget estimate from the original mining project's feasibility study

4.3 Production rate results and analysis for the three modelling techniques

4.3.1 Production rate determination by Mineral Resource tonnage-based modelling

The first step of determining production rate, according to the tonnage-based modelling technique, requires a review of the Mineral Resource block model. Figure 4.4 depicts the GTC drawn from the Mineral Resource block model.

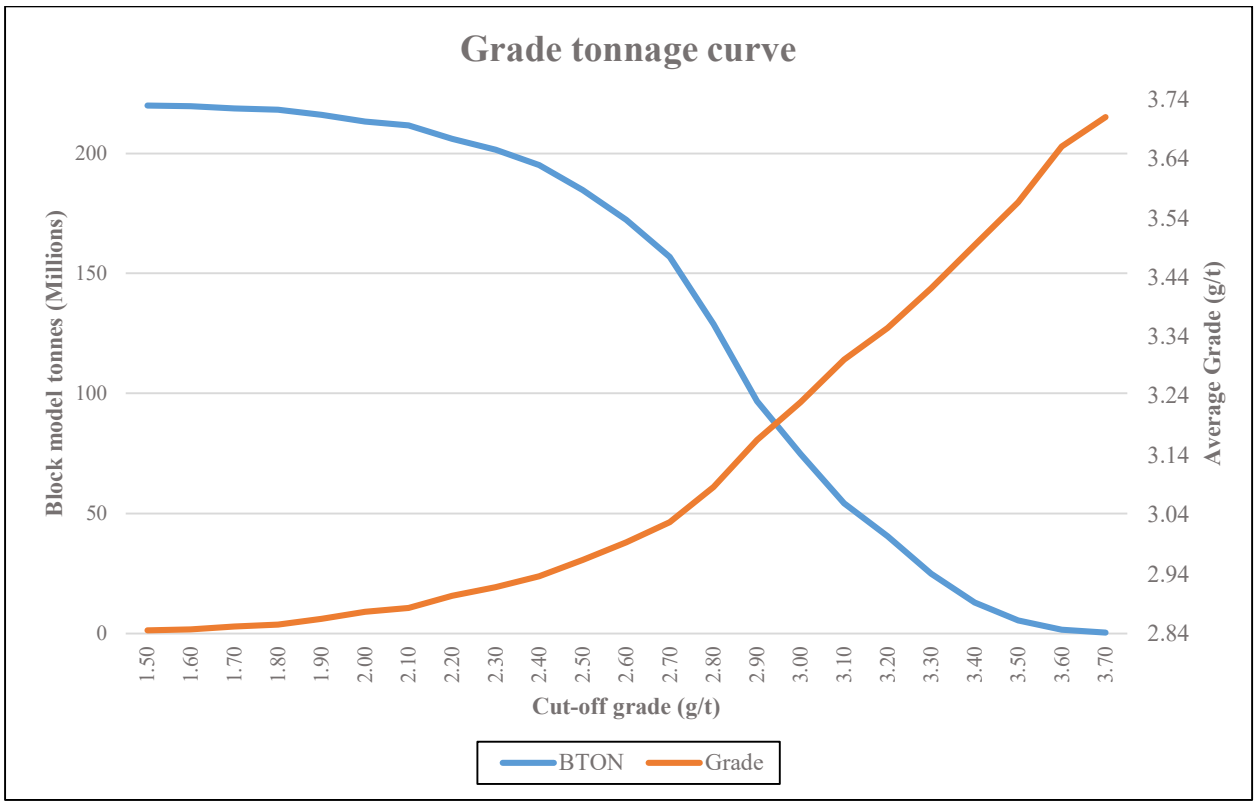

Figure 4.4: The grade tonnage curve for the case study Mineral Resource

The resource block model has an overall volume of 68.1 million m^3, translating to 220 million tonnes of ore-bearing Mineral Resource at a 2.85 g/t of 4E grade. The resource of 220 million tonnes is before any cut-off grade has been applied.

The second step in determining production rate according to the tonnage-based modelling technique, was to determine and apply the cut-off grade on the Mineral Resource. For comparison, the original mining project's feasibility study cut-off grade was applied in this study. The cut-off grade for the original mining project's feasibility study was calculated as being 2.31 g/t 4E as per Equation 18 and using input parameters shown in Table 3.1.

$$Cut-off\ grade\ = Total\ cost\ /\ (Metal\ price\ x\ 4E\ Recovery\ x\ Net\ smelter\ return\ x\ Mine\ call\ factor)$$

$$Cut-off\ grade\ = \$69.56\ /\ (\$42.22\ x\ 84\%\ x\ 85\%\ x\ 100\%)$$
$$= 2.31\ g/t$$

The cut-off grade was applied to the GTC as shown in Figure 4.5

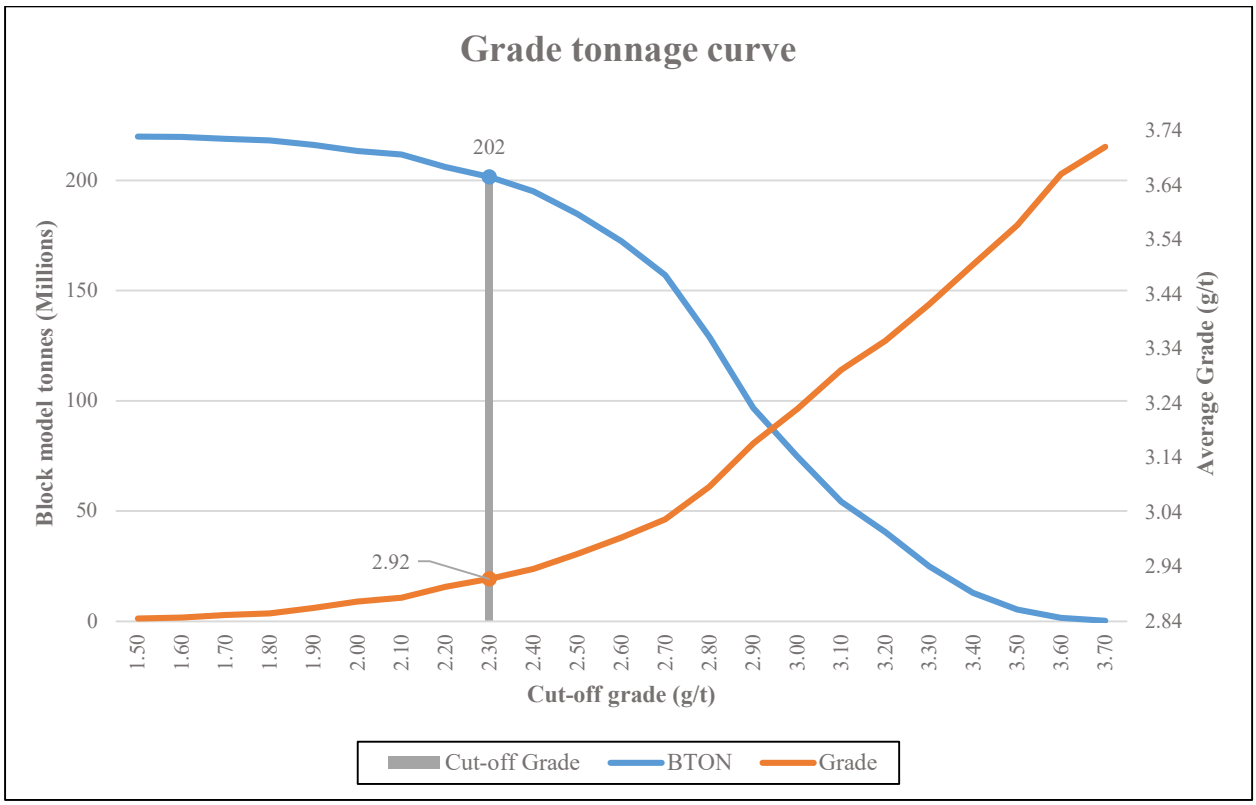

Figure 4.5: Grade tonnage curve with applied cut-off grade

Figure 4.5 shows that after the cut-off grade of 2.31 g/t is applied to the Mineral Resource, the Mineral Reserve is reduced from 220 million tonnes to 201.5 million tonnes at a 2.92 g/t resource grade. The GTC gradually reduces in Mineral Resource tonnes as the cut-off grade increase with no sharp drop-off experienced.

During the third step in determining the production rate, Long and Singer (2001)'s formula shown by Equation 19 was applied as below:

$$Production\ (\frac{Mt}{day}) = 0.297\ x\ Tonnage^{(0.562)}$$

$$= 0.297\ x\ 201.5^{(0.562)}$$

$$= 13\ 797\ tonnes\ per\ day$$

Long and Singer (2001)'s formula resulted in a production rate of 13 797 tonnes per day. This results in a monthly production rate of 410 ktpm rounded when assuming 30 working days per month as per Table 4.1. This results in a LOM of 24.3 years which does not cater for production

ramp-up or the production ramp-down, but only steady-state production. This production rate is 146.4% more than the original project feasibility study's 280 ktpm production rate.

In addition to determining the production rate for the Mineral Resource as a whole, the production rate was also calculated for its size as per the feasibility study of the original mining project. The size of the Mineral Resource used in the original feasibility study, was only 135.2 million tonnes. This resulted in a rounded production rate of 330 ktpm, which is 117.9% of the reviewed mining project's feasibility study. Table 4.4 shows the analysis and the comparison to the original mining project's feasibility study.

Table 4.4: Resource tonnage-based production rate calculation technique results

Item	Mineral Resource Tonnage	Prod / Anum	LOM - years	% Change – Original Project
Total Mineral Resource	201 515 416.00	4 966 840.00	24.30	146.40
Mineral Resource – Original mining project's feasibility study	135 214 800.00	3 969 123.00	20.40	117.90

4.3.2 Production rate determination by microeconomic modelling

The monthly production rate was tested for the microeconomic modelling instead of the daily production rate tested for the tonnage-based modelling. This implies considering the total monthly costs and not daily totals. A total fixed cost of USD12.6 million was determined to be the average monthly fixed cost over the LOM for the original mining project's feasibility study. The average variable cost for the original mining project's feasibility study was USD20.02 per mined tonne. The input parameters as per Table 3.2 were used to determine the TC using Equation 10. An incremental production rate of one-ktpm was tested during the microeconomic modelling technique. This incremental production rate resulted in the construction of the TR and unit cost curves. Figure 4.6 shows the TR and cost curves, whereas Figure 4.7 shows the unit cost curves.

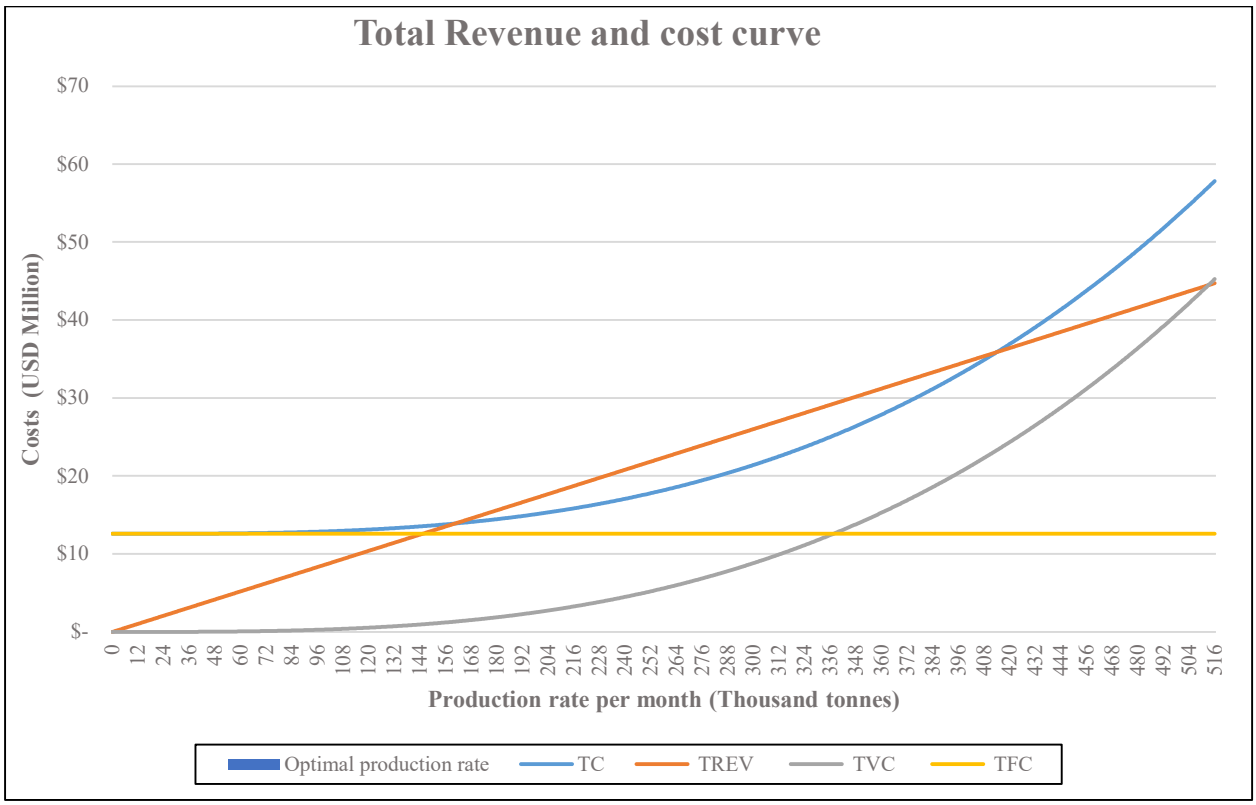

Figure 4.6: Total revenue and cost curves

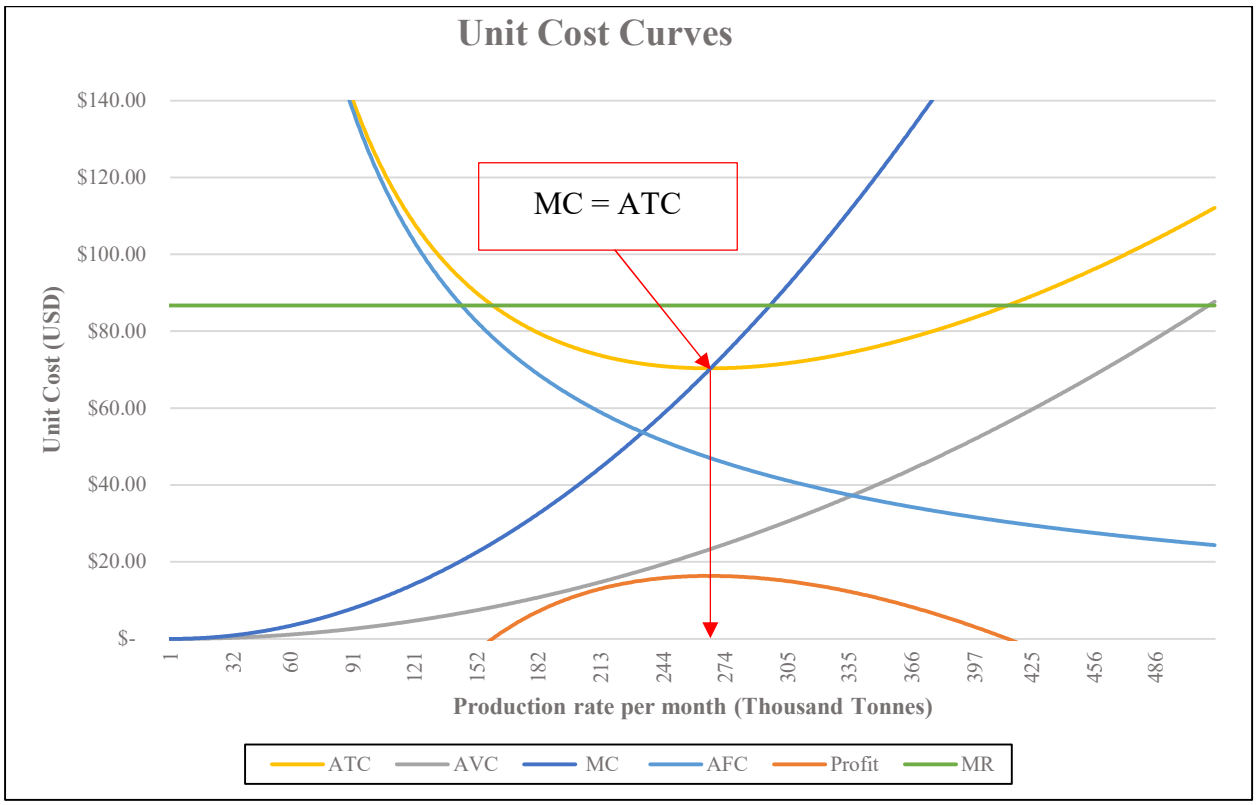

Figure 4.7: Unit cost curves

Figure 4.6 and Figure 4.7 show that this study is profitable between 161 ktpm and 414 ktpm. This profitable zone is determined at the two intersection points in Figure 4.6, where the total revenue curve intersects the total cost curve. In Figure 4.7, this profitable zone is depicted by the two intersecting points of the marginal revenue, with the average total cost curve. Figure 4.7 shows that the marginal cost intersects the average total cost at the production rate of 268 ktpm or 270 ktpm rounded. According to the microeconomic modelling technique, this is the optimal production rate for the Mineral Resource. This production rate is 96.4% of the original mining project feasibility study's production rate.

The last step in the modelling process, as proposed by Hutton (2015), was to integrate the production rate with the microeconomic Mineral Resource modelling. This is a fundamental process by which the cost curve data and the obtained production rate is integrated with the Mineral Resource model. Appendix R depicts the integration process whereby the production rate was incorporated into the GTC derived from the Mineral Resource model, based on the input parameters shown in Table 3.3. The results obtained from the integration process is displayed in Table 4.5, and graphically represented in Figure 4.8.

Table 4.5: Results from integration of production rate with Mineral Resource modelling

Item	Quantity
Optimal cut-off grade (g/t)	3.30
Average grade (g/t)	3.42
Optimal payability of resource (%)	11.30
Optimal resource (Million Tonnes)	24.80
Discounted Optimal profits – (USD Million)	191.10
Optimal profits - Post Expected CAPEX (USD Million)	402.80

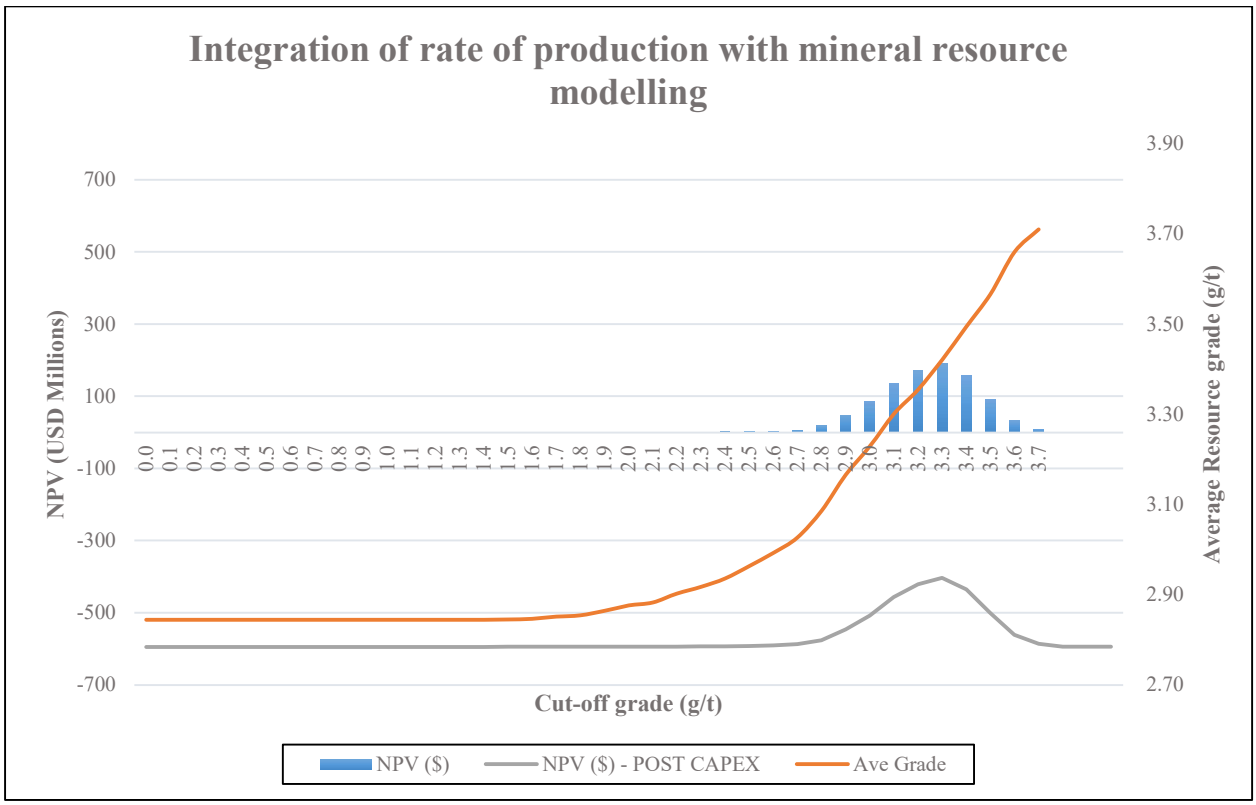

Figure 4.8: Integration of production rate with Mineral Resource modelling

Figure 4.8 shows that a cut-off grade of 3.3 g/t at an optimal Mineral Resource of 24.8 million tonnes and a payability of 11.3% results in the highest possible discounted profit of USD191.2 million pre-CAPEX. After the CAPEX, the optimal discounted profit is -USD402.8 million.

Figure 4.9 depicts a graphical representation of a 3D construct of the integration process of the microeconomic cost curve results using the Mineral Resource modelling. This construct depicts the value peak when taking all the variables such as cut-off grade, production rate, and LOM into consideration.

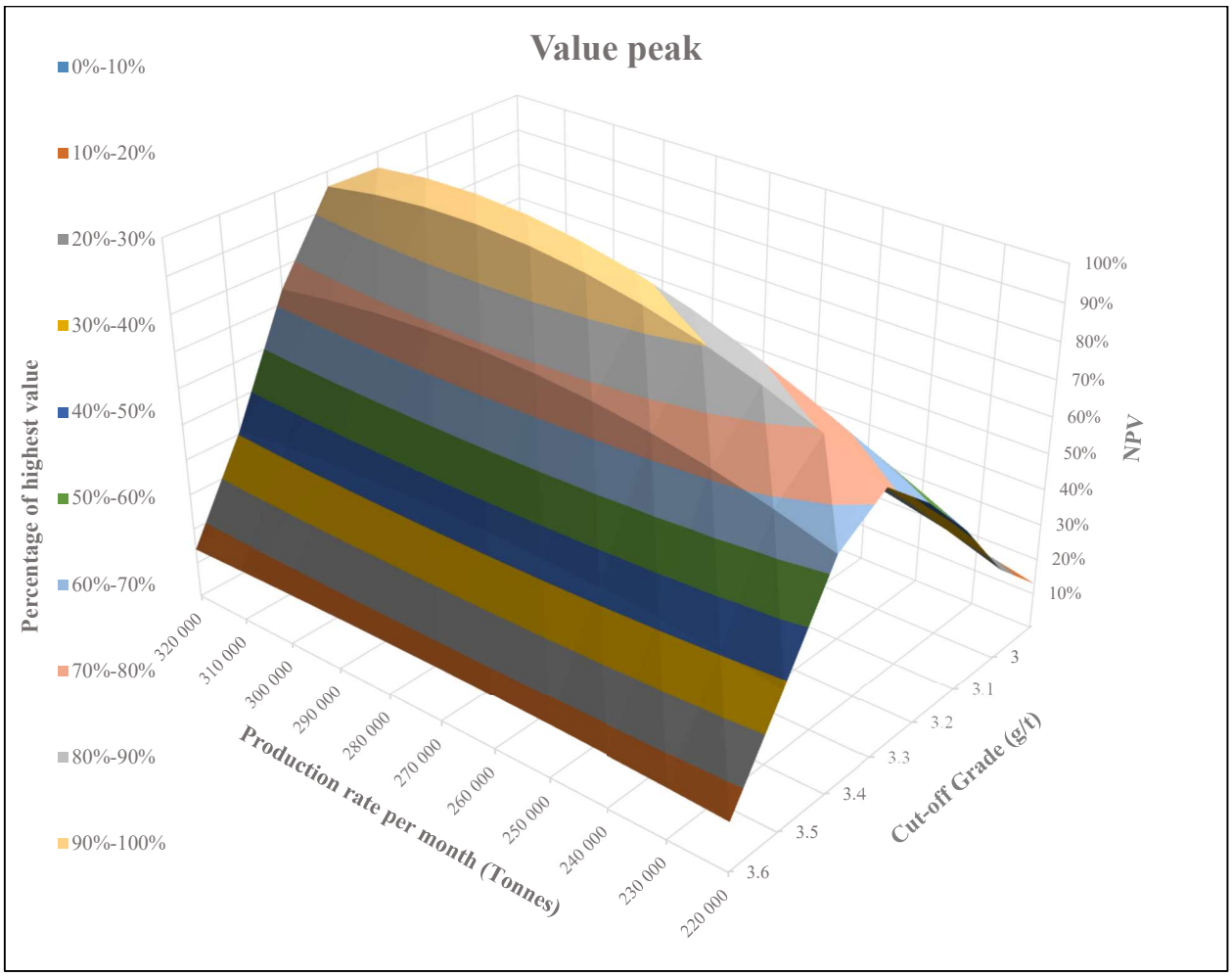

Figure 4.9: Value peak graph of three-dimensional integration

Figure 4.9 depicts that the highest value on the 3D graph is reached at a production rate of 270 ktpm and a cut-off grade of 3.3 g/t. This point of highest value is represented as 100% in Figure 4.9 and in Appendix S.

4.3.3 Production rate determination by marginal-analysis modelling technique

The first step in production rate determination, according to the marginal-analysis modelling technique, was to determine PVMR and PVMC. PVMR was calculated using Equation 13, and the input parameters shown in Table 3.4. PVMC was calculated using Equation 14, and the input parameters shown in Table 3.4. The second step in this process was to repeat the calculations of PVMR and PVMC for production rate increments of 0.1 ktpm. This enabled the construction of a graph where the intersection point between the PVMR and PVMC could be graphically depicted as shown in Figure 4.10.

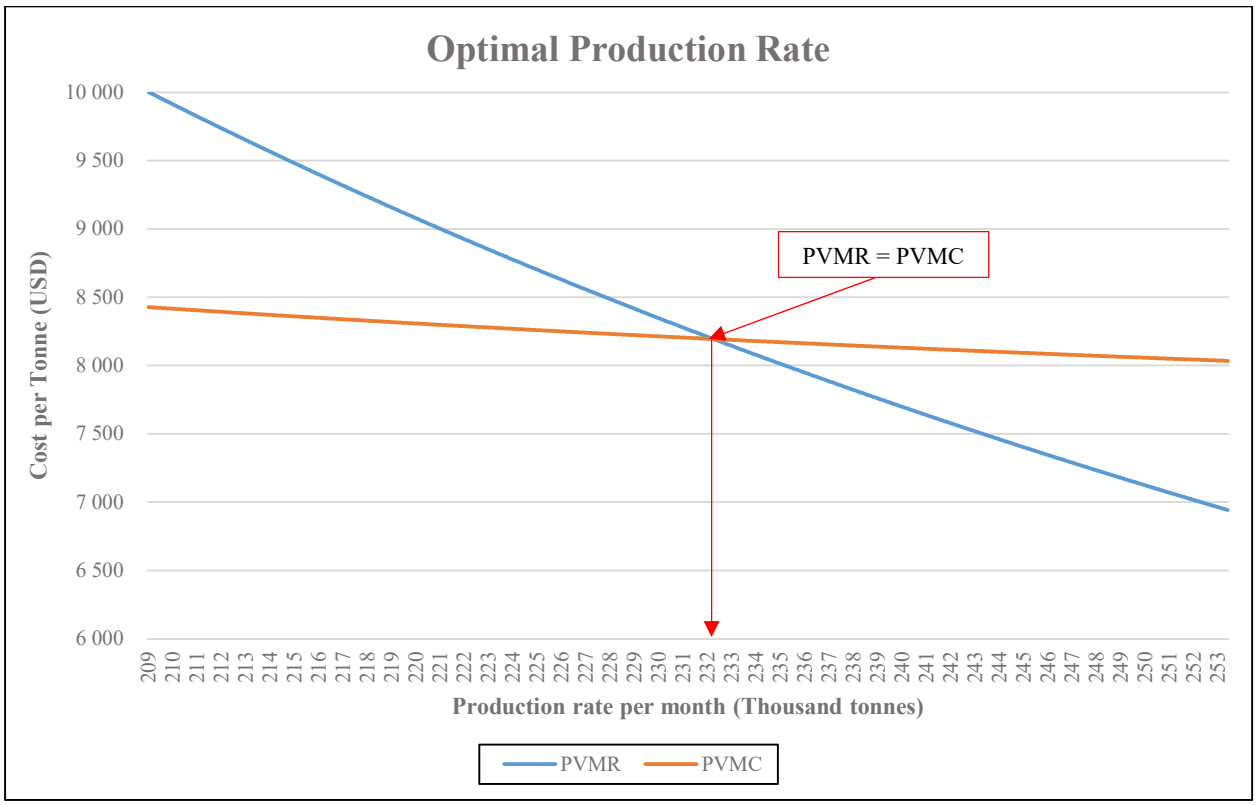

Figure 4.10: Optimal production rate using marginal-analysis modelling

The optimal production rate, according to the marginal-analysis modelling technique, is the point where the PVMR line intersects the PVMC line. This rate is represented by the red arrows in Figure 4.10 at USD8195 per tonne. The optimal production rate was determined as 232.5 ktpm or 230 ktpm rounded. This is 82.1% of the original mining project's feasibility study production rate. For the purposes of this study, the rounded number of 230 ktpm was utilised going further in this study.

4.4 Valuation results of production rates through DCF analysis

4.4.1 Production rate scheduling

Production scheduling forms the basis of determining the revenue generated and production costs incurred by a mining project. It is a fundamental input parameter in the DCF model, which is subjected to various factors. The factors considered (Section 2.3) in the LOM production profiles for each of the respective production rate determination techniques are Mineral Resource characteristics, extraction strategy, scheduling constraints and operating data. These factors influenced the generation of the LOM production profiles for each of production rates as determined in Section 4.3. The Mineral Resource tonnage-based modelling technique yielded the

highest production rate of 410 ktpm and the shortest LOM of 31 years. The microeconomic modelling technique resulted in the second-highest production rate of 270 ktpm and the second shortest LOM of 42 years. The marginal-analysis modelling technique resulted in the lowest production rate of 230 ktpm with the longest LOM of 50 years of production. Figure 4.11 depicts the LOM production profiles used as input parameters for the DCF modelling. The detailed LOM scheduling results are presented in the following subsection.

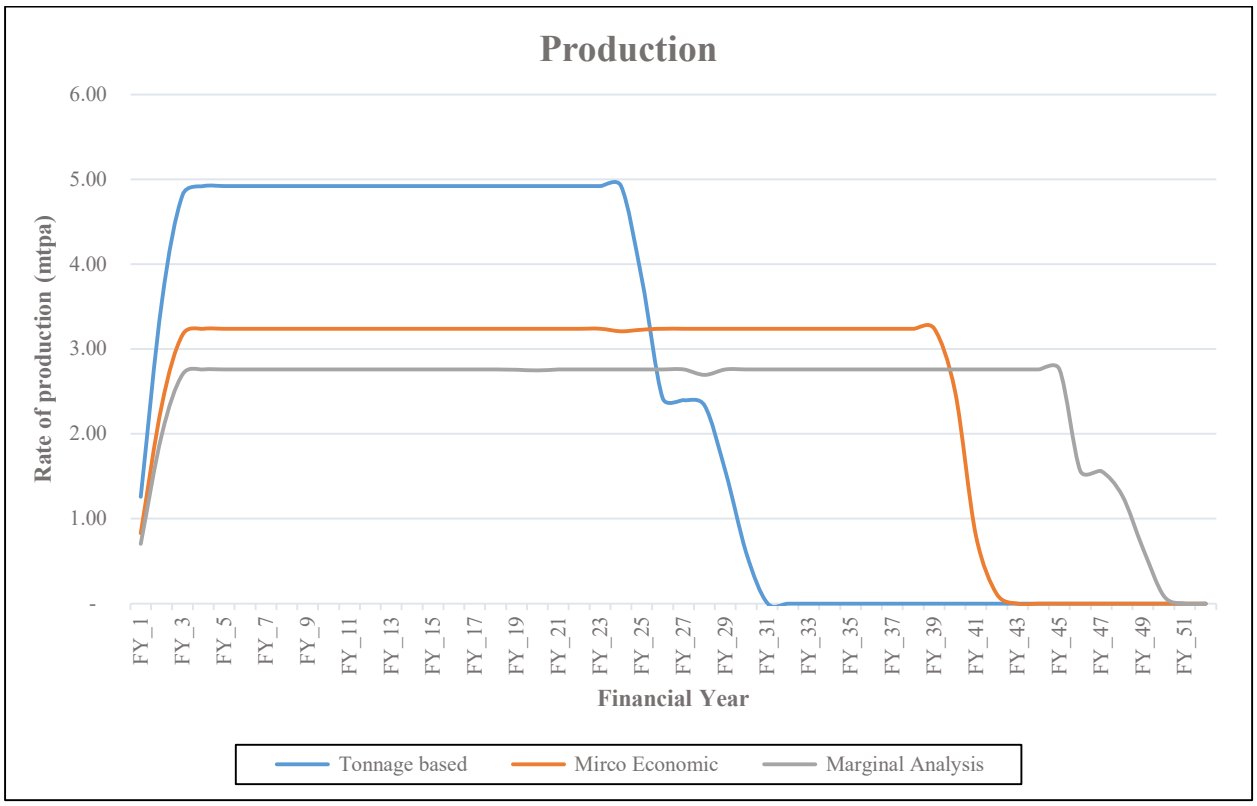

Figure 4.11: DCF results – LOM production

Mineral Resource tonnage-based modelling

The tonnage-based modelling technique obtained a production rate of 410 ktpm with a resultant LOM of 30.1 years. Figure 4.12 depicts the LOM production profile for the tonnage-based modelling technique.

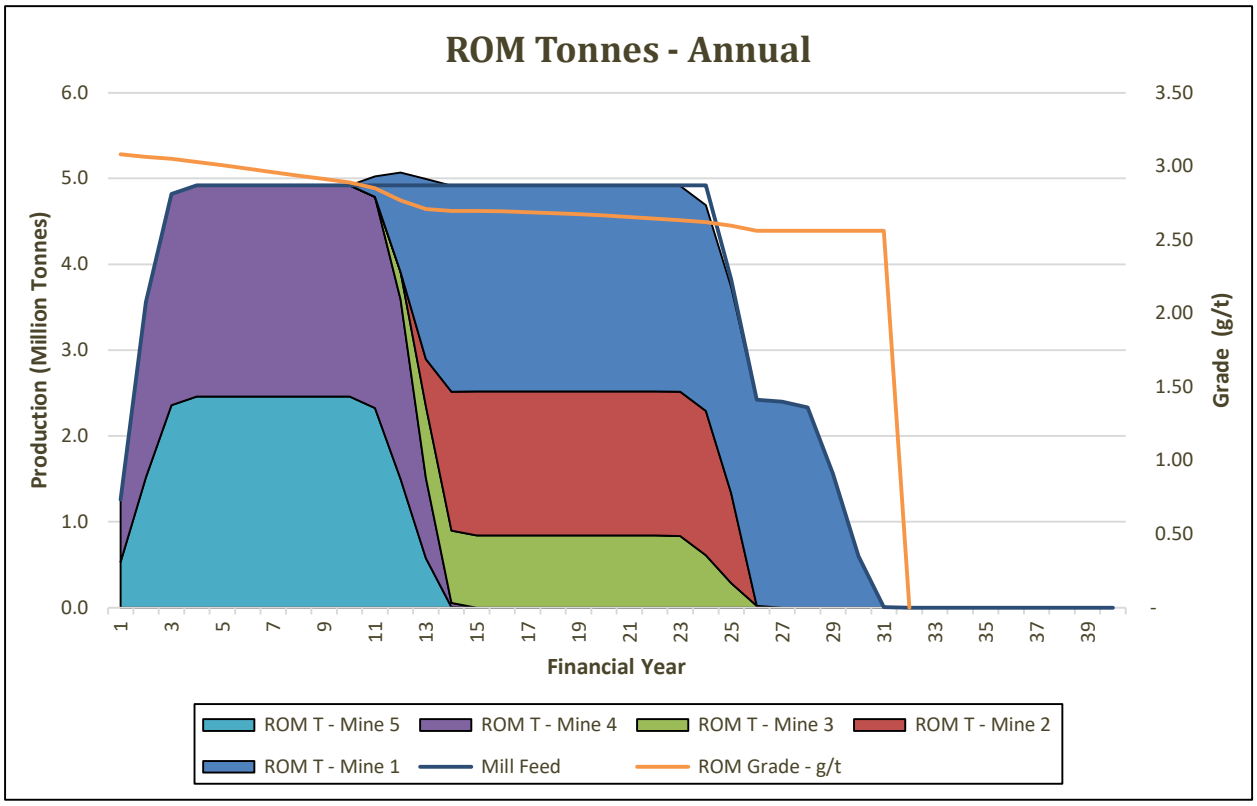

Figure 4.12: ROM Production profile for the tonnage-based modelling technique

Mine 5 and Mine 4 are each required to produce at 205 ktpm starting in the first month of the overall tonnage-based mining project. Mine 3 is required to start in month 134 by producing 70 ktpm. Mine 2 can only start after a minimum of twelve months (i.e. month 146) after Mine 3, and must produce 140 ktpm. Mine 1 starts in month 124 at a production rate of 200 ktpm.

Microeconomic modelling

The microeconomic modelling technique obtained a production rate of 270 ktpm with a resultant LOM of 41.5 years. Figure 4.13 depicts the LOM production profile for the microeconomic modelling technique.

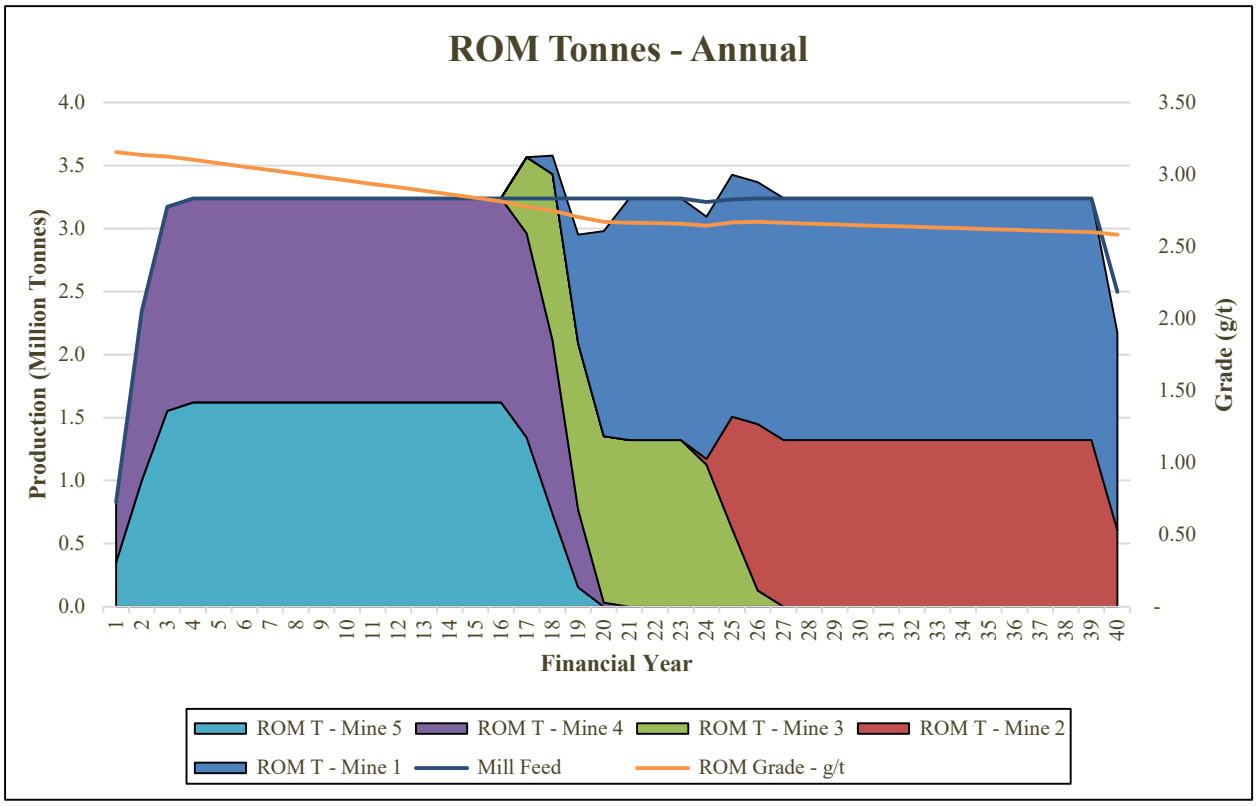

Figure 4.13: ROM Production profile for the Microeconomic modelling technique

Mine 5 and Mine 4 are each required to produce at 135 ktpm and start in the first month of the overall microeconomic mining project. Mine 3 is required to start in month 193 by producing 110 ktpm. Mine 2 can only start in month 285 due to having to conform to the overall microeconomic mining project's production target by succeeding mine three and must produce 110 ktpm. Mine 1 starts in month 209 at a production rate of 160 ktpm.

Marginal-analysis modelling

The marginal-analysis modelling technique obtained a production rate of 230 ktpm with a resultant LOM of 49.5 years. Figure 4.14 depicts the LOM production profile for the marginal-analysis modelling technique.

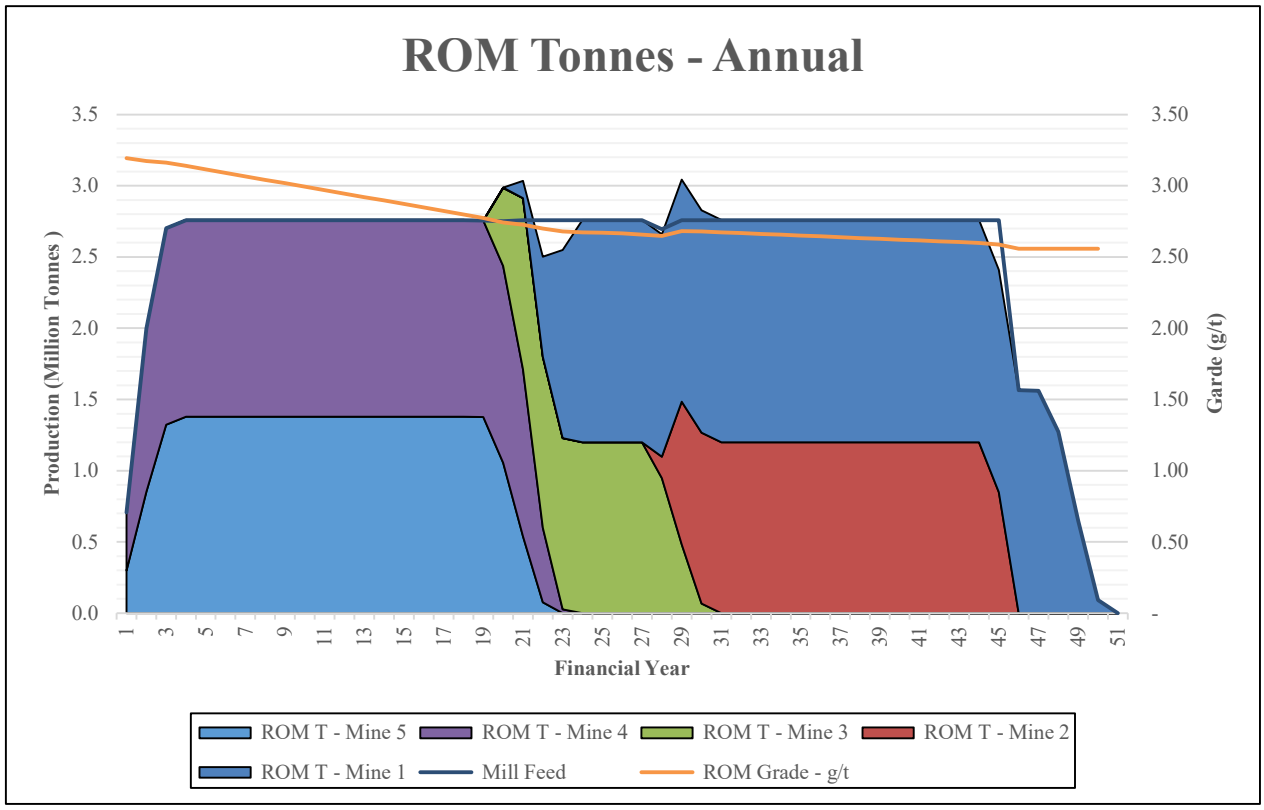

Figure 4.14: ROM Production profile - Marginal-analysis modelling

Mine 5 and Mine 4 are each required to produce at 115 ktpm and start in the first month of the overall marginal-analysis mining project. Mine 3 is required to start in month 229 by producing 100 ktpm. Mine 2 can only start in month 330 after conforming to the overall production target of the mining project by succeeding Mine 3 and has to produce 100 ktpm. Mine 1 starts in month 245 at a production rate of 245 ktpm.

4.4.2 Operational expenditure

The operational expenditure model from the original project's feasibility study was updated based on the three production rates calculated. Appendix F, Appendix G, Appendix H and Appendix I displays the costs. The overall direct mining OPEX for each respective modelling technique compares well with the feasibility study of the original mining project. The only cost component

that does differ from the feasibility study is the labour component, which is lower. This can be attributed to the total active underground mines at any point during the respective LOMs. To draw a suitable comparison, the labour models from the feasibility study and the microeconomic modelling technique were compared. The microeconomic modelling technique was chosen for this comparison since its production rate is the closest to that of the feasibility study. The feasibility study has a maximum of three active underground mines, whereas the microeconomic modelling technique has a maximum of two active mines. This additional active mine increases the required senior management and services required, which in effect increases the labour cost per mined tonne. The underground labour, services, mining support – cleaning, power, general surface maintenance, water cost and underground contractor cost made up the fixed cost portion of the mining cost. Explosives, drilling cost, support cost, and stores made up the variable cost portion of the mining cost.

Appendix G shows the engineering related to the OPEX. The original mining project's feasibility study and the modelling techniques compare well with each other, with no significant deviance recorded. The trackless mobile machinery (TM3) operating cost and the conveyor's cost constitute the fixed costs, and the engineering related mining costs are variable cost.

Appendix H shows the concentrator related operational costs. There are two noticeable differences in the concentrator OPEX between the original mining project's feasibility study, and the modelling techniques. The first difference is in the labour cost component and the second in the power cost component. The difference in both cost components is attributed to the fact that during the original mining project's feasibility study, the concentrator is be commissioned in the second financial year. For the modelling techniques, the concentrator is be commissioned during the first financial year.

Appendix I shows the concentrate OPEX costs. In the concentrator OPEX cost, the reagents cost component is not a fixed cost. All the modelling technique's concentrate costs compare well with that of the original mining project's feasibility study with no significant deviances recorded. The concentrate transportation cost component is deemed a variable cost, and the concentrate treatment cost component deemed a fixed cost.

Appendix J shows the summarised updated unit cost OPEX results for all the respective modelling techniques. Appendix K shows the summary unit OPEX per 4E ounce produced. The tonnage-based modelling technique has a cost that is 98.8% of that of the original mining project's feasibility

study. This is because of the economies of scale benefit. The cost of the microeconomic modelling technique relates well with that of the original mining project's feasibility study at 100.5% of the original cost. The cost of the marginal-analysis modelling technique is 101.9% of that of the original operational expenditure cost. This is due to the opposite of the tonnage-based modelling technique, whereby diseconomies of scale is reached. This results in the economies of scale being negatively affected by the lower monthly production output relative to the incurred fixed costs.

The summary shown in Appendix K does not reflect the same deviances for the original mining project's feasibility study costs as per Appendix J. This is due to the lower overall grade achieved during the LOM production in exploiting the Mineral Resource. The inclusion of Mine 1 with an average Mineral Reserve grade of 2.56 g/t, in effect, dilutes the overall produced grade to 2.78 g/t 4E. This is a 9.7% grade reduction from the feasibility study's grade of 2.88g/t. The feasibility study's average LOM grade was 2.88 g/t 4E, which means that for every 10.8 tonnes produced, an ounce of 4E is produced. This figure goes up for the rescheduled LOM production profiles that include Mine 1, with 6.7%. This means 11.5 tonnes has to be mined at an average grade of 2.78 g/t average 4E grade, for one ounce of 4E to be produced.

Appendix L shows a summary of unit OPEX per tonne divided into fixed, variable and SIB capital expenditure costs. Appendix M shows a summary of unit cost per ounce produced with the same deviance encountered as between Appendix J and Appendix K. Figure 4.15 shows the normalised mining cost of the original mining project feasibility study's position as indicated on the Southern African platinum cost curve.

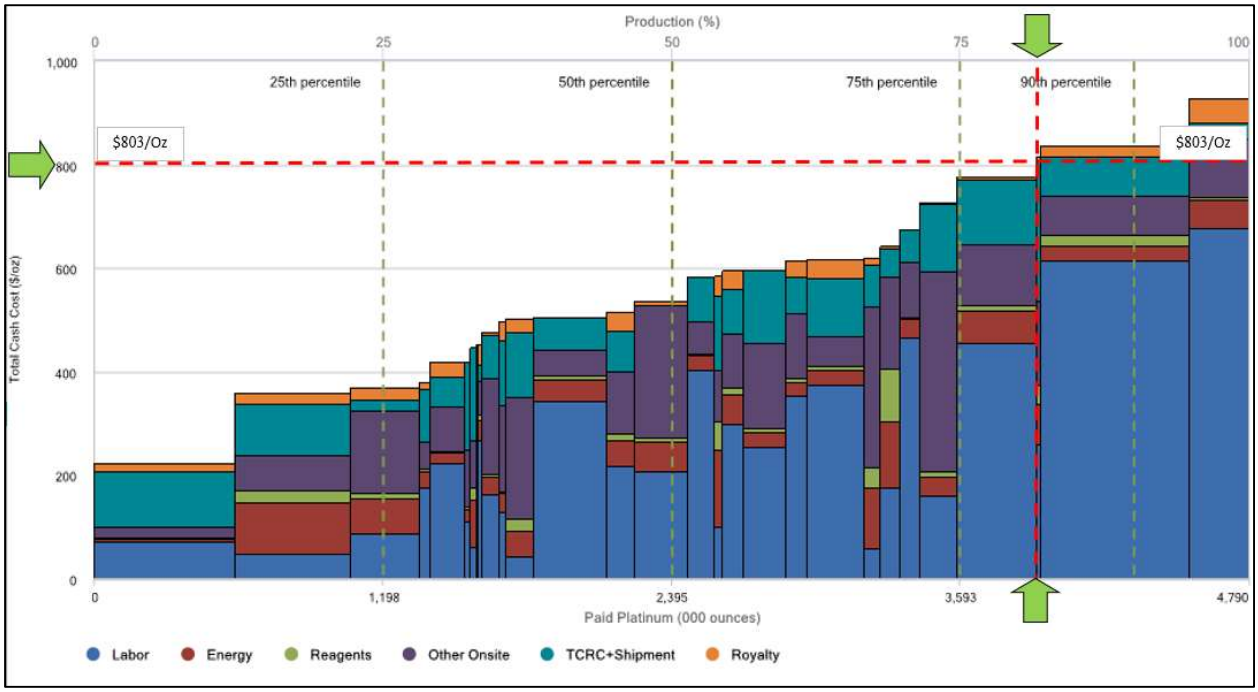

Figure 4.15: Southern African industry cost curve – Normalized

(Source: S&P_Global, 2020)

The original mining project feasibility study's position moved from within the 75th percentile (Figure 4.2) to the 90th percentile after escalation (86.5th percentile). All three production rate determination techniques resulted in the project falling outside of the industry cost curve as their cost per mined ounce exceeds USD1000 per mined ounce.

Mineral Resource tonnage-based modelling

The OPEX resulted in a total average LOM cost of USD75.37 per mined or milled tonne or USD1005.08 per 4E ounce as per Appendix Q. This total cost can be subdivided up into an average fixed cost of 48.52USD/tonne, an average variable cost of USD20.18/tonne and an average SIB cost of USD6.67/tonne.

Microeconomic modelling

The OPEX resulted in a total average LOM cost of USD76.48 per mined or milled tonne or USD1020.18 per 4E ounce as per Appendix Q. This total cost can be subdivided up into an average fixed cost of USD49.44/tonne, an average variable cost of USD20.18/tonne and an average SIB cost of USD6.86/tonne.

Marginal-analysis modelling

The OPEX resulted in a total average LOM cost of USD77.83 per mined or milled tonne or USD1038.27 per 4E ounce as per Appendix Q. This total cost can be subdivided up into an average fixed cost of USD50.61/tonne, an average variable cost of USD20.18/tonne and an average SIB cost of USD7.05/tonne.

4.4.3 Capital expenditure

As with the operational expenditure, the original mining project feasibility study's CAPEX data was collected in 2016. This meant that the CAPEX data had to be escalated by applying the factors in Table 3.5. After the escalation process, the original mining project feasibility study's capital budget estimate was updated to reflect each of the production rates as determined by the respective modelling techniques. This entailed updating all the individual line items of the capital budget estimate in line with the production rate for the respective modelled technique. This updating process was based on benchmarked costs and factorization of existing costs where no benchmark costs were available.

Appendix N displays the results obtained from the escalation process, along with the updated CAPEX for each of the respective modelling techniques. The CAPEX for the original mining project's feasibility study after the escalation process amounted to USD593.99 million. The original mining project's feasibility study was based on four individual mines that mined all except Mine 1's Mineral Resource. The three modelling techniques analysed in this study included all the five individual mines mentioned in previous sections and included the whole of the Mineral Resource. Thus, the increase in CAPEX on the underground mining's side can be attributed to the additional costs associated with Mine 1. Also, provision was made for the increase or decrease associated with the individual mine's production rates. On the concentrator's side, the additional CAPEX is attributed to the required increase in the overall concentrating and processing capacity for the tonnage-based technique only. The overall infrastructural and project indirect cost requirements were adjusted or factorised in line with the overall production rate for each of the respective modelling techniques.

Appendix O and Appendix P, show the unit CAPEX per mined tonne and mined 4E ounce, respectively. In both Appendix O and Appendix P, the original mining project feasibility study's

unit cost, USD per tonne and USD per ounce, are higher than that of the techniques analysed in this study. This is due to the increase in total mined Mineral Resource included by the modelled techniques compared to the original mining project's feasibility study.

The Mineral Resource tonnage-based modelling techniques yielded the highest CAPEX, which totalled USD957.24 million spread over the first eighteen years of operation. The microeconomic modelling technique accounted for the second-highest CAPEX that totalled USD726.24 million spread over the first twenty-five years of underground production. The marginal-analysis modelling technique accounted for the lowest CAPEX, totalling USD658.76 million spread over the first thirty-one years of operation. Figure 4.16 depicts the LOM CAPEX for each of the modelled techniques used as input parameter for the DCF modelling.

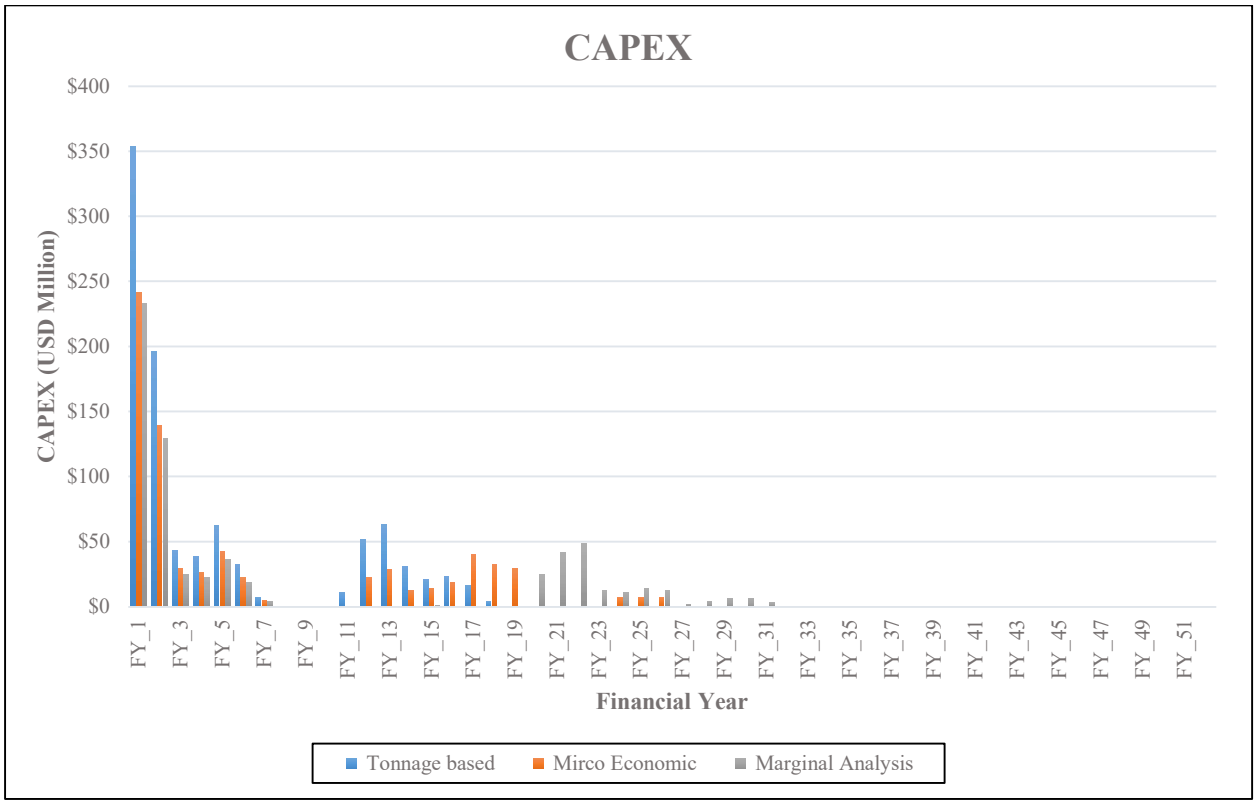

Figure 4.16: DCF results – Capital expenditure

4.4.4 SIB CAPEX

SIB Capex was calculated as 14.32% of the total fixed cost for the original mining project's feasibility study and only started in the third financial year. The SIB Capex, as per the original mining project's feasibility study, was replicated during the DCF modelling for each of the three modelling techniques analysed.

4.4.5 Royalty tax

The royalty payable is calculated according to the Mineral and Petroleum Resource Royalty Act 28 of 2008 for unrefined minerals, which is capped at a maximum of 7%.

4.4.6 Input data used to calculate revenue

Table 4.6 shows the prill splits and recovery rates used in this study, while Table 4.7 shows the commodity prices used in the study. These were collected from the original project's feasibility study. A 4E prill split is a representation of the percentages of constituent metals that make up the 4E grade.

Table 4.6: Prill split and processing recovery

Description	Prill split (%)	Recovery (%)
Platinum	53.70	84.20
Palladium	35.60	83.20
Rhodium	3.20	80.60
Gold	7.50	86.60
4E Average	**100.00**	**83.90**

Table 4.7: Metal price assumptions

Metal prices				
Description	**Price**	**Units**	**Price**	**Units**
Platinum	1 350.00	USD/oz	43.40	USD/g
Palladium	900.00	USD/oz	28.94	USD/g
Rhodium	1 050.00	USD/oz	33.76	USD/g
Gold	1 248.00	USD/oz	40.12	USD/g
4E Basket – Pre-Recovery	1 173.00	USD/oz	37.70	USD/g
4E Basket – Post-Recovery	985.00	USD/oz	31.67	USD/g

4.5 DCF Results and analysis

4.5.1 Cumulative cashflows

The tonnage-based modelling technique has the highest discounted NPV and IRR, followed by the macroeconomic modelling technique. The marginal-analysis modelling technique had the lowest discounted NPV and IRR. Figure 4.17 graphically represents all of the various considered options' s cumulative cash flows.

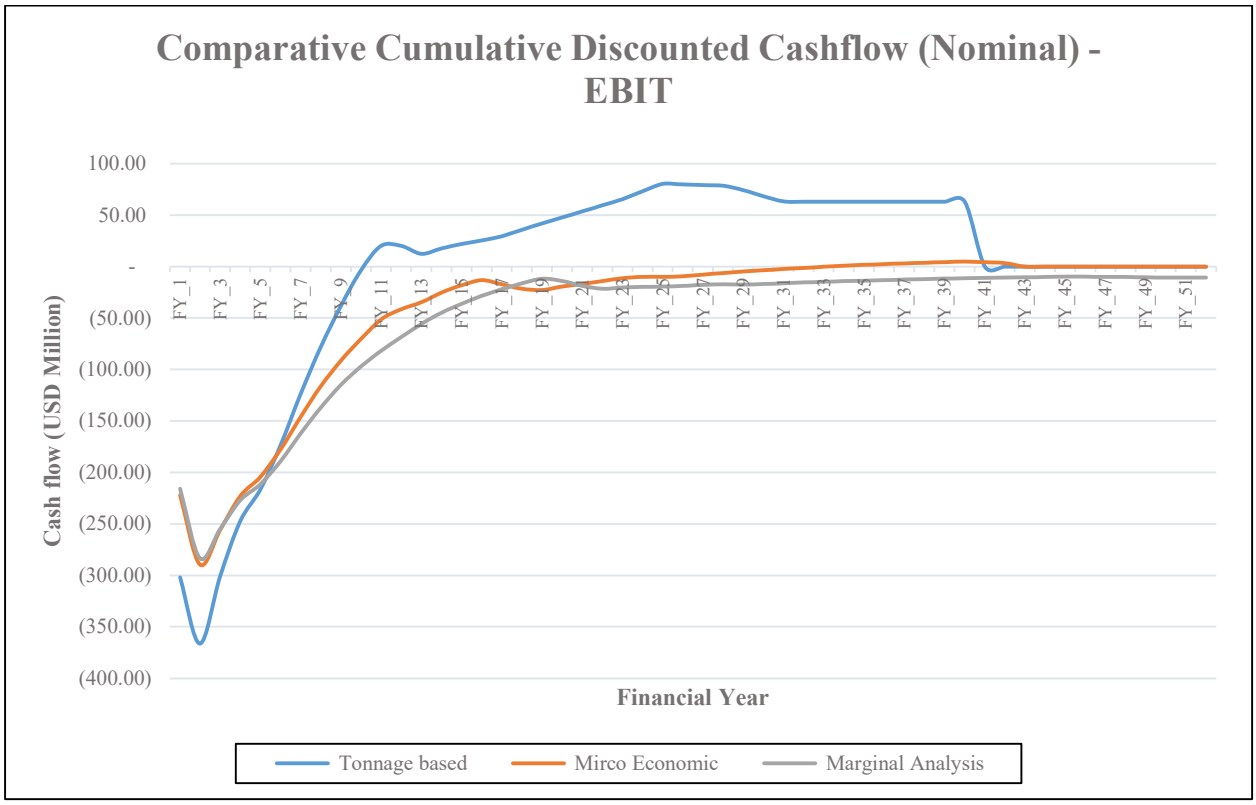

Figure 4.17: DCF results – Cumulative cashflow

Mineral Resource tonnage-based modelling

The peak capital funding for the tonnage-based modelling technique amounted to USD409.83 million incurred in the second financial year. The payback period for the tonnage-based modelling technique is ten years. The DCF results equalled an NPV of USD63.12 million at an IRR of 12.85%.

Microeconomic modelling

The peak capital funding for the microeconomic modelling technique amounts to USD325.62 million incurred in the second financial year. The payback period for the microeconomic modelling technique is thirty-three years. The DCF results equalled an NPV of USD3.49 million at an IRR of 10.17%.

Marginal-analysis modelling

The peak capital funding for the marginal-analysis modelling technique amounts to USD318.86 million incurred in the second financial year. The marginal-analysis modelling technique does not manage to pay back the capital incurred during the initial years of the mining project. The DCF results equalled an NPV of negative USD10.69 million at an IRR of 9.47%.

4.5.2 NPV results and analysis

Figure 4.18 and Appendix Q displays the summary of the final results obtained from the DCF modelling.

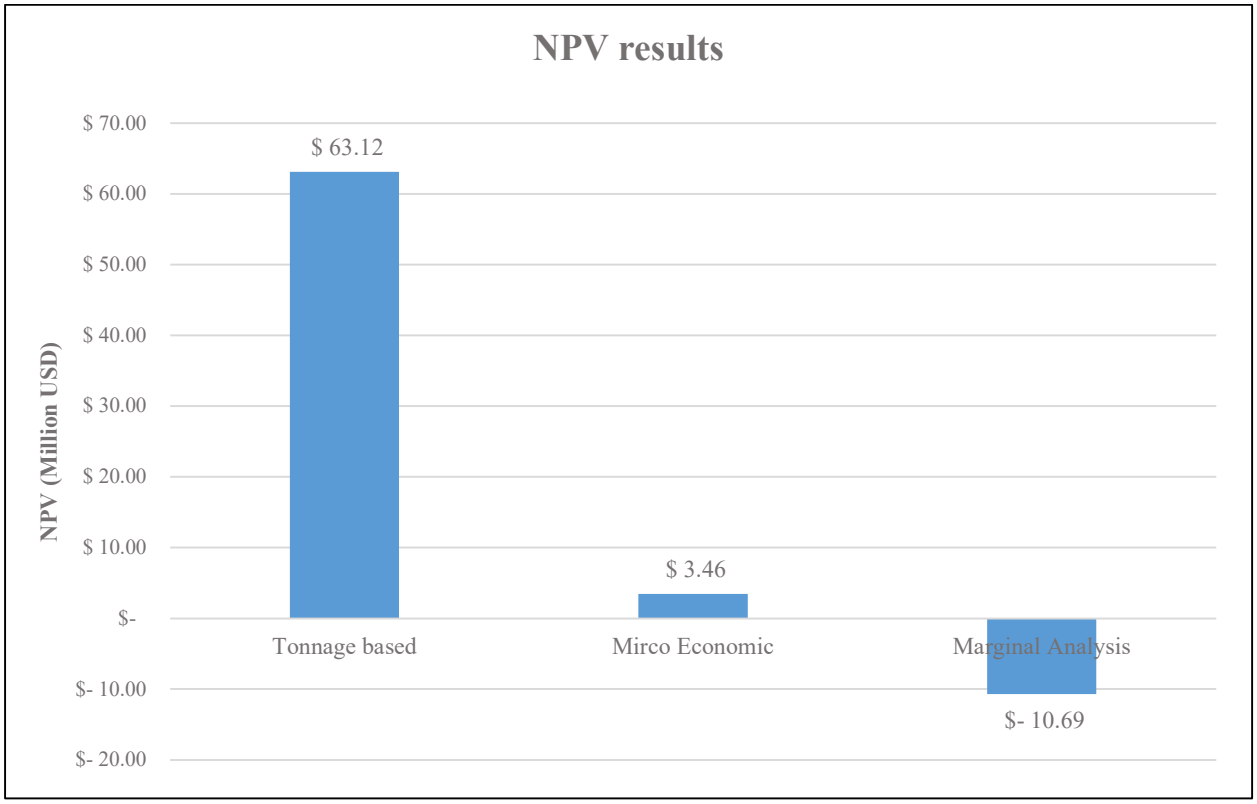

Figure 4.18: DCF results

Figure 4.18 shows that the tonnage-based modelling technique has the highest NPV, followed by the macroeconomic modelling and, lastly, the marginal-analysis modelling technique. Observations revealed that the tonnage-based modelling technique managed to accumulate value much quicker early in the LOM due to its higher production rate. The other two considered options were unable to match this technique in acquiring early value due to lower rates of production. It was also noted that the maximum NPV's are not incurred at the end of the LOM. The NPVs are reduced during the end of the LOM production profiles.

The final results obtained from the financial valuation for the original mining project's feasibility study was that the mining project was financially viable. The results obtained included an overall project NPV of USD225 million over the tested twenty years of production, including an IRR of 18.99%.

4.6 Chapter summary

This chapter constitutes the data analysis component of the study. The analysis of the collected data includes the original mining project's Mineral Resource model, the extraction strategy, LOM production profiles, OPEX and CAPEX models and financial models. The original mining project's feasibility study was indicated on the platinum industry cost curve before and after the original mining project's data escalation. The analysed data was used to assess the three optimal production rate determination modelling techniques. Analysis of the three techniques resulted in three different rates of production. The tonnage-based modelling technique resulted in a production rate of 410 ktpm, whilst the microeconomic modelling technique resulted in 270 ktpm, and finally the marginal-analysis modelling technique resulted in 230 ktpm.

The respective production rates were then used as the basis for updating the LOM production schedules, OPEX and CAPEX models. Data obtained through this process, along with financial data from the original mining project, was then used as input into a DCF model. The DCF validation of the three modelling techniques was utilised to determine the most optimal modelling technique. The Tonnage-based modelling technique's DCF resulted in an NPV of USD63.12 million at an IRR of 12.85%. The microeconomic modelling technique's DCF resulted in an NPV of USD3.49 million at an IRR of 10.17%. The marginal-analysis technique resulted in an NPV of negative USD10.69 million at an IRR of 9.47%. Therefore, the tonnage-based modelling technique was

found to be the most optimal production rate determination technique from the three tested modelling techniques.

5 CONCLUSIONS AND RECOMMENDATION

5.1 Chapter overview

This chapter concludes the research work. The results from each of the techniques modelled are discussed, together with the results from the DCF analysis. From the conclusion, recommendations are derived and presented for future work to be undertaken. Research limitations encountered during this study are also discussed.

5.2 Research findings

5.2.1 Tonnage-based modelling

The tonnage-based modelling technique is a simple technique that only requires the Mineral Resource model information. By applying the relevant equation (e.g. Equation 3 or Equation 4) as per Table 2.1, to the total available Mineral Resource, a production rate is obtained. The production rate obtained during the modelling of the resource tonnage-based modelling technique was the highest of all of the modelled techniques at 410 ktpm. This production rate resulted in the fastest depletion of the reviewed Mineral Resource with a LOM of just over 30 years. This overall high production rate did require that the respective underground mines be significantly upgraded to enable the higher required production rates. This required that the maximum individual underground mine production rate be increased from 140 ktpm to 205 ktpm for Mine 4 and 5. Mine 2 and Mine 3's production rate increased to 70 ktpm and 140 ktpm, respectively. As Mine 1 was not planned during the original mining project's feasibility study, the 200 ktpm underground mine was an addition to the project. Figure 4.12 shows that Mines 4 and 5 will be mined concurrently at a total production rate of 410 ktpm, which will be followed by Mines 3, 2 and 1 being mined concurrently producing a total of 410 ktpm.

The high production rate resulted in the lowest operational expenditure cost of all modelled techniques with a USD75.37 per mined tonne. This is a 1% reduction in cost per tonne in relation to the original mining project's feasibility study. This cost reduction is mainly attributed to the economies of scale concept whereby the fixed costs are diluted with additional production output. The CAPEX for the tonnage-based modelling technique is USD957.24 million, which is the highest

overall CAPEX based on the highest required production output. The payback period for the tonnage-based modelling technique was the lowest with 8 years.

5.2.2 Microeconomic modelling

The microeconomic modelling technique requires Mineral Resource information, commodity price and cost data. This modelling technique starts by calculating total fixed cost, total variable cost and total revenue, from which the total cost curves are drawn. These costs are then used to calculate unit cost from which the unit cost curve graphs are drawn. From the unit cost curve graph, the production rate is determined when the marginal cost curve intersects the ATC curve. The production rate obtained from the microeconomic modelling technique resulted in the second-highest production rate overall with 270 ktpm. This resulted in Mine 4 and 5 having a slightly reduced production rate of 135 ktpm. Changes were incurred on Mine 2 and 3, which had to be upscaled to 110 ktpm to balance the overall production output with that of Mine 1. Mine 1's required production rate was determined to be 160 ktpm. Figure 4.13 shows that Mines 4 and 5 will be mined concurrently at a total production rate of 270 ktpm, which will be followed by Mines 3 and 1 being mined concurrently producing a total of 270 ktpm. Mine 2 will only be mined after Mine 3 is depleted in order to maintain the 270 ktpm production rate.

The operational expenditure for the microeconomic modelling technique resulted in USD76.68 per mined tonne. This is 0.4% more on a unit cost base and does correlate well with the OPEX for the original mining project's feasibility study. CAPEX for the microeconomic modelling technique amounted to USD726.24 million and ranked the second highest CAPEX modelled. The payback period for this technique was 9 years, which was the second-lowest payback period.

5.2.3 Marginal-analysis modelling

The marginal-analysis modelling technique requires input data which include the costs, metal price, Mineral Reserve and the financial information of the project to determine the production rate. The inputs are used to calculate PVMR and PVMC using Equation 13, 14, 16, and 17. The point at which PVMR intersects PVMC determines the optimal production rate. Applying this modelling technique resulted in a production rate of 230 ktpm. This is the lowest production rate obtained from all of the tested modelling techniques. This resulted in Mine 4 and 5 being sized to produce at 115 ktpm each, Mine 2 and 3 to produce at 100 ktpm and Mine 1 to produce at 130 ktpm

respectively. Figure 4.14 shows that Mines 4 and 5 will be mined concurrently at a total production rate of 230 ktpm, which will be followed by Mines 3 and 1 being mined concurrently producing a total of 230 ktpm. Mine 2 will only be mined after Mine 3 is depleted in order to maintain the 230 ktpm production rate.

The operational expenditure for the marginal-analysis modelling technique averaged USD77.83 per mined tone through the LOM. This is 2.2% more per mined tonnes through the LOM than that of the original mining project's feasibility study. The respective mine's production outputs directed the process of updating the capital expenditure, which amounted to USD658.76 million. This is the lowest CAPEX incurred on all the tested techniques during this study and reflects the lowest production rate modelled. The marginal-analysis modelling technique's payback period was 10 years. This was the longest payback period from all of the modelling techniques tested during this study.

5.3 Conclusions

The DCF results for the tonnage-based modelling resulted in an NPV of USD63.12 million and an IRR of 12.85%. The microeconomic modelling DCF resulted in an NPV of USD3.46 million and an IRR of 10.17%. The marginal-analysis modelling technique was the worst-performing technique with an NPV of -USD10.69 million and an IRR of 9.47%. This technique obtained the best peak capital funding, followed by the microeconomic technique and, lastly, the tonnage-based technique. The best payback period was incurred by the tonnage modelling technique, where the capital was paid off within the first eight years of the LOM. Therefore, the optimal production rate determination modelling technique was determined to be the tonnage-based modelling technique. This was followed by the microeconomic technique and, lastly, the marginal-analysis technique.

5.4 Research limitations

This research study was limited to the original mining project's feasibility study reviewed during this study, including all data that was utilised during this study. Therefore, the findings of this study can be limited to similar mining operations under similar mining and market conditions. In addition this research study did not consider any owner preferences or sensitivities, such as operational capacity, operational readiness or capital sensitivity, among others. These factors may limit the

overall outcomes and the resultant final production rate of similar projects when subjected to such factors, preferences and sensitivities.

5.5 Recommendations for optimised production rate determination

Mineral Resource tonnage-based modelling may be further investigated in other commodities other than platinum or other multi-element/polymetallic mineral deposits in line with the South African mining industry. This will result in a South African mining industry-specific calibration to be formulated that will yield industry-specific coefficients for a South African context.

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7 APPENDICES

Appendix A: Ethical clearance certificate from the University of the Witwatersrand

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

SCHOOL OF MINING ETHICS COMMITTEE
CONSTITUTED UNDER THE UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: EMINN/2020/04W**
PROJECT TITLE	A comparison of various modelling techniques to optimize production rate on a platinum mining project
INVESTIGATOR	Mr Jaco Dreyer
SCHOOL/DEPARTMENT OF INVESTIGATOR	School of Mining
DATE CONSIDERED	12 October 2020
DECISION OF THE COMMITTEE	Approved unconditionally
RISK LEVEL	NO RISK
EXPIRY DATE	12 October 2023

ISSUE DATE OF CERTIFICATE 08 February 2021 **CHAIRPERSON** _____
(Mr H Thomas)

cc: Supervisor: Tinashe Tholana

DECLARATION OF INVESTIGATOR

To be completed in duplicate and ONE COPY returned to the Chairperson of the School/Department ethics committee.

I fully understand the conditions under which I am are authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

Signature _____ **Date** 12/02/2021

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Appendix B: Direct mining operational expenditure

Cost Component	Total Mined Tonnes - Mil	Total Cost - (USD Mil)	Cost per Mined Tonne (USD/t)	Total Mined Oz	Cost per Mined Tonne (USD/oz)
Underground Labour	60.37	672.16	11.13	5.72	117.41
Explosives	60.37	101.45	1.68	5.72	17.72
Drilling costs	60.37	287.79	4.77	5.72	50.27
Support Cost	60.37	113.01	1.87	5.72	19.74
Stores	60.37	6.47	0.11	5.72	.13
Services	60.37	86.71	1.44	5.72	15.15
Mining support - Cleaning	60.37	144.92	2.40	5.72	25.31
Power	60.37	115.36	1.91	5.72	20.15
General Surface Maintenance	60.37	38.50	0.64	5.72	6.72
Water Cost	60.37	0.60	0.01	5.72	0.10
Underground Contractor cost	60.37	12.28	0.20	5.72	2.15
Direct Mining OPEX Cost	**60.37**	**1 579.25**	**26.16**	**5.72**	**275.86**

Appendix C: Engineering related operational expenditure

Cost Component	Total Mined Tonnes - Mil	Total Cost - (USD Mil)	Cost per Mined Tonne (USD/t)	Total Mined Oz	Cost per Mined Tonne (USD/oz)
Engineering - TM3 Operating Cost	60.37	453.92	7.52	5.72	79.29
Engineering - Conveyors	60.37	2.09	0.03	5.72	0.37
Engineering Related Mining Costs	60.37	21.77	0.36	5.72	3.80
Total Engineering OPEX Cost	**60.37**	**477.78**	**7.91**	**5.72**	**83.46**

Appendix D: Concentrator related operation expenditure

Cost Component	Total Mined Tonnes - Mil	Total Cost - ($ Mil)	Cost per Mined Tonne (USD/t)	Total Mined Oz	Cost per Mined Tonne (USD/oz)
Concentrator Labour	60.37	55.14	0.91	5.72	9.63
Power Cost	60.37	361.53	5.99	5.72	63.15
Liners	60.37	22.69	0.38	5.72	3.96
Grinding Media	60.37	119.35	1.98	5.72	20.85
Reagents	60.37	206.21	3.42	5.72	36.02
Maintenance	60.37	41.64	0.69	5.72	7.27
Laboratory	60.37	15.32	0.25	5.72	2.68
TSF Deposition Cost	60.37	8.74	0.14	5.72	1.53
Concentrator OPEX Costs	**60.37**	**830.63**	**13.76**	**5.72**	**145.09**

Appendix E: Concentrate operational expenditure

Cost Component	Total Mined Tonnes - Mil	Total Cost - (USD Mil)	Cost per Mined Tonne (USD/t)	Total Mined Oz	Cost per Mined Tonne (USD/oz)
Concentrate transportation	60.37	230.78	3.82	5.72	40.31
Concentrate Treatment	60.37	269.37	4.46	5.72	47.05
Concentrate Costs	**60.37**	**500.14**	**8.28**	**5.72**	**87.36**

Appendix F: Direct mining operational expenditure – Normalised original mining project's feasibility study vs production rate determination techniques

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**
Underground Labour (USD/Ton)	13.90	10.39	11.54	12.30
Explosives (USD/Ton)	2.10	2.13	2.13	2.13
Drilling costs (USD/Ton)	5.96	6.04	6.05	6.05
Support Cost (USD/Ton)	2.34	2.37	2.38	2.37
Stores (USD/Ton)	0.14	0.14	0.14	0.14
Services (USD/Ton)	1.80	1.82	1.82	1.82
Mining support - Cleaning (USD/Ton)	3.00	3.04	3.05	3.04
Power (USD/Ton)	2.39	2.86	2.48	2.29
General Surface Maintenance (USD/Ton)	0.80	0.80	0.81	0.81
Water Cost (USD/Ton)	0.01	0.01	0.01	0.01
Underground Contractor cost (USD/Ton)	0.25	-	-	-
Direct Mining OPEX Cost (USD/Ton)	**32.68**	**29.60**	**30.40**	**30.96**

Appendix G: Engineering related operational expenditure – Normalised original mining project's feasibility study vs production rate determination techniques

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**
Engineering - TM3 Operating Cost (USD/Ton)	9.39	9.79	9.86	9.96
Engineering - Conveyors (USD/Ton)	0.04	0.04	0.05	0.06
Engineering Related Mining Costs (USD/Ton)	0.45	0.46	0.46	0.46
Total Engineering OPEX Cost (USD/Ton)	**9.88**	**10.30**	**10.37**	**10.49**

Appendix H: Concentrator related operation expenditure – Normalised original mining project's feasibility study vs production rate determination techniques

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**
Concentrator Labour (USD/Ton)	1.14	1.08	1.46	1.72
Power Cost (USD/Ton)	7.48	8.71	8.57	8.53
Liners (USD/Ton)	0.47	0.47	0.47	0.47
Grinding Media (USD/Ton)	2.47	2.47	2.48	2.47
Reagents (USD/Ton)	4.27	4.27	4.28	4.27
Maintenance (USD/Ton)	0.86	0.86	0.86	0.86
Laboratory (USD/Ton)	0.31	0.32	0.32	0.32
TSF Deposition Cost (USD/Ton)	0.17	0.18	0.18	0.18
Concentrator OPEX Costs (USD/Ton)	**17.19**	**18.36**	**18.62**	**18.83**

Appendix I: Concentrate operational expenditure – Normalised original mining project's feasibility study vs production rate determination techniques

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**
Concentrate transportation (USD/Ton)	4.77	4.77	4.78	4.78
Concentrate Treatment (USD/Ton)	5.57	5.57	5.58	5.58
Concentrate Costs (USD/Ton)	**10.34**	**10.34**	**10.36**	**10.36**

Appendix J: Operation expenditure summary USD per tonne – Normalised original mining project's feasibility study vs production rate determination techniques

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**
Total Underground Mining Cost (USD/Ton)	42.85	39.90	40.78	41.45
Contractor Mining Cost - Underground (USD/Ton)	-	-	-	-
Concentrate Costs (USD/Ton)	10.34	10.34	10.36	10.36
Concentrator (USD/Ton)	17.19	18.36	18.62	18.83
SIB (USD/Ton)	6.06	6.93	7.09	7.22
Total Cost + SIB (USD/Ton)	**76.44**	**75.53**	**76.85**	**77.86**

Appendix K: Operation expenditure summary USD per 4E ounce – Normalised original mining project's feasibility study vs production rate determination techniques

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined Oz**	**Cost per Mined Oz**	**Cost per Mined Oz**	**Cost per Mined Oz**
Total Underground Mining Cost (USD/Oz)	448.79	532.02	543.73	552.72
Contractor Mining Cost - Underground (USD/Oz)	-	-	-	-
Concentrate Costs (USD/Oz)	109.07	137.92	138.20	138.14
Concentrator (USD/Oz)	181.26	244.81	248.24	251.15
SIB (USD/Oz)	63.89	92.45	94.58	96.29
Total Cost + SIB (USD/Oz)	**803.00**	**1007.20**	**1024.74**	**1038.30**

Appendix L: Fixed and variable cost breakdown USD per tonne – Normalised original mining project's feasibility study vs production rate determination techniques

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**
Mining Fixed Cost (USD/Ton)	22.15	18.93	19.71	20.27
Mining Variable (USD/Ton)	10.53	10.67	10.69	10.69
Engineering Fixed Cost (USD/Ton)	9.43	9.83	9.91	10.03
Engineering Variable Cost (USD/Ton)	0.45	0.46	0.46	0.46
Concentrator Fixed Cost (USD/Ton)	12.92	14.09	14.34	14.56
Concentrator Variable Cost (USD/Ton)	4.27	4.27	4.28	4.27
Concentrate Fixed Cost (USD/Ton)	5.57	5.57	5.58	5.58
Concentrate Variable Cost (USD/Ton)	4.77	4.77	4.78	4.78
SIB (USD/Ton)	6.06	6.93	7.09	7.22
Total Fixed Cost (USD/Ton)	50.07	48.42	49.54	50.44
Total Variable Cost (USD/Ton)	20.02	20.18	20.22	20.21
Total Cost (USD/Ton)	**76.44**	**75.53**	**76.85**	**77.86**

Appendix M: Fixed and variable cost breakdown USD per 4E ounce – Normalised original mining project's feasibility study vs production rate determination techniques

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined Oz**	**Cost per Mined Oz**	**Cost per Mined Oz**	**Cost per Mined Oz**
Mining Fixed Cost (USD/Oz)	233.55	252.42	262.80	270.27
Mining Variable (USD/Oz)	111.05	142.32	142.60	142.54
Engineering Fixed Cost (USD/Oz)	99.45	131.10	132.12	133.72
Engineering Variable Cost (USD/Oz)	4.74	6.19	6.20	6.20
Concentrator Fixed Cost (USD/Oz)	136.20	187.89	191.21	194.15
Concentrator Variable Cost (USD/Oz)	45.05	56.92	57.03	57.00
Concentrate Fixed Cost (USD/Oz)	58.75	74.29	74.44	74.41
Concentrate Variable Cost (USD/Oz)	50.32	63.63	63.76	63.73
SIB (USD/Oz)	38.67	92.45	94.58	96.29
Total Fixed Cost (USD/Oz)	527.96	645.70	660.58	672.54
Total Variable Cost (USD/Oz)	211.16	269.05	269.59	269.47
Total Cost (USD/Oz)	**803.00**	**1007.20**	**1024.74**	**1038.30**

Appendix N: Total Capex

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Total Cost - ($ Mil)**	**Total Cost - ($ Mil)**	**Total Cost - ($ Mil)**	**Total Cost - ($ Mil)**
Underground Mining (USD Mil)	260.82	502.96	404.40	346.28
Concentrator (USD Mil)	153.13	251.71	153.13	153.13
Infrastructure (USD Mil)	63.79	76.04	60.39	58.74
Indirect Cost (USD Mil)	116.25	126.53	108.33	100.62
Other (USD Mil)	-	-	-	-
Capital Budget Estimate (USD Mil)	**593.99**	**957.24**	**726.24**	**658.76**

Appendix O: Unit CAPEX (USD per tonne mined)

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**	**Cost per Mined Tonne**
Underground Mining (USD/Ton)	4.32	3.99	3.21	2.75
Concentrator (USD/Ton)	2.54	2.00	1.21	1.21
Infrastructure (USD/Ton)	1.06	0.60	0.48	0.47
Indirect Cost (USD/Ton)	1.93	1.00	0.86	0.80
Other (USD/Ton)	-	-	-	-
Capital Budget Estimate (USD/Ton)	**9.84**	**7.59**	**5.76**	**5.22**

Appendix P: Unit CAPEX (USD per 4E ounce mined)

	Original Mining Project	Tonnage based	Micro Economic	Marginal Analysis
Cost Component	**Cost per Mined OZ**	**Cost per Mined OZ**	**Cost per Mined OZ**	**Cost per Mined OZ**
Underground Mining (USD/Oz)	45.56	44.63	35.88	30.72
Concentrator (USD/Oz)	26.75	22.33	13.59	13.59
Infrastructure (USD/Oz)	11.14	6.75	5.36	5.21
Indirect Cost (USD/Oz)	20.31	11.23	9.61	8.93
Other (USD/Oz)	-	-	-	-
Capital Budget Estimate (USD/Oz)	**103.76**	**84.93**	**64.44**	**58.45**

Appendix Q: DCF results

	Tonnage based	Microeconomic	Marginal analysis
Production rate (Ktpm)	410.00	270.00	230.00
LOM (Years)	31.00	42.00	50.00
NPV Discounted @ 10% (USD Mil)	63.12	3.46	-10.69
IRR (%)	12.85	10.17	9.47
Payback Period (Years)	10	33	No Payback
Project Average Cost – OPEX (USD/Ton)	75.37	76.48	77.83
Project Average Fixed Cost - OPEX (USD/Ton)	48.52	49.44	50.61
Project Average Variable Cost - OPEX (USD/Ton)	20.18	20.18	20.18
Project Average SIB Cost - OPEX (USD/Ton)	6.67	6.86	7.05
Project Average Cost - OPEX (USD/Oz)	1005.08	1020.18	1038.27
Project Average Fixed Cost - OPEX (USD/Oz)	647.07	659.53	675.06
Project Average Variable Cost - OPEX (USD/Oz)	269.05	269.16	269.15
Project Average SIB Cost - OPEX (USD/Oz)	88.96	91.50	94.06

Appendix R: Integration of production rate with Mineral Resource modelling – 270 000 tpm

Cut-off Grade (g/t)	Ave Grade (g/t)	Tons	Ounces	Payability (%)	Revenue (USD)	Royalty (USD)	OP. Cost (USD)	Op. Profit (USD)	LOM (Years)	LOM Profit (USD)	NPV (USD)	NPV POST CAPEX (USD)
0	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
0.1	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
0.2	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
0.3	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
0.4	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
0.5	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
0.6	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
0.7	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
0.8	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
0.9	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
1	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
1.1	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
1.2	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
1.3	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
1.4	2.85	219 970 319	20 121 051	100.00	22 827 352	433 720	23 050 270	- 222 918	67.90	- 181 612 349	- 281 132	-594 274 819
1.5	2.85	219 941 443	20 119 681	99.99	22 828 795	433 747	23 050 297	- 221 502	67.90	- 180 435 070	- 279 547	-594 273 234
1.6	2.85	219 650 065	20 104 764	99.85	22 842 130	434 000	23 050 550	- 208 421	67.80	- 169 554 091	- 264 950	-594 258 637
1.7	2.85	218 795 063	20 058 711	99.47	22 878 864	434 698	23 051 248	- 172 385	67.50	- 139 692 177	- 223 847	-594 217 534
1.8	2.85	218 168 652	20 023 370	99.18	22 904 130	435 178	23 051 728	- 147 599	67.30	- 119 264 502	- 194 667	-594 188 354
1.9	2.86	216 033 404	19 896 479	98.21	22 983 930	436 695	23 053 245	- 69 315	66.70	- 55 460 597	- 96 393	-594 090 080
2	2.88	213 328 005	19 728 071	96.98	23 078 401	438 490	23 055 040	23 361	65.80	18 457 816	34 738	-593 958 949
2.1	2.88	211 644 275	19 617 535	96.21	23 131 663	439 502	23 056 052	75 612	65.30	59 269 620	117 210	-593 876 476
2.2	2.90	206 045 420	19 231 734	93.67	23 292 947	442 566	23 059 116	233 831	63.60	178 443 978	416 068	-593 577 619
2.3	2.92	201 515 416	18 903 140	91.61	23 409 635	444 783	23 061 333	348 302	62.20	259 956 146	692 526	-593 301 161
2.4	2.94	195 075 194	18 415 507	88.68	23 558 661	447 615	23 064 165	494 497	60.20	357 274 120	1 150 309	-592 843 378
2.5	2.96	184 699 472	17 599 826	83.97	23 779 990	451 820	23 068 370	711 621	57.00	486 799 846	2 126 761	-591 866 926
2.6	2.99	172 353 558	16 587 109	78.35	24 017 036	456 324	23 072 874	944 162	53.20	602 702 678	3 786 141	-590 207 546
2.7	3.03	156 927 534	15 273 384	71.34	24 288 745	461 486	23 078 036	1 210 709	48.40	703 680 039	6 958 960	-587 034 727
2.8	3.09	128 909 494	12 793 965	58.60	24 767 902	470 590	23 087 140	1 680 762	39.80	802 467 240	18 094 287	-575 899 400
2.9	3.17	96 760 041	9 848 735	43.99	25 401 150	482 622	23 099 172	2 301 978	29.90	824 961 061	47 893 172	-546 100 515
3	3.23	74 735 640	7 759 852	33.98	25 911 624	492 321	23 108 871	2 802 753	23.10	775 798 209	86 091 863	-507 901 824
3.1	3.30	54 262 120	5 759 559	24.67	26 488 750	503 286	23 119 836	3 368 914	16.70	677 053 365	137 213 265	-456 780 422
3.2	3.35	40 463 109	4 364 337	18.39	26 917 082	511 425	23 127 975	3 789 107	12.50	567 848 342	172 701 101	-421 292 586
3.3	**3.42**	**24 841 720**	**2 732 759**	**11.29**	**27 452 930**	**521 606**	**23 138 156**	**4 314 774**	**7.70**	**396 986 712**	**191 165 744**	**-402 827 943**
3.4	3.49	12 801 790	1 438 210	5.82	28 036 283	532 689	23 149 239	4 887 044	4.00	231 714 475	159 002 387	-434 991 300
3.5	3.57	5 379 179	616 824	2.45	28 616 346	543 711	23 160 261	5 456 086	1.70	108 700 966	92 792 227	-501 201 460
3.6	3.66	1 495 415	175 982	0.68	29 368 131	557 994	23 174 544	6 193 587	0.50	34 303 641	32 827 327	-561 166 360
3.7	3.71	341 687	40 763	0.16	29 771 817	565 665	23 182 215	6 589 603	0.10	8 339 197	8 255 797	-585 737 890

Appendix S: Value peak graph data points - % of Maximum value

Grade (g/t) Cut-off	NPV (USD) @ 320 KTPM	NPV (USD) @ 310 KTPM	NPV (USD) @ 300 KTPM	NPV (USD) @ 290 KTPM	NPV (USD) @ 280 KTPM	NPV (USD) @ 270 KTPM	NPV (USD) @ 260 KTPM	NPV (USD) @ 250 KTPM	NPV (USD) @ 240 KTPM	NPV (USD) @ 230 KTPM	NPV (USD) @ 220 KTPM
0	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
0.1	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
0.2	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
0.3	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
0.5	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
0.6	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
0.7	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
0.8	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
0.9	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
1	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
1.1	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
1.2	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
1.3	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
1.4	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
1.5	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
1.6	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4
1.7	0.4	0.5	0.6	0.7	0.7	0.8	0.7	0.7	0.6	0.5	0.4
1.8	0.4	0.5	0.6	0.7	0.8	0.8	0.8	0.7	0.7	0.6	0.4
1.9	0.5	0.6	0.7	0.8	0.8	0.9	0.8	0.8	0.7	0.6	0.5
2	0.6	0.7	0.8	0.9	0.9	1.0	1.0	0.9	0.8	0.7	0.6
2.1	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.8	0.6
2.2	0.8	1.0	1.1	1.2	1.3	1.3	1.3	1.2	1.1	1.0	0.8
2.3	1.0	1.2	1.3	1.4	1.5	1.5	1.5	1.5	1.4	1.2	1.0
2.4	1.3	1.5	1.7	1.8	1.9	1.9	1.9	1.8	1.7	1.5	1.3
2.5	1.9	2.2	2.4	2.6	2.7	2.7	2.7	2.6	2.5	2.2	1.9
2.6	2.9	3.3	3.6	3.8	3.9	4.0	4.0	3.9	3.6	3.3	2.9
2.7	4.7	5.2	5.7	6.0	6.2	6.3	6.3	6.1	5.8	5.3	4.7
2.8	10.8	11.7	12.5	13.1	13.5	13.7	13.6	13.3	12.7	11.9	10.7
2.9	25.6	27.5	29.0	30.2	30.9	31.3	31.2	30.6	29.5	27.8	25.4
3	43.6	46.3	48.6	50.3	51.4	51.9	51.8	50.9	49.3	46.8	43.3
3.1	66.4	70.1	73.1	75.3	76.8	77.5	77.3	76.1	74.0	70.6	66.1
3.2	81.5	85.6	88.9	**91.5**	**93.2**	**93.9**	**93.7**	**92.4**	89.9	86.2	81.1
3.3	87.9	**91.9**	**95.2**	**97.6**	**99.3**	**100.0**	**99.8**	**98.5**	**96.1**	**92.5**	87.6
3.4	71.5	74.5	76.9	78.7	79.9	80.4	80.2	79.3	77.6	74.9	71.3
3.5	41.0	42.6	43.8	44.7	45.4	45.7	45.6	45.1	44.2	42.8	40.9
3.6	14.2	14.7	15.1	15.4	15.6	15.7	15.7	15.5	15.2	14.8	14.2
3.7	3.6	3.7	3.8	3.8	3.9	3.9	3.9	3.9	3.8	3.7	3.5

Appendix T: DCF for the tonnage-based modelling technique

Description	**Unit**																
Production	**Project Year**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Tonnes Milled	Million Tonnes	-	1.26	3.56	4.82	4.92	4.92	4.92	4.92	4.92	4.92	4.92	4.92	4.92	4.92	4.92	4.92
Tonnes Milled	Tonnes	-	1 259 818	3 557 682	4 817 500	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000
Content Milled	g	-	3 833 164	10 894 253	14 696 288	14 903 413	14 788 164	14 672 915	14 557 666	14 442 417	14 327 168	14 211 919	14 021 201	13 631 023	13 339 125	13 266 512	13 264 804
Mill Head Grade	g /t	-	3.04	3.06	3.05	3.03	3.01	2.98	2.96	2.94	2.91	2.89	2.85	2.77	2.71	2.70	2.70
Milled Recovery	%	**83.9**	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9
4E Produced	g	-	3 216 636	9 142 016	12 332 530	12 506 340	12 409 628	12 312 916	12 216 203	12 119 491	12 022 779	11 926 066	11 766 024	11 438 602	11 193 653	11 132 719	11 131 285
4E Produced	oz	-	103 417	293 923	396 500	402 088	398 979	395 869	392 760	389 651	386 541	383 432	378 286	367 760	359 884	357 925	357 879
Revenue																	
4E Basket Price (Nominal)	$/Oz	**1 172.52**	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173
Exchange Rate	R/US$	**17.00**	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
SA 4E Basket Price	R/g	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86
SA 4E Basket Price	R/Oz	**19 932.89**	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89
Gross Sales Revenue	USD Millions	**0.00**	**121.26**	**344.63**	**464.91**	**471.46**	**467.81**	**464.17**	**460.52**	**456.87**	**453.23**	**449.58**	**443.55**	**431.21**	**421.97**	**419.68**	**419.62**
Costs																	
Total Fixed Costs	USD Millions	**0.00**	(80.06)	(163.45)	(211.23)	(221.22)	(221.79)	(222.34)	(222.34)	(219.07)	(218.74)	(219.37)	(223.94)	(237.92)	(245.56)	(235.88)	(240.81)
Total Variable Costs	USD Millions		(19.41)	(60.82)	(91.19)	(98.78)	(99.27)	(99.27)	(99.27)	(99.27)	(99.27)	(99.27)	(99.59)	(100.37)	(101.73)	(97.81)	(99.27)
SIB - Mining	USD Millions	0.00	0.00	0.00	(30.24)	(31.67)	(31.75)	(31.83)	(31.83)	(31.37)	(31.32)	(31.41)	(32.06)	(34.06)	(35.16)	(33.77)	(34.48)
Total Costs	**USD Millions**	**0.00**	**(99.46)**	**(224.26)**	**(332.66)**	**(351.67)**	**(352.81)**	**(353.44)**	**(353.44)**	**(349.71)**	**(349.33)**	**(350.05)**	**(355.59)**	**(372.35)**	**(382.46)**	**(367.46)**	**(374.55)**
Average Cost		0.00	(78.95)	(63.04)	(69.05)	(71.48)	(71.71)	(71.84)	(71.84)	(71.08)	(71.00)	(71.15)	(72.27)	(75.68)	(77.73)	(74.69)	(76.13)
Net Sales Revenue (operating profit)	USD Millions	**0.00**	**21.80**	**120.37**	**132.24**	**119.79**	**115.00**	**110.72**	**107.08**	**107.17**	**103.90**	**99.53**	**87.96**	**58.85**	**39.52**	**52.21**	**45.07**
Tax Shield																	
Capital Expenditure (Nominal)	**USD Millions**	**(957.24)**	**(353.38)**	**(196.28)**	**(42.99)**	**(38.99)**	**(62.82)**	**(32.58)**	**(7.17)**	**(0.41)**	**(0.07)**	**0.00**	**(10.95)**	**(52.08)**	**(63.50)**	**(31.08)**	**(21.20)**
Underground Mining	USD Millions		(67.83)	(71.08)	(33.25)	(29.25)	(53.09)	(22.84)	(3.71)	(0.41)	(0.07)	0.00	(10.95)	(52.08)	(63.50)	(31.08)	(20.08)
Concentrator	USD Millions		(201.37)	(50.34)	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
Infrastructure	USD Millions		(33.98)	(40.94)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(1.12)
Indirect Cost	USD Millions		(50.21)	(33.92)	(9.74)	(9.74)	(9.74)	(9.74)	(3.46)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	USD Millions		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
Unredeemed Capex	USD Millions		(353.38)	(429.30)	(340.05)	(259.25)	(207.07)	(128.93)	(29.02)	0.00	0.00	0.00	0.00	0.00	(23.98)	(2.84)	0.00
Net Sales Revenue after Capex	USD Millions		**(331.59)**	**(75.92)**	**89.25**	**80.80**	**52.18**	**78.14**	**99.91**	**106.75**	**103.84**	**99.53**	**77.01**	**6.77**	**(23.98)**	**21.14**	**23.87**
Royalties																	
EBIT for Royalty Calculation	%		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**78.15**	**103.90**	**99.53**	**87.96**	**58.85**	**0.00**	**0.00**	**42.23**
X=(EBIT Royalty /Gross Sales)			0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.10	22.93	22.14	19.83	13.65	0.00	0.00	10.06
Refined Royalty Rate (Y=0.5+(X/12.5) - Max 7%	%	7	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.87	2.33	2.27	2.09	1.59	0.50	0.50	1.31
Royalty Paid	USD Millions		(0.61)	(1.72)	(2.32)	(2.36)	(2.34)	(2.32)	(2.30)	(8.54)	(10.58)	(10.21)	(9.25)	(6.86)	(2.11)	(2.10)	(5.48)
Cash Flow																	
Actual Cashflow after tax (Nominal) - EBIT	USD Millions		**(332.19)**	**(77.64)**	**86.93**	**78.44**	**49.84**	**75.82**	**97.61**	**98.22**	**93.26**	**89.32**	**67.75**	**(0.09)**	**(26.09)**	**19.04**	**18.39**
DCF (Nominal) - EBIT	USD Millions	**10.0**	**(301.99)**	**(64.16)**	**65.31**	**53.58**	**30.95**	**42.80**	**50.09**	**45.82**	**39.55**	**34.44**	**23.75**	**(0.03)**	**(7.56)**	**5.01**	**4.40**
Cumulative Cashflow after tax (Nominal) - EBIT	USD Millions		**(332.19)**	**(409.83)**	**(322.91)**	**(244.47)**	**(194.63)**	**(118.80)**	**(21.20)**	**77.02**	**170.28**	**259.60**	**327.35**	**327.26**	**301.17**	**320.21**	**338.60**
Cumulative DCF (Nominal) - EBIT	USD Millions		**(301.99)**	**(366.16)**	**(300.85)**	**(247.27)**	**(216.33)**	**(173.53)**	**(123.44)**	**(77.62)**	**(38.07)**	**(3.63)**	**20.11**	**20.08**	**12.53**	**17.54**	**21.94**

Description	Unit															
Production	**Project Year**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Tonnes Milled	Million Tonnes	4.92	4.92	4.92	4.92	4.92	4.92	4.92	4.92	4.92	3.82	2.42	2.40	2.33	1.56	0.60
Tonnes Milled	Tonnes	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	4 920 000	3 824 919	2 422 581	2 400 000	2 333 333	1 560 000	600 000
Content Milled	g	13 249 633	13 226 040	13 194 904	13 157 104	13 113 519	13 065 028	13 012 511	12 956 525	12 886 255	9 932 877	6 202 464	6 143 666	5 973 009	3 993 383	1 535 916
Mill Head Grade	g /t	2.69	2.69	2.68	2.67	2.67	2.66	2.64	2.63	2.62	2.60	2.56	2.56	2.56	2.56	2.56
Milled Recovery	%	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9
4E Produced	g	11 118 555	11 098 757	11 072 628	11 040 908	11 004 333	10 963 642	10 919 571	10 872 591	10 813 623	8 335 268	5 204 856	5 155 515	5 012 307	3 351 085	1 288 879
4E Produced	oz	357 470	356 833	355 993	354 973	353 798	352 489	351 072	349 562	347 666	267 985	167 340	165 754	161 149	107 740	41 438
Revenue																
4E Basket Price (Nominal)	$/Oz	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173
Exchange Rate	R/US$	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
SA 4E Basket Price	R/g	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86
SA 4E Basket Price	R/Oz	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89
Gross Sales Revenue	USD Millions	**419.14**	**418.40**	**417.41**	**416.21**	**414.84**	**413.30**	**411.64**	**409.87**	**407.65**	**314.22**	**196.21**	**194.35**	**188.95**	**126.33**	**48.59**
Costs																
Total Fixed Costs	USD Millions	(240.82)	(240.90)	(240.12)	(239.16)	(237.44)	(231.26)	(225.18)	(219.74)	(204.65)	(149.67)	(133.99)	(133.51)	(130.21)	(127.20)	(104.95)
Total Variable Costs	USD Millions	(99.27)	(99.27)	(99.27)	(99.27)	(99.27)	(99.27)	(99.27)	(97.61)	(88.66)	(58.73)	(48.84)	(48.42)	(48.42)	(46.27)	(32.35)
SIB - Mining	USD Millions	(34.48)	(34.49)	(34.38)	(34.24)	(34.00)	(33.11)	(32.24)	(31.46)	(29.30)	(21.43)	(19.18)	(19.12)	(18.64)	(18.21)	(15.03)
Total Costs	**USD Millions**	**(374.57)**	**(374.66)**	**(373.77)**	**(372.67)**	**(370.70)**	**(363.64)**	**(356.68)**	**(348.81)**	**(322.61)**	**(229.83)**	**(202.02)**	**(201.05)**	**(197.28)**	**(191.68)**	**(152.33)**
Average Cost		(76.13)	(76.15)	(75.97)	(75.75)	(75.35)	(73.91)	(72.50)	(70.90)	(65.57)	(60.09)	(83.39)	(83.77)	(84.55)	(122.87)	(253.89)
Net Sales Revenue (operating profit)	USD Millions	**44.58**	**43.73**	**43.64**	**43.55**	**44.13**	**49.67**	**54.96**	**61.05**	**85.03**	**84.39**	**(5.81)**	**(6.70)**	**(8.33)**	**(65.35)**	**(103.74)**
Tax Shield																
Capital Expenditure (Nominal)	**USD Millions**	**(23.27)**	**(16.45)**	**(4.02)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Underground Mining	USD Millions	(23.27)	(16.45)	(4.02)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Concentrator	USD Millions	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
Infrastructure	USD Millions	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
Indirect Cost	USD Millions	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
Other	USD Millions	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
Unredeemed Capex	USD Millions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(5.81)	(12.51)	(20.84)	(86.18)	(189.93)
Net Sales Revenue after Capex	USD Millions	**21.30**	**27.28**	**39.62**	**43.55**	**44.13**	**49.67**	**54.96**	**61.05**	**85.03**	**84.39**	**(5.81)**	**(6.70)**	**(8.33)**	**(65.35)**	**(103.74)**
Royalties																
EBIT for Royalty Calculation	%	**44.58**	**43.73**	**43.64**	**43.55**	**44.13**	**49.67**	**54.96**	**61.05**	**85.03**	**84.39**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
X=(EBIT Royalty /Gross Sales)		10.63	10.45	10.46	10.46	10.64	12.02	13.35	14.90	20.86	26.86	0.00	0.00	0.00	0.00	0.00
Refined Royalty Rate (Y=0.5+(X/12.5) - Max 7%	%	1.35	1.34	1.34	1.34	1.35	1.46	1.57	1.69	2.17	2.65	0.50	0.50	0.50	0.50	0.50
Royalty Paid	USD Millions	(5.66)	(5.59)	(5.58)	(5.56)	(5.60)	(6.04)	(6.45)	(6.93)	(8.84)	(8.32)	(0.98)	(0.97)	(0.94)	(0.63)	(0.24)
Cash Flow																
Actual Cashflow after tax (Nominal) - EBIT	USD Millions	**15.64**	**21.69**	**34.05**	**37.98**	**38.53**	**43.63**	**48.50**	**54.12**	**76.19**	**76.07**	**(6.79)**	**(7.67)**	**(9.27)**	**(65.98)**	**(103.99)**
DCF (Nominal) - EBIT	USD Millions	**3.40**	**4.29**	**6.12**	**6.21**	**5.73**	**5.90**	**5.96**	**6.04**	**7.74**	**7.02**	**(0.57)**	**(0.59)**	**(0.64)**	**(4.16)**	**(5.96)**
Cumulative Cashflow after tax (Nominal) - EBIT	USD Millions	**354.25**	**375.94**	**409.98**	**447.97**	**486.49**	**530.12**	**578.62**	**632.74**	**708.94**	**785.00**	**778.21**	**770.54**	**761.27**	**695.29**	**591.30**
Cumulative DCF (Nominal) - EBIT	USD Millions	**25.35**	**29.64**	**35.76**	**41.97**	**47.70**	**53.60**	**59.55**	**65.60**	**73.33**	**80.35**	**79.78**	**79.20**	**78.56**	**74.40**	**68.44**

Description	Unit											
Production	**Project Year**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	
Tonnes Milled	Million Tonnes	0.01	-	-	-	-	-	-	-	-	-	**126.10**
Tonnes Milled	Tonnes	6 667	-	-	-	-	-	-	-	-	-	**126 102 500**
Content Milled	g	17 066	-	-	-	-	-	-	-	-	-	**350 509 933**
Mill Head Grade	g /t	2.56	-	-	-	-	-	-	-	-	-	**2.78**
Milled Recovery	%	83.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
4E Produced	g	14 321	-	-	-	-	-	-	-	-	-	**294 133 728**
4E Produced	oz	460	-	-	-	-	-	-	-	-	-	**9 456 619**
Revenue												
4E Basket Price (Nominal)	$/Oz	1 173	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Exchange Rate	R/US$	17.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
SA 4E Basket Price	R/g	640.86	-	-	-	-	-	-	-	-	-	
SA 4E Basket Price	R/Oz	19 932.89	-	-	-	-	-	-	-	-	-	
Gross Sales Revenue	USD Millions	**0.54**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**11 088.11**
Costs												
Total Fixed Costs	USD Millions	(74.10)	(2.45)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**(6 119.07)**
Total Variable Costs	USD Millions	(13.46)	(2.10)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**(2 544.33)**
SIB - Mining	USD Millions	(10.61)	(0.35)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**(841.22)**
Total Costs	**USD Millions**	**(98.17)**	**(4.90)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**(9 504.63)**
Average Cost		(14 725.40)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**(75.37)**
Net Sales Revenue (operating profit)	USD Millions	**(97.63)**	**(4.90)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1 583.48**
Tax Shield												
Capital Expenditure (Nominal)	**USD Millions**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**(957.24)**
Underground Mining	USD Millions											(502.96)
Concentrator	USD Millions											(251.71)
Infrastructure	USD Millions											(76.04)
Indirect Cost	USD Millions											(126.53)
Other	USD Millions											0.00
Unredeemed Capex	USD Millions	(287.56)	(292.46)	(292.46)	(292.46)	(292.46)	(292.46)	(292.46)	(292.46)	(292.46)	(292.46)	
Net Sales Revenue after Capex	USD Millions	**(97.63)**	**(4.90)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**626.24**
Royalties												
EBIT for Royalty Calculation	%	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
X=(EBIT Royalty /Gross Sales)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Refined Royalty Rate (Y=0.5+(X/12.5) - Max 7%	%	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Royalty Paid	USD Millions	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**(137.47)**
Cash Flow												
Actual Cashflow after tax (Nominal) - EBIT	USD Millions	**(97.63)**	**(4.90)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**488.77**
DCF (Nominal) - EBIT	USD Millions	**(5.09)**	**(0.23)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**63.12**
Cumulative Cashflow after tax (Nominal) - EBIT	USD Millions	**493.67**	**488.77**	**488.77**	**488.77**	**488.77**	**488.77**	**488.77**	**488.77**	**488.77**	**488.77**	**488.77**
Cumulative DCF (Nominal) - EBIT	USD Millions	**63.35**	**63.12**	**63.12**	**63.12**	**63.12**	**63.12**	**63.12**	**63.12**	**63.12**	**63.12**	**63.12**

Appendix U: DCF for the microeconomic modelling technique

Description	**Unit**																
Production	**Project Year**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Tonnes Milled	Million Tonnes	-	0.83	2.34	3.17	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24
Tonnes Milled	Tonnes	-	829 636	2 342 864	3 172 500	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000
Content Milled	g	-	2 585 441	7 348 037	9 910 907	10 050 328	9 972 615	9 894 902	9 817 189	9 739 476	9 661 763	9 584 050	9 506 337	9 428 625	9 350 912	9 273 199	9 195 486
Mill Head Grade	g /t	-	3.12	3.14	3.12	3.10	3.08	3.05	3.03	3.01	2.98	2.96	2.93	2.91	2.89	2.86	2.84
Milled Recovery	%	**83.9%**	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9
4E Produced	g	-	2 169 597	6 166 175	8 316 832	8 433 828	8 368 614	8 303 401	8 238 187	8 172 974	8 107 760	8 042 547	7 977 333	7 912 120	7 846 906	7 781 692	7 716 479
4E Produced	oz	-	69 754	198 247	267 392	271 154	269 057	266 961	264 864	262 767	260 671	258 574	256 477	254 381	252 284	250 187	248 091
Revenue																	
4E Basket Price (Nominal)	$/Oz	**$ 1 172.52**	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173
Exchange Rate	R/US$	**$ 17.00**	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
SA 4E Basket Price	R/g	R 640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86
SA 4E Basket Price	R/Oz	**R 19 932.89**	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89
Gross Sales Revenue	USD Millions	**$0.00**	**81.79**	**232.45**	**313.52**	**317.93**	**315.48**	**313.02**	**310.56**	**308.10**	**305.64**	**303.18**	**300.73**	**298.27**	**295.81**	**293.35**	**290.89**
Costs																	
Total Fixed Costs	USD Millions	**$0.00**	(66.94)	(126.55)	(152.51)	(154.15)	(154.15)	(154.55)	(154.55)	(154.74)	(154.74)	(155.19)	(152.63)	(151.25)	(151.25)	(151.62)	(154.60)
Total Variable Costs	USD Millions		(16.74)	(47.27)	(64.01)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)
SIB - Mining	USD Millions	$0.00	0.00	0.00	(21.84)	(22.07)	(22.07)	(22.13)	(22.13)	(22.15)	(22.15)	(22.22)	(21.85)	(21.65)	(21.65)	(21.71)	(22.14)
Total Costs	**USD Millions**	**$0.00**	**(83.68)**	**(173.82)**	**(238.36)**	**(241.59)**	**(241.59)**	**(242.05)**	**(242.05)**	**(242.26)**	**(242.26)**	**(242.79)**	**(239.85)**	**(238.28)**	**(238.28)**	**(238.70)**	**(242.11)**
Average Cost		$0.00	(100.86)	(74.19)	(75.13)	(74.56)	(74.56)	(74.71)	(74.71)	(74.77)	(74.77)	(74.93)	(74.03)	(73.54)	(73.54)	(73.67)	(74.73)
Net Sales Revenue (operating profit)	USD Millions	**$0.00**	**(1.89)**	**58.63**	**75.16**	**76.35**	**73.89**	**70.97**	**68.51**	**65.84**	**63.38**	**60.40**	**60.87**	**59.99**	**57.53**	**54.65**	**48.78**
Tax Shield																	
Capital Expenditure (Nominal)	**USD Millions**	**($726.24)**	**(241.70)**	**(139.08)**	**(29.11)**	**(26.48)**	**(42.17)**	**(22.26)**	**(5.01)**	**(0.27)**	**(0.04)**	**0.00**	**0.00**	**(22.35)**	**(28.42)**	**(12.50)**	**(14.12)**
Underground Mining	USD Millions		(44.67)	(46.81)	(21.90)	(19.26)	(34.96)	(15.04)	(2.44)	(0.27)	(0.04)	0.00	0.00	(22.35)	(28.42)	(12.50)	(13.00)
Concentrator	USD Millions		(122.50)	(30.63)	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
Infrastructure	USD Millions		(26.64)	(32.63)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(1.12)
Indirect Cost	USD Millions		(47.89)	(29.02)	(7.21)	(7.21)	(7.21)	(7.21)	(2.56)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	USD Millions		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
Unredeemed Capex	USD Millions		(241.70)	(322.16)	(276.11)	(226.24)	(194.53)	(145.81)	(82.31)	(16.74)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Sales Revenue after Capex	USD Millions		**(243.59)**	**(80.46)**	**46.05**	**49.87**	**31.71**	**48.72**	**63.51**	**65.57**	**63.34**	**60.40**	**60.87**	**37.64**	**29.11**	**42.14**	**34.66**
Royalties																	
EBIT for Royalty Calculation	%		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**46.64**	**60.40**	**60.87**	**59.99**	**57.53**	**54.65**	**48.78**
X=(EBIT Royalty /Gross Sales)			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.26	19.92	20.24	20.11	19.45	18.63	16.77
Refined Royalty Rate (Y=0.5+(X/12.5) - Max 7%	%	7%	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.72	2.09	2.12	2.11	2.06	1.99	1.84
Royalty Paid	USD Millions		(0.41)	(1.16)	(1.57)	(1.59)	(1.58)	(1.57)	(1.55)	(1.54)	(5.26)	(6.35)	(6.37)	(6.29)	(6.08)	(5.84)	(5.36)
Cash Flow																	
Actual Cashflow after tax (Nominal) - EBIT	USD Millions		**(244.00)**	**(81.62)**	**44.48**	**48.28**	**30.14**	**47.15**	**61.95**	**64.03**	**58.08**	**54.05**	**54.50**	**31.35**	**23.03**	**36.31**	**29.30**
DCF (Nominal) - EBIT	USD Millions	**10.0%**	**(221.82)**	**(67.45)**	**33.42**	**32.97**	**18.71**	**26.61**	**31.79**	**29.87**	**24.63**	**20.84**	**19.10**	**9.99**	**6.67**	**9.56**	**7.01**
Cumulative Cashflow after tax (Nominal) - EBIT	USD Millions		**(244.00)**	**(325.62)**	**(281.14)**	**(232.86)**	**(202.72)**	**(155.57)**	**(93.62)**	**(29.60)**	**28.48**	**82.53**	**137.03**	**168.37**	**191.40**	**227.71**	**257.01**
Cumulative DCF (Nominal) - EBIT	USD Millions		**(221.82)**	**(289.28)**	**(255.85)**	**(222.88)**	**(204.17)**	**(177.55)**	**(145.76)**	**(115.89)**	**(91.26)**	**(70.42)**	**(51.32)**	**(41.33)**	**(34.66)**	**(25.10)**	**(18.09)**

Description	Unit																	
Production	**Project Year**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Tonnes Milled	Million Tonnes	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.21	3.23	3.24	3.24	3.24	3.24	3.24	3.24	3.24
Tonnes Milled	Tonnes	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 209 482	3 229 101	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000
Content Milled	g	9 117 773	9 000 138	8 916 397	8 789 129	8 662 809	8 629 352	8 625 385	8 610 058	8 488 288	8 611 183	8 657 351	8 631 276	8 613 873	8 596 510	8 579 147	8 561 784	8 544 421
Mill Head Grade	g /t	2.81	2.78	2.75	2.71	2.67	2.66	2.66	2.66	2.64	2.67	2.67	2.66	2.66	2.65	2.65	2.64	2.64
Milled Recovery	%	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9
4E Produced	g	7 651 265	7 552 551	7 482 279	7 375 480	7 269 478	7 241 403	7 238 074	7 225 212	7 123 027	7 226 156	7 264 898	7 243 017	7 228 413	7 213 843	7 199 272	7 184 702	7 170 132
4E Produced	oz	245 994	242 820	240 561	237 127	233 719	232 816	232 709	232 296	229 011	232 326	233 572	232 868	232 399	231 930	231 462	230 994	230 525
Revenue																		
4E Basket Price (Nominal)	$/Oz	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173
Exchange Rate	R/US$	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
SA 4E Basket Price	R/g	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86
SA 4E Basket Price	R/Oz	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89
Gross Sales Revenue	USD Millions	**288.43**	**284.71**	**282.06**	**278.04**	**274.04**	**272.98**	**272.86**	**272.37**	**268.52**	**272.41**	**273.87**	**273.04**	**272.49**	**271.94**	**271.39**	**270.85**	**270.30**
Costs																		
Total Fixed Costs	USD Millions	(154.67)	(169.93)	(176.95)	(168.26)	(165.11)	(163.90)	(157.44)	(157.43)	(157.53)	(170.87)	(166.48)	(160.33)	(157.98)	(158.02)	(158.33)	(157.21)	(155.92)
Total Variable Costs	USD Millions	(65.37)	(69.01)	(69.16)	(62.16)	(62.47)	(65.37)	(65.37)	(65.37)	(64.07)	(68.31)	(66.80)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)
SIB - Mining	USD Millions	(22.14)	(24.33)	(25.33)	(24.09)	(23.64)	(23.47)	(22.54)	(22.54)	(22.55)	(24.46)	(23.83)	(22.95)	(22.62)	(22.62)	(22.67)	(22.51)	(22.32)
Total Costs	**USD Millions**	**(242.18)**	**(263.27)**	**(271.44)**	**(254.50)**	**(251.22)**	**(252.73)**	**(245.35)**	**(245.35)**	**(244.16)**	**(263.64)**	**(257.11)**	**(248.65)**	**(245.97)**	**(246.02)**	**(246.38)**	**(245.09)**	**(243.62)**
Average Cost		(74.75)	(81.26)	(83.78)	(78.55)	(77.54)	(78.00)	(75.73)	(75.72)	(76.07)	(81.65)	(79.35)	(76.75)	(75.92)	(75.93)	(76.04)	(75.65)	(75.19)
Net Sales Revenue (operating profit)	USD Millions	**46.25**	**21.45**	**10.62**	**23.53**	**22.82**	**20.25**	**27.50**	**27.03**	**24.36**	**8.76**	**16.76**	**24.39**	**26.53**	**25.92**	**25.02**	**25.75**	**26.68**
Tax Shield																		
Capital Expenditure (Nominal)	**USD Millions**	**(18.62)**	**(40.21)**	**(32.72)**	**(29.51)**	**0.00**	**0.00**	**0.00**	**0.00**	**(7.22)**	**(7.22)**	**(7.22)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Underground Mining	USD Millions	(18.62)	(40.21)	(32.72)	(29.51)	0.00	0.00	0.00	0.00	(7.22)	(7.22)	(7.22)	0.00	0.00	0.00	0.00	0.00	0.00
Concentrator	USD Millions	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
Infrastructure	USD Millions	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
Indirect Cost	USD Millions	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
Other	USD Millions	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
Unredeemed Capex	USD Millions	0.00	(18.77)	(40.87)	(46.85)	(24.03)	(3.78)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Sales Revenue after Capex	USD Millions	**27.63**	**(18.77)**	**(22.10)**	**(5.98)**	**22.82**	**20.25**	**27.50**	**27.03**	**17.14**	**1.55**	**9.54**	**24.39**	**26.53**	**25.92**	**25.02**	**25.75**	**26.68**
Royalties																		
EBIT for Royalty Calculation	%	**46.25**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**23.72**	**27.03**	**24.36**	**8.76**	**16.76**	**24.39**	**26.53**	**25.92**	**25.02**	**25.75**	**26.68**
X=(EBIT Royalty /Gross Sales)		16.03	0.00	0.00	0.00	0.00	0.00	8.70	9.92	9.07	3.22	6.12	8.93	9.73	9.53	9.22	9.51	9.87
Refined Royalty Rate (Y=0.5+(X/12.5) - Max 7%	%	1.78	0.50	0.50	0.50	0.50	0.50	1.20	1.29	1.23	0.76	0.99	1.21	1.28	1.26	1.24	1.26	1.29
Royalty Paid	USD Millions	(5.14)	(1.42)	(1.41)	(1.39)	(1.37)	(1.36)	(3.26)	(3.52)	(3.29)	(2.06)	(2.71)	(3.32)	(3.48)	(3.43)	(3.36)	(3.41)	(3.49)
Cash Flow																		
Actual Cashflow after tax (Nominal) - EBIT	USD Millions	**22.49**	**(20.19)**	**(23.51)**	**(7.37)**	**21.45**	**18.88**	**24.24**	**23.50**	**13.85**	**(0.52)**	**6.83**	**21.07**	**23.04**	**22.49**	**21.66**	**22.34**	**23.19**
DCF (Nominal) - EBIT	USD Millions	**4.89**	**(3.99)**	**(4.23)**	**(1.20)**	**3.19**	**2.55**	**2.98**	**2.62**	**1.41**	**(0.05)**	**0.57**	**1.61**	**1.60**	**1.42**	**1.24**	**1.16**	**1.10**
Cumulative Cashflow after tax (Nominal) - EBIT	USD Millions	**279.50**	**259.31**	**235.80**	**228.43**	**249.88**	**268.76**	**293.01**	**316.51**	**330.36**	**329.84**	**336.67**	**357.75**	**380.79**	**403.28**	**424.94**	**447.28**	**470.47**
Cumulative DCF (Nominal) - EBIT	USD Millions	**(13.19)**	**(17.19)**	**(21.42)**	**(22.62)**	**(19.43)**	**(16.88)**	**(13.90)**	**(11.28)**	**(9.87)**	**(9.92)**	**(9.35)**	**(7.74)**	**(6.14)**	**(4.72)**	**(3.48)**	**(2.32)**	**(1.22)**

Description	Unit														
Production	**Project Year**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	
Tonnes Milled	Million Tonnes	3.24	3.24	3.24	3.24	3.24	3.24	3.24	2.50	0.80	0.11	-	-	-	**126.35**
Tonnes Milled	Tonnes	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	3 240 000	2 496 917	800 000	112 000	-	-	-	**126 352 500**
Content Milled	g	8 527 058	8 509 695	8 492 332	8 474 969	8 457 606	8 440 243	8 422 880	6 456 173	2 047 889	286 704	-	-	-	**351 069 690**
Mill Head Grade	g /t	2.63	2.63	2.62	2.62	2.61	2.61	2.60	2.59	2.56	2.56	-	-	-	**2.78**
Milled Recovery	%	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	0.0	0.0	0.0	
4E Produced	g	7 155 561	7 140 991	7 126 421	7 111 850	7 097 280	7 082 710	7 068 139	5 417 759	1 718 505	240 591	-	-	-	**294 603 453**
4E Produced	oz	230 057	229 588	229 120	228 651	228 183	227 714	227 246	174 185	55 251	7 735	-	-	-	**9 471 721**
Revenue															
4E Basket Price (Nominal)	$/Oz	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	0	0	0	
Exchange Rate	R/US$	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	0.00	0.00	0.00	
SA 4E Basket Price	R/g	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	-	-	-	
SA 4E Basket Price	R/Oz	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	-	-	-	
Gross Sales Revenue	USD Millions	**269.75**	**269.20**	**268.65**	**268.10**	**267.55**	**267.00**	**266.45**	**204.24**	**64.78**	**9.07**	**0.00**	**0.00**	**0.00**	**11 105.81**
Costs															
Total Fixed Costs	USD Millions	(154.60)	(153.06)	(152.89)	(152.89)	(152.89)	(152.89)	(152.86)	(117.15)	(70.51)	(41.35)	0.00	0.00	0.00	**(6 246.84)**
Total Variable Costs	USD Millions	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(65.37)	(45.17)	(16.14)	(2.26)	0.00	0.00	0.00	**(2 549.38)**
SIB - Mining	USD Millions	(22.13)	(21.91)	(21.89)	(21.89)	(21.89)	(21.89)	(21.88)	(16.77)	(10.10)	(5.92)	0.00	0.00	0.00	**(866.68)**
Total Costs	**USD Millions**	**(242.11)**	**(240.35)**	**(240.15)**	**(240.15)**	**(240.15)**	**(240.15)**	**(240.11)**	**(179.09)**	**(96.75)**	**(49.53)**	**0.00**	**0.00**	**0.00**	**(9 662.89)**
Average Cost		(74.72)	(74.18)	(74.12)	(74.12)	(74.12)	(74.12)	(74.11)	(71.72)	(120.94)	(442.23)	0.00	0.00	0.00	**(76.48)**
Net Sales Revenue (operating profit)	USD Millions	**27.64**	**28.85**	**28.50**	**27.95**	**27.40**	**26.85**	**26.34**	**25.14**	**(31.97)**	**(40.46)**	**0.00**	**0.00**	**0.00**	**1 442.92**
Tax Shield															
Capital Expenditure (Nominal)	**USD Millions**	**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**	**(726.24)**
Underground Mining	USD Millions	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	(404.40)
Concentrator	USD Millions	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	(153.13)
Infrastructure	USD Millions	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	(60.39)
Indirect Cost	USD Millions	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	(108.33)
Other	USD Millions	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
Unredeemed Capex	USD Millions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(31.97)	(72.43)	(72.43)	(72.43)	(72.43)	
Net Sales Revenue after Capex	USD Millions	**27.64**	**28.85**	**28.50**	**27.95**	**27.40**	**26.85**	**26.34**	**25.14**	**(31.97)**	**(40.46)**	**0.00**	**0.00**	**0.00**	**716.67**
Royalties															
EBIT for Royalty Calculation	%	**27.64**	**28.85**	**28.50**	**27.95**	**27.40**	**26.85**	**26.34**	**25.14**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
X=(EBIT Royalty /Gross Sales)		10.25	10.72	10.61	10.43	10.24	10.06	9.88	12.31	0.00	0.00	0.00	0.00	0.00	
Refined Royalty Rate (Y=0.5+(X/12.5) - Max 7%	%	1.32	1.36	1.35	1.33	1.32	1.30	1.29	1.48	0.50	0.50	0.00	0.00	0.00	
Royalty Paid	USD Millions	(3.56)	(3.65)	(3.62)	(3.58)	(3.53)	(3.48)	(3.44)	(3.03)	(0.32)	(0.05)	0.00	0.00	0.00	**(128.23)**
Cash Flow															
Actual Cashflow after tax (Nominal) - EBIT	USD Millions	**24.08**	**25.19**	**24.88**	**24.37**	**23.87**	**23.37**	**22.90**	**22.11**	**(32.29)**	**(40.51)**	**0.00**	**0.00**	**0.00**	**588.45**
DCF (Nominal) - EBIT	USD Millions	**1.04**	**0.99**	**0.89**	**0.79**	**0.70**	**0.62**	**0.56**	**0.49**	**(0.65)**	**(0.74)**	**0.00**	**0.00**	**0.00**	**3.46**
Cumulative Cashflow after tax (Nominal) - EBIT	USD Millions	**494.55**	**519.74**	**544.62**	**568.99**	**592.86**	**616.23**	**639.13**	**661.24**	**628.95**	**588.45**	**588.45**	**588.45**	**588.45**	**588.45**
Cumulative DCF (Nominal) - EBIT	USD Millions	**(0.18)**	**0.80**	**1.69**	**2.48**	**3.18**	**3.80**	**4.36**	**4.85**	**4.20**	**3.46**	**3.46**	**3.46**	**3.46**	**3.46**

Appendix V: DCF for the marginal-analysis modelling technique

Description	**Unit**																
Production	**Project Year**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Tonnes Milled	Million Tonnes	-	0.71	2.00	2.70	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76
Tonnes Milled	Tonnes	-	706 727	1 995 773	2 702 500	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000
Content Milled	g	-	2 228 480	6 333 546	8 543 155	8 663 432	8 596 441	8 529 449	8 462 458	8 395 466	8 328 475	8 261 483	8 194 492	8 127 500	8 060 509	7 993 517	7 926 526
Mill Head Grade	g /t	-	3.15	3.17	3.16	3.14	3.11	3.09	3.07	3.04	3.02	2.99	2.97	2.94	2.92	2.90	2.87
Milled Recovery	%	**83.9**	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9
4E Produced	g	-	1 870 050	5 314 855	7 169 070	7 270 001	7 213 784	7 157 568	7 101 351	7 045 135	6 988 918	6 932 702	6 876 485	6 820 269	6 764 052	6 707 836	6 651 619
4E Produced	oz	-	60 124	170 877	230 491	233 736	231 929	230 121	228 314	226 506	224 699	222 892	221 084	219 277	217 469	215 662	213 855
Revenue																	
4E Basket Price (Nominal)	$/Oz	**1 172.52**	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173
Exchange Rate	R/US$	**17.00**	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
SA 4E Basket Price	R/g	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86
SA 4E Basket Price	R/Oz	**19 932.89**	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89
Gross Sales Revenue	USD Millions	**0.00**	**70.50**	**200.36**	**270.26**	**274.06**	**271.94**	**269.82**	**267.70**	**265.58**	**263.46**	**261.35**	**259.23**	**257.11**	**254.99**	**252.87**	**250.75**
Costs																	
Total Fixed Costs	USD Millions	**0.00**	(60.24)	(111.06)	(132.97)	(134.44)	(134.44)	(134.78)	(134.78)	(134.94)	(134.94)	(135.33)	(135.33)	(134.86)	(131.45)	(131.65)	(134.20)
Total Variable Costs	USD Millions		(14.26)	(40.27)	(54.53)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)
SIB - Mining	USD Millions	0.00	0.00	0.00	(19.04)	(19.25)	(19.25)	(19.30)	(19.30)	(19.32)	(19.32)	(19.38)	(19.38)	(19.31)	(18.82)	(18.85)	(19.21)
Total Costs	**USD Millions**	**0.00**	**(74.50)**	**(151.33)**	**(206.54)**	**(209.37)**	**(209.37)**	**(209.76)**	**(209.76)**	**(209.95)**	**(209.95)**	**(210.40)**	**(210.40)**	**(209.85)**	**(205.95)**	**(206.19)**	**(209.10)**
Average Cost		0.00	(105.41)	(75.83)	(76.42)	(75.86)	(75.86)	(76.00)	(76.00)	(76.07)	(76.07)	(76.23)	(76.23)	(76.03)	(74.62)	(74.71)	(75.76)
Net Sales Revenue (operating profit)	USD Millions	**0.00**	**(4.00)**	**49.02**	**63.72**	**64.69**	**62.57**	**60.06**	**57.94**	**55.64**	**53.52**	**50.95**	**48.83**	**47.25**	**49.03**	**46.68**	**41.65**
Tax Shield																	
Capital Expenditure (Nominal)	**USD Millions**	**(658.76)**	**(232.81)**	**(129.72)**	**(24.80)**	**(22.55)**	**(35.92)**	**(18.96)**	**(4.26)**	**(0.23)**	**(0.04)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**(1.12)**
Underground Mining	USD Millions		(38.05)	(39.88)	(18.65)	(16.41)	(29.78)	(12.81)	(2.08)	(0.23)	(0.04)	0.00	0.00	0.00	0.00	0.00	0.00
Concentrator	USD Millions		(122.50)	(30.63)	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
Infrastructure	USD Millions		(25.34)	(32.28)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(1.12)
Indirect Cost	USD Millions		(46.91)	(26.94)	(6.14)	(6.14)	(6.14)	(6.14)	(2.18)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	USD Millions		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
Unredeemed Capex	USD Millions		(232.81)	(313.50)	(274.59)	(232.45)	(205.81)	(164.71)	(111.03)	(55.63)	(2.15)	0.00	0.00	0.00	0.00	0.00	0.00
Net Sales Revenue after Capex	USD Millions		**(236.81)**	**(80.70)**	**38.92**	**42.13**	**26.64**	**41.10**	**53.68**	**55.40**	**53.48**	**50.95**	**48.83**	**47.25**	**49.03**	**46.68**	**40.53**
Royalties																	
EBIT for Royalty Calculation	%		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**48.80**	**48.83**	**47.25**	**49.03**	**46.68**	**41.65**
X=(EBIT Royalty /Gross Sales)			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.67	18.84	18.38	19.23	18.46	16.61
Refined Royalty Rate (Y=0.5+(X/12.5) - Max 7%	%	7	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.99	2.01	1.97	2.04	1.98	1.83
Royalty Paid	USD Millions		(0.35)	(1.00)	(1.35)	(1.37)	(1.36)	(1.35)	(1.34)	(1.33)	(1.32)	(5.21)	(5.20)	(5.07)	(5.20)	(5.00)	(4.59)
Cash Flow																	
Actual Cashflow after tax (Nominal) - EBIT	USD Millions		**(237.16)**	**(81.70)**	**37.57**	**40.76**	**25.28**	**39.75**	**52.34**	**54.08**	**52.16**	**45.74**	**43.62**	**42.19**	**43.84**	**41.68**	**35.95**
DCF (Nominal) - EBIT	USD Millions	**10.0**	**(215.60)**	**(67.52)**	**28.23**	**27.84**	**15.70**	**22.44**	**26.86**	**25.23**	**22.12**	**17.63**	**15.29**	**13.44**	**12.70**	**10.98**	**8.61**
Cumulative Cashflow after tax (Nominal) - EBIT	USD Millions		**(237.16)**	**(318.86)**	**(281.29)**	**(240.53)**	**(215.25)**	**(175.49)**	**(123.16)**	**(69.08)**	**(16.92)**	**28.82**	**72.44**	**114.63**	**158.47**	**200.15**	**236.09**
Cumulative DCF (Nominal) - EBIT	USD Millions		**(215.60)**	**(283.12)**	**(254.90)**	**(227.05)**	**(211.36)**	**(188.92)**	**(162.06)**	**(136.83)**	**(114.71)**	**(97.08)**	**(81.79)**	**(68.34)**	**(55.65)**	**(44.67)**	**(36.07)**

Description	Unit																	
Production	**Project Year**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Tonnes Milled	Million Tonnes	2.76	2.76	2.76	2.76	2.75	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.69	2.76	2.76	2.76	2.76
Tonnes Milled	Tonnes	2 760 000	2 760 000	2 760 000	2 756 406	2 750 365	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 694 738	2 760 000	2 760 000	2 760 000	2 760 000
Content Milled	g	7 859 534	7 792 543	7 725 551	7 648 464	7 546 463	7 533 558	7 465 296	7 399 495	7 375 651	7 371 830	7 357 662	7 334 371	7 134 740	7 397 865	7 398 446	7 380 555	7 364 703
Mill Head Grade	g /t	2.85	2.82	2.80	2.77	2.74	2.73	2.70	2.68	2.67	2.67	2.67	2.66	2.65	2.68	2.68	2.67	2.67
Milled Recovery	%	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9
4E Produced	g	6 595 402	6 539 186	6 482 969	6 418 281	6 332 686	6 321 856	6 264 574	6 209 356	6 189 348	6 186 141	6 174 252	6 154 707	5 987 184	6 207 988	6 208 476	6 193 462	6 180 160
4E Produced	oz	212 047	210 240	208 432	206 353	203 601	203 252	201 411	199 635	198 992	198 889	198 507	197 878	192 492	199 591	199 607	199 124	198 697
Revenue																		
4E Basket Price (Nominal)	$/Oz	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173
Exchange Rate	R/US$	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
SA 4E Basket Price	R/g	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86
SA 4E Basket Price	R/Oz	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89
Gross Sales Revenue	USD Millions	**248.63**	**246.51**	**244.39**	**241.95**	**238.73**	**238.32**	**236.16**	**234.08**	**233.32**	**233.20**	**232.75**	**232.02**	**225.70**	**234.03**	**234.04**	**233.48**	**232.98**
Costs																		
Total Fixed Costs	USD Millions	(134.20)	(134.20)	(134.20)	(135.46)	(148.51)	(150.19)	(137.51)	(135.69)	(140.20)	(138.29)	(137.44)	(137.49)	(138.66)	(150.23)	(141.99)	(138.47)	(138.47)
Total Variable Costs	USD Millions	(55.69)	(55.69)	(55.69)	(55.62)	(58.12)	(58.73)	(52.81)	(53.34)	(55.69)	(55.69)	(55.69)	(55.69)	(53.97)	(58.85)	(56.44)	(55.69)	(55.69)
SIB - Mining	USD Millions	(19.21)	(19.21)	(19.21)	(19.39)	(21.26)	(21.50)	(19.69)	(19.43)	(20.07)	(19.80)	(19.68)	(19.69)	(19.85)	(21.51)	(20.33)	(19.82)	(19.82)
Total Costs	**USD Millions**	**(209.10)**	**(209.10)**	**(209.10)**	**(210.47)**	**(227.89)**	**(230.43)**	**(210.01)**	**(208.46)**	**(215.96)**	**(213.77)**	**(212.80)**	**(212.87)**	**(212.48)**	**(230.59)**	**(218.76)**	**(213.98)**	**(213.98)**
Average Cost		(75.76)	(75.76)	(75.76)	(76.36)	(82.86)	(83.49)	(76.09)	(75.53)	(78.24)	(77.45)	(77.10)	(77.13)	(78.85)	(83.55)	(79.26)	(77.53)	(77.53)
Net Sales Revenue (operating profit)	USD Millions	**39.53**	**37.41**	**35.30**	**31.48**	**10.83**	**7.89**	**26.15**	**25.61**	**17.37**	**19.43**	**19.95**	**19.15**	**13.23**	**3.43**	**15.28**	**19.50**	**19.00**
Tax Shield																		
Capital Expenditure (Nominal)	**USD Millions**	**0.00**	**0.00**	**0.00**	**0.00**	**(24.59)**	**(41.41)**	**(48.93)**	**(12.57)**	**(11.13)**	**(14.22)**	**(12.85)**	**(1.94)**	**(4.29)**	**(6.56)**	**(6.56)**	**(3.28)**	**0.00**
Underground Mining	**USD Millions**	0.00	0.00	0.00	0.00	(24.59)	(41.41)	(48.93)	(12.57)	(11.13)	(14.22)	(12.85)	(1.94)	(4.29)	(6.56)	(6.56)	(3.28)	0.00
Concentrator	**USD Millions**	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
Infrastructure	**USD Millions**	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
Indirect Cost	**USD Millions**	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
Other	**USD Millions**	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
Unredeemed Capex	USD Millions	0.00	0.00	0.00	0.00	(13.76)	(47.27)	(70.05)	(57.01)	(50.78)	(45.57)	(38.46)	(21.25)	(12.32)	(15.45)	(6.73)	0.00	0.00
Net Sales Revenue after Capex	USD Millions	**39.53**	**37.41**	**35.30**	**31.48**	**(13.76)**	**(33.52)**	**(22.78)**	**13.04**	**6.23**	**5.21**	**7.11**	**17.21**	**8.93**	**(3.13)**	**8.72**	**16.22**	**19.00**
Royalties																		
EBIT for Royalty Calculation	%	**39.53**	**37.41**	**35.30**	**31.48**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**12.77**	**19.00**
X=(EBIT Royalty /Gross Sales)		15.90	15.18	14.44	13.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.47	8.15
Refined Royalty Rate (Y=0.5+(X/12.5) - Max 7%	%	1.77	1.71	1.66	1.54	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.94	1.15
Royalty Paid	USD Millions	(4.41)	(4.23)	(4.05)	(3.73)	(1.19)	(1.19)	(1.18)	(1.17)	(1.17)	(1.17)	(1.16)	(1.16)	(1.13)	(1.17)	(1.17)	(2.19)	(2.68)
Cash Flow																		
Actual Cashflow after tax (Nominal) - EBIT	USD Millions	**35.13**	**33.19**	**31.25**	**27.76**	**(14.95)**	**(34.71)**	**(23.96)**	**11.87**	**5.07**	**4.05**	**5.94**	**16.05**	**7.80**	**(4.30)**	**7.55**	**14.03**	**16.31**
DCF (Nominal) - EBIT	USD Millions	**7.64**	**6.57**	**5.62**	**4.54**	**(2.22)**	**(4.69)**	**(2.94)**	**1.33**	**0.51**	**0.37**	**0.50**	**1.22**	**0.54**	**(0.27)**	**0.43**	**0.73**	**0.77**
Cumulative Cashflow after tax (Nominal) - EBIT	USD Millions	**271.22**	**304.41**	**335.66**	**363.42**	**348.46**	**313.76**	**289.79**	**301.67**	**306.73**	**310.78**	**316.72**	**332.77**	**340.57**	**336.27**	**343.82**	**357.85**	**374.16**
Cumulative DCF (Nominal) - EBIT	USD Millions	**(28.42)**	**(21.85)**	**(16.23)**	**(11.70)**	**(13.92)**	**(18.61)**	**(21.55)**	**(20.23)**	**(19.71)**	**(19.34)**	**(18.84)**	**(17.62)**	**(17.07)**	**(17.35)**	**(16.91)**	**(16.18)**	**(15.41)**

Description	Unit																		
Production	**Project Year**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	
Tonnes Milled	Million Tonnes	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	1.57	1.56	1.27	0.65	0.09	**126.39**
Tonnes Milled	Tonnes	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	2 760 000	1 565 991	1 560 000	1 274 000	650 000	91 000	**126 387 500**
Content Milled	g	7 348 861	7 333 020	7 317 178	7 301 337	7 285 495	7 269 654	7 253 812	7 237 970	7 222 129	7 206 287	7 190 446	7 174 604	7 144 637	4 008 761	3 993 383	3 261 263	1 663 910	232 947	**351 177 345**
Mill Head Grade	g /t	2.66	2.66	2.65	2.65	2.64	2.63	2.63	2.62	2.62	2.61	2.61	2.60	2.59	2.56	2.56	2.56	2.56	2.56	**2.78**
Milled Recovery	%	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	
4E Produced	g	6 166 867	6 153 573	6 140 279	6 126 986	6 113 692	6 100 399	6 087 105	6 073 811	6 060 518	6 047 224	6 033 930	6 020 637	5 995 489	3 363 990	3 351 085	2 736 719	1 396 285	195 480	**294 693 793**
4E Produced	oz	198 269	197 842	197 415	196 987	196 560	196 132	195 705	195 278	194 850	194 423	193 995	193 568	192 759	108 155	107 740	87 988	44 892	6 285	**9 474 625**
Revenue																				
4E Basket Price (Nominal)	$/Oz	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	1 173	
Exchange Rate	R/US$	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	
SA 4E Basket Price	R/g	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	640.86	
SA 4E Basket Price	R/Oz	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	19 932.89	
Gross Sales Revenue	USD Millions	**232.48**	**231.97**	**231.47**	**230.97**	**230.47**	**229.97**	**229.47**	**228.97**	**228.47**	**227.97**	**227.46**	**226.96**	**226.01**	**126.81**	**126.33**	**103.17**	**52.64**	**7.37**	**11 109.22**
Costs																				
Total Fixed Costs	USD Millions	(138.42)	(138.36)	(138.36)	(138.35)	(135.94)	(133.68)	(133.12)	(133.12)	(133.12)	(133.12)	(133.12)	(133.12)	(125.70)	(91.38)	(91.30)	(81.62)	(61.58)	(35.95)	**(6 395.94)**
Total Variable Costs	USD Millions	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(55.69)	(51.79)	(31.53)	(31.48)	(25.71)	(13.11)	(1.84)	**(2 550.08)**
SIB - Mining	USD Millions	(19.82)	(19.81)	(19.81)	(19.81)	(19.46)	(19.14)	(19.06)	(19.06)	(19.06)	(19.06)	(19.06)	(19.06)	(18.00)	(13.08)	(13.07)	(11.69)	(8.82)	(5.15)	**(891.20)**
Total Costs	**USD Millions**	**(213.93)**	**(213.85)**	**(213.85)**	**(213.85)**	**(211.09)**	**(208.51)**	**(207.87)**	**(207.87)**	**(207.87)**	**(207.87)**	**(207.87)**	**(207.87)**	**(195.49)**	**(135.99)**	**(135.85)**	**(119.01)**	**(83.51)**	**(42.93)**	**(9 837.23)**
Average Cost		(77.51)	(77.48)	(77.48)	(77.48)	(76.48)	(75.55)	(75.31)	(75.31)	(75.31)	(75.31)	(75.31)	(75.31)	(70.83)	(86.84)	(87.08)	(93.41)	(128.48)	(471.80)	**(77.83)**
Net Sales Revenue (operating profit)	USD Millions	**18.55**	**18.12**	**17.62**	**17.12**	**19.38**	**21.46**	**21.60**	**21.10**	**20.60**	**20.10**	**19.60**	**19.10**	**30.53**	**(9.18)**	**(9.52)**	**(15.84)**	**(30.87)**	**(35.56)**	**1 271.99**
Tax Shield																				
Capital Expenditure (Nominal)	**USD Millions**	**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**	**(658.76)**
Underground Mining	**USD Millions**	0.00	0.00																	(346.28)
Concentrator	**USD Millions**	0.00	0.00																	(153.13)
Infrastructure	**USD Millions**	0.00	0.00																	(58.74)
Indirect Cost	**USD Millions**	0.00	0.00																	(100.62)
Other	**USD Millions**	0.00	0.00																	0.00
Unredeemed Capex	USD Millions	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	(9.18)	(18.70)	(34.54)	(65.42)	(100.98)	
Net Sales Revenue after Capex	USD Millions	**18.55**	**18.12**	**17.62**	**17.12**	**19.38**	**21.46**	**21.60**	**21.10**	**20.60**	**20.10**	**19.60**	**19.10**	**30.53**	**(9.18)**	**(9.52)**	**(15.84)**	**(30.87)**	**(35.56)**	**613.23**
Royalties																				
EBIT for Royalty Calculation	%	**18.55**	**18.12**	**17.62**	**17.12**	**19.38**	**21.46**	**21.60**	**21.10**	**20.60**	**20.10**	**19.60**	**19.10**	**30.53**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
X=(EBIT Royalty /Gross Sales)		7.98	7.81	7.61	7.41	8.41	9.33	9.41	9.22	9.02	8.82	8.62	8.41	13.51	0.00	0.00	0.00	0.00	0.00	
Refined Royalty Rate (Y=0.5+(X/12.5) - Max 7%	%	1.14	1.12	1.11	1.09	1.17	1.25	1.25	1.24	1.22	1.21	1.19	1.17	1.58	0.50	0.50	0.50	0.50	0.50	
Royalty Paid	USD Millions	(2.65)	(2.61)	(2.57)	(2.52)	(2.70)	(2.87)	(2.88)	(2.83)	(2.79)	(2.75)	(2.71)	(2.66)	(3.57)	(0.63)	(0.63)	(0.52)	(0.26)	(0.04)	**(113.36)**
Cash Flow																				
Actual Cashflow after tax (Nominal) - EBIT	USD Millions	**15.90**	**15.51**	**15.05**	**14.60**	**16.68**	**18.60**	**18.73**	**18.27**	**17.81**	**17.35**	**16.89**	**16.43**	**26.96**	**(9.81)**	**(10.15)**	**(16.36)**	**(31.14)**	**(35.60)**	**499.87**
DCF (Nominal) - EBIT	USD Millions	**0.68**	**0.61**	**0.54**	**0.47**	**0.49**	**0.50**	**0.46**	**0.40**	**0.36**	**0.32**	**0.28**	**0.25**	**0.37**	**(0.12)**	**(0.12)**	**(0.17)**	**(0.29)**	**(0.30)**	**(10.69)**
Cumulative Cashflow after tax (Nominal) - EBIT	USD Millions	**390.06**	**405.57**	**420.63**	**435.23**	**451.90**	**470.50**	**489.22**	**507.49**	**525.30**	**542.65**	**559.54**	**575.98**	**602.93**	**593.12**	**582.97**	**566.61**	**535.47**	**499.87**	**499.87**
Cumulative DCF (Nominal) - EBIT	USD Millions	**(14.72)**	**(14.12)**	**(13.58)**	**(13.11)**	**(12.62)**	**(12.12)**	**(11.67)**	**(11.26)**	**(10.91)**	**(10.59)**	**(10.31)**	**(10.06)**	**(9.69)**	**(9.81)**	**(9.93)**	**(10.10)**	**(10.39)**	**(10.69)**	**(10.69)**