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BREACHING THE PLATINUM COST CURVE

Cost curve selection and development, marginal production survival

Peter Schmitz

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

Johannesburg, 2019

DECLARATION

I declare that this research report is my own unaided work. It is being submitted in partial fulfilment of the Degree of Master of Science in Mining Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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 and I undertake to abide by the decision of any such investigation.

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ABSTRACT

The report considers survival mechanisms used by Platinum Group Metal (PGM) producers over the period 2008 to 2017 when mining operations were considered marginal for an extended period. Various methods to build cost curves for the PGM industry were tested, with co-product costing, inclusive of sustaining capital, selected. Industry cost curves were developed for the period, showing that a significant portion of producers were marginal from 2014 to 2017, with Impala lease area, Rustenburg mines and Lonmin marginal for more than two years in that period. Survival was achieved through cross-subsidisation, utilising cash reserves, deferring sustaining capital, re-capitalisation and working capital management, before ultimately restructuring through sale or closure took place. While industry cost curves were effective at indicating operational competitiveness in a particular year, a mechanism to indicate relative financial strength (ability to sustain this position) needs to be sought.

To the family.

I may emerge from the study shortly.

ACKNOWLEDGEMENTS

Partial assistance by Anglo American, both financial and in time, is gratefully acknowledged. The support of the University of the Witwatersrand in being able to complete the degree on a part-time basis and in particular the help and guidance of Prof. Minnitt are both much appreciated.

The author is employed by Anglo American and has access to privileged information. The author has exercised caution, ensuring that all sources and data are exclusively from the public domain for this research report, including company annual reports, analyst reports and conference proceedings.

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LIST OF ACRONYMS

AISC	All-In-Sustaining-Cost
CTL	Coal To Liquids
EBIT	Earnings Before Interest and Tax
GDP	Gross Domestic Product
GTL	Gas To Liquids
LPPM	London Platinum and Palladium Market
NERSA	National Energy Regulator South Africa
Non-GAAP	non-Generally Accepted Accounting Principles
PGE	Platinum Group Element
PGM	Platinum Group Metal
UG2	Upper Group 2

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1 INTRODUCTION

1.1 Purpose

The purpose of the research report is to identify sub-economic producers of platinum, as determined using a cash cost curve, and investigate mechanisms by which a company is able to operate in what appears to be a cash negative position for a period of time without closing operations. The platinum industry is used as it has been in an extended down-turn and may serve as a proxy for other mining operations and metal producers. Cost curves are built up for the period 2008 to 2017, marginal producers were identified and tested, and individual company behaviour was investigated.

The study provides the basis for future work, suggesting that a mechanism is required that can combine an endogenous measure of resilience of the business (as provided by balance sheets) with an exogenous measure of resilience (as provided by cost curves).

1.2 Research Motivation

Cash cost curves are used to analyse competitive commodity markets, where production volumes for individual suppliers are plotted cumulatively on the horizontal axis with production costs on the vertical axis, ranked from lowest cost to highest cost. Herfindahl (1955), building on work done

by Gray (1913) and Hotelling (1931), discussed some of the rank order competitiveness required in the mining industry, specifically the difference between production cost and price for more than one producer. From the 1980's, recognisable minerals industry cost curves have been more widely used for competitor analysis, for example by Torries (1988) for nickel. Industry supply curves today are still used for competitor analysis, however they are also used together with expected demand to determine the "marginal cost" around which prices are expected to fluctuate (McKinsey & Company, 2009).

Cost curves are used as they provide a convenient, succinct way to provide an overview of intra-industry competitiveness for individual production units at a specific time. While the principle behind cost curves is simple, the information shown may not always give a true reflection of competitiveness where co-production of various minerals occurs. They correctly reflect the impact of productivity or cost related issues that impact unit cash cost and hence competitiveness. However, they do not indicate non-cash issues that may impact competitive position. This may result in specific sites, companies or operations continuing when they theoretically would not be expected to, according to cost curves, and vice versa. This potentially calls into question the reliability of cost curves in explaining industry fundamentals and representing relative competitiveness.

This study aims to provide the groundwork for making analysis grounded on cost curves more reliable, or at least show that analysis should consider some measure of business health. It does this by empirically identifying mechanisms by which a significant volume of production was able to continue in what appeared to be a cash negative environment in the South African platinum industry over 2008 to 2017.

1.3 Research Approach and Report Layout

The South African platinum industry has been analysed for the period 2007 to 2011 by Tholana (2012). This research extends the analysis to the global platinum and palladium industry over 2008 to 2017 and identifies potential survival mechanisms employed by marginal producers over that period.

The report starts with a review of the theoretical background to cost curves and company survival, followed by industry background. The body of the report consists of the development and analysis of platinum industry cost curves. The concluding section discusses survival mechanisms employed by marginal producers.

Data was collected from publicly available sources and, where in unsuitable format or incomplete, was converted into a suitable form with

omissions estimated. This information was represented in alternative forms on various cost curves, to test for suitable ways to analyse an industry that produces platinum, but also derives significant value from palladium, nickel, copper, other Platinum Group Metals (PGMs) (i.e. rhodium, iridium, osmium and ruthenium) and silver and cobalt. Once a suitable method was selected, rather than use the drawing method demonstrated by Tholana (2012), specific software was used, as provided by Think-Cell (2019). This was the basis for selecting producers that have survived for a longer period while appearing to be cash negative.

For these marginal producers, empirical evidence was sought to identify the mechanism(s) by which they survived. From the literature review, a few measures were suggested that would enable survival by reducing costs or increasing productivity. While these need to be understood, they are reflected on a correctly drawn cost curve. This study sought evidence for mechanisms not directly related to cost or productivity, as presented in the final chapters.

The research was done as an analytical, desktop investigation. The research is limited to publicly available data, including company annual and production reports, analyst presentations and analyst papers. It has not included suppliers of recycled material, or producers that primarily supply other (non-platinum) metals. While industry stocks are expected to

have a significant influence on buffering the relationship between costs and price in metals, the question being investigated relates to individual mine survival, hence industry stocks are excluded from the analysis.

1.4 Research Hypothesis

The hypothesis is that sub-economic, or marginal, suppliers do not shut down from one year to the next for reasons that are not immediately apparent using cost curves to analyse the industry. These may include:

- *Cross-subsidisation.* Diversification across sites, geographies or companies may allow for sub-economic production to continue for some time.
- *Sustaining capital deferral.* The ability to defer sustaining capital may influence the decision, at the cost of future higher capital spend or increased future operating cost.
- *Cash reserves.* Reserves built up over periods when prices were high may allow for a deferral of care and maintenance or closure.
- *Working capital optimisation.* While less liquid than cash, inventory could be monetised, including both pipeline and finished stocks. Alternatively, accounts payables could be deferred, accounts receivables accelerated.
- *Debt obtained/equity issued.* While not directly affecting cash costs, issuing equity may defer the decision to close.

- *Hedging.* Both exchange rates, affecting supply purchases, as well as commodity prices, affecting sales, can be hedged, reducing volatility and potential downside.
- *Exit costs.* Existing take-or-pay contracts, environmental and closure costs may influence the shut decision.

1.5 Assumptions

It was assumed that the period 2008 to 2017 showed a transition from when most South African platinum producers were running on a net cash positive basis, to where a significant proportion no longer did. Pricing was viewed as being transparent, with over the counter pricing relatively limited. Specifically, by-product pricing was assumed to be transparent to all market participants, with all by-products fully accounted for and priced despite potentially being minor metals with limited trade. Costs and figures as presented in the annual financial statements of the companies investigated were assumed to be correct and comparable, with corrected figures used if they were published later. While platinum was used for this study, it was assumed that the results would be transportable to other commodity markets that use industry cost curves for competitive analysis (e.g. thermal coal, metallurgical coal, iron ore, nickel).

2 LITERATURE REVIEW

This chapter deals with the theoretical issues influencing a company or mine's competitive position. Macroeconomic and minerals industry related influences are discussed, with industry cost curves introduced and competitive position determining factors discussed.

2.1 Macroeconomic

Demand for commodities results from a need for commodity as input into production of goods. Goods are required for investment and consumption, both by the public and governments. While global economic activities require both goods and services, most growing and developing economies continue to require goods to some extent (Olivier, 2011).

Supply costs are based to some extent in local currency terms, while prices are US Dollar based, hence the local exchange rate relative to the US Dollar influences competitiveness relative to producers in other countries (Minnitt, 2015). This is subject to the exchange rate being independent of the commodity being exported. i.e. the commodity should not make up a significant portion of exports for that country, hence influencing the balance of payments. If a commodity does make up a significant portion of exports, this may lead to the so-called *Dutch Disease*, where a country, its exchange rate and eventually almost its whole economy becomes dependant on that one commodity (Minnitt, 2015).

Other macro-economic influences on supply costs include inflation and trade barriers. They may differentially affect a producer's cost of production in a particular country, rather than affecting all producers equally, hence influencing competitive position. To adjust for inflation and make comparisons over time, costs and prices may be expressed in "real" terms, i.e. as at a selected date (Pindyck & Rubinfeld, 2009).

2.2 Minerals Industry

2.2.1 Metals markets and prices

Minerals are considered commodities, as they are unbranded and reasonably homogeneous. This is particularly the case when sold at a high purity in metal form, as Platinum Group Metals (PGMs) are (London Platinum and Palladium Market, 2018). Metals are reasonably easily traded, with low storage and transport cost relative to their underlying value. Pricing is transparent, with PGMs traded transparently in markets such as on the London Platinum and Palladium Market (LPPM). While arbitrage opportunities may exist, they are expected to quickly be exploited and closed, with the markets displaying characteristics following the efficient market hypothesis (Timmermann & Granger, 2004).

In an efficient and competitive market, prices are not able to be set by any one buyer or seller. Prices are set where supply meets demand, at a cost and volume acceptable to both sides of the market and visible to all participants. Suppliers of the product are price takers, with the only power they can exert being to shut down if they find they are unable to ensure business survival at market quoted prices, or to expand production at existing or new sites if the market price and future expectations allow for it (Pindyck & Rubinfeld, 2009).

2.2.2 Competitive advantage

"Businesses become successful because they possess some advantage relative to their competitors" (Pearce & Robinson, 2005). Competitive advantage is generally achieved using two routes: either providing the product at a lower cost than other producers, or by providing a product that is different in the customer's mind to what others are providing (Pearce & Robinson, 2005). Differentiation provides something unique at a premium to the customer. It relates to skills or resources that provide unique attributes, such as product engineering, marketing ability, creative talent, research abilities, reputation, tradition or co-operation from other sectors. Differentiating products is not possible when homogenous, unbranded products are sold into a competitive market, though there may be some opportunity for differentiating the service associated with delivery of the product (Pearce & Robinson, 2005).

Cost leadership has the advantage that it reduces pricing pressure and the risk of buyers finding substitutes and discourages new entrants to the market that don't have the associated scale and learning benefits. It has the risk that cost benefits are able to be duplicated over time and may result in other competitive advantages reducing, if applied too aggressively. (Pearce & Robinson, 2005)

In using a low cost approach, it implies that competitive advantage leads to a sale at an acceptable price to both seller and buyer, where price is greater than production cost if the producer is not marginal in the industry. "Products" implies that not only one output needs to be considered, but rather the full suite of products related to a particular cost. Lastly, differentiation relates to *value* to the customer, or perceived value rather than necessarily a measured value (Borthwick, 1991).

In the case of mining, cost leadership receives most focus due to the homogenous nature of particularly metal products. The business can differentiate itself, however, by diversifying into other product lines, operating or behaving differently, or using different technology. Effectively this still results in cost leadership, rather than *product* differentiation.

2.3 Industry Cost Curves Representing Competitiveness

2.3.1 Building industry cost curves

In order to represent individual producers' competitive position, a supply curve may be drawn by showing cumulative industry production capacity (horizontal axis), where the unit cost of production for each supplier (vertical axis) is ranked from lowest to highest cost in the industry, thereby building an "industry cost curve", as per McKinsey & Company (2009) in Figure 2.1 below. For a given level of market demand, when demand is virtually price inelastic, the corresponding marginal industry unit cost of production can be found. As it corresponds to the industry price at which production can sustainably occur, it is of interest to various stakeholders, including investors, management and industry commentators. It has found extensive use in industry, competitor and pricing analysis (McKinsey & Company, 2009).

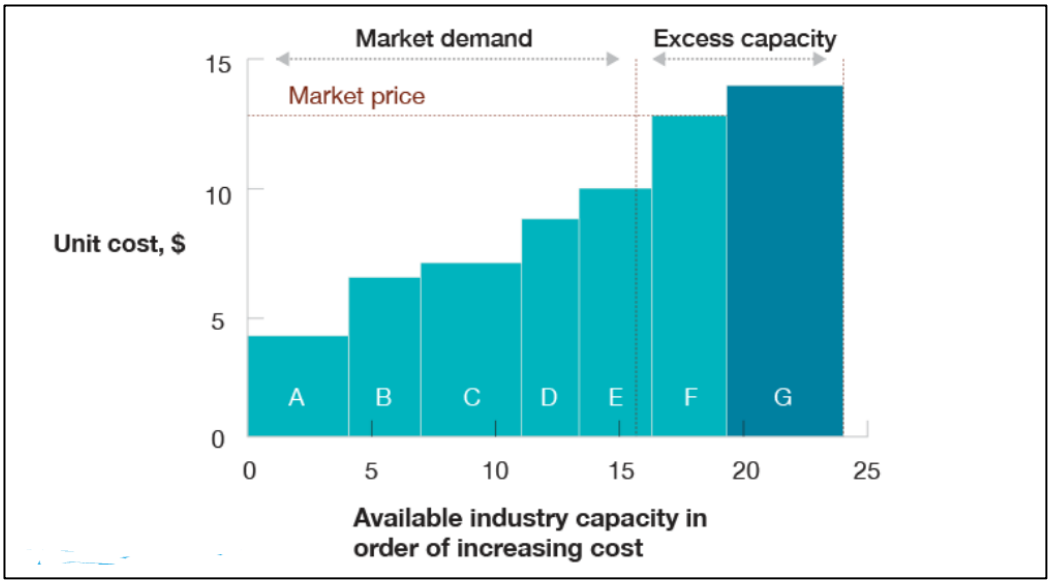


Figure 2.1: Cost curve example ***(McKinsey & Company, 2009)***

Markets generally have non-convexities (are indivisible and non-linear), resulting in discrete volumes being added or dropped from the whole curve. This implies over or under supply and/or investment on an industry level, which is physically solved by stocks. It is likely one of the reasons for the empirically observed behaviour that prices are not at exactly the marginal unit cost of production, but treated by industry analysts as being at or near the 95th percentile of the required supply, as a proxy for the market clearing price (O'Neill, et al., 2005).

2.3.2 Costs included in constructing industry cost curves

Items typically included are dependent on the purpose of the cost curve. Direct mining costs, direct processing costs, general administration related to the mine, other on-site costs and transport to the point of sale are included (Tholana, 2012). Government costs such as royalties are included, whereas income tax and financing are not. If an operation is marginal, there are no returns to shareholders and governments. There is some contention as to whether sustaining capital expenditure, corporate overheads or exploration should be included, with Tholana (2012) suggesting that these should not be included, as expansions, new equipment, corporate management and new ventures need to be financed by the profit represented by the difference between operating cost and price.

SNL, a division of S&P Global Market Intelligence see this as a useful measure of short term mine site profitability. They do, however, include overheads, closure provision, exploration (mine site) costs and sustaining capital costs in All-In Sustaining Cost (AISC), as this represents costs required to maintain production at a mine site on a continuous basis. The decision to include a particular cost or not is a function of whether it is necessary to ensure continuation of supply for the period under consideration, and whether it influences relative competitive position (S&P Global Market Intelligence, 2017). As this report aims to measure an operation's performance against a long-term cost level, the SNL approach is used in the rest of the report.

Other complications in measuring competitiveness across companies includes accumulating costs differently, as well as differing accounting and taxation treatment in financial statements (Tholana, 2012). This research project uses cash flows where possible. While accounting measures aim to provide an accurate reflection of the historical state of a business, cashflow is the critical measure by which forward looking, value based decisions over both the near term and long term are taken (Lumby & Jones, 2004).

2.3.3 Currency considerations in determining costs

Commodities are typically priced in US Dollars. Exposure of operating costs to local currency and its fluctuations (excluding foreign manufactured capital equipment, imported oil based fuels) impacts competitiveness on an equivalent US Dollar basis (Venmyn Deloitte, 2016). The South African Rand has fluctuated considerably over the period under consideration, both in nominal and real terms, as can be seen in Figure 2.2 below with data from The Reserve Bank of South Africa (2018) and the U.S. Bureau of Labor Statistics (2018), as per Appendix 8.14.

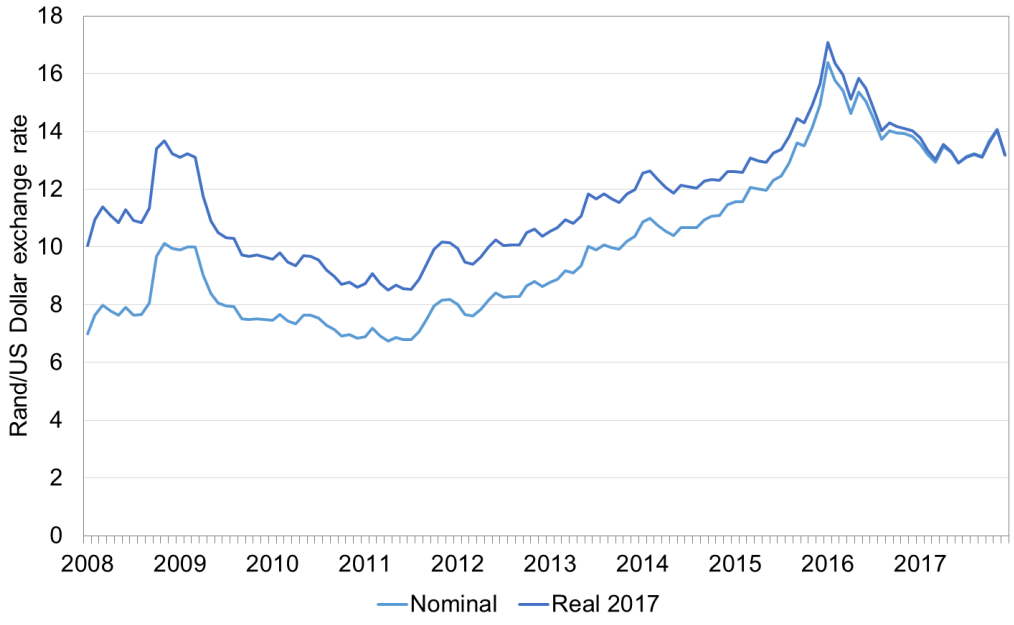


Figure 2.2: Rand/US Dollar Exchange Rate. After Appendix 8.14

2.3.4 Production selected for constructing industry cost curves

A complication for evaluating the PGM industry is that several metals are produced. For the cost curve, where costs are expressed per unit of output, the output unit needs to be defined. As mining and concentrating covers 80% of costs, Tholana (2012) suggests using a tonne of ore processed. While recognising that grade differences and prill splits (proportion of metals) in ores may differ, it is seen as a reasonable approximation and neatly avoids the need to apportion costs to different products (Tholana, 2012).

An alternative suggested by SNL is to use by-product costing, where all by-product revenues are subtracted from costs. This is reasonable where by-products are small in value relative to the main product. In the case of PGM production at most mines, there is rarely a clear main product to use as the basis. As a result, a “basket” of Platinum Group Element (PGE) products may be used, with 2PGE (platinum, palladium), 4PGE (platinum, palladium, rhodium and normally gold) and 6PGE (platinum, palladium, rhodium, iridium, ruthenium, gold or sometimes osmium) all being used by various companies in their reports.

Another alternative, also suggested by SNL and applied by Wood Mackenzie (2019), is to use a “co-product” methodology. In this method,

costs that are clearly able to be allocated to a particular metal are accounted for in that product, while a revenue weighted split is used to allocate remaining “mixed” costs to all metals individually. If it is assumed there are no clear individually allocable costs, this effectively applies the same margin to each individual metal. It is most applicable where competitiveness is a function of all products collectively, rather than each individually (S&P Global Market Intelligence, 2017).

This research tests the various methods, but finally selects the co-product method for producing cost curves as the most appropriate for the platinum industry. This measure allows for individual mine product mixes and the impact on competitiveness to be represented, while still correctly representing the interdependence of the metals on each other.

2.4 Factors Influencing Producer’s Position in the Industry Cost Curve

2.4.1 Market size

Cost curves are dynamic and the position of a particular producer is constantly shifting (Tholana, 2012). Competitive position may change with market size adjustments. In a growing market, an uncompetitive producer may become relatively competitive as new entrants are necessarily drawn in to produce marginal volumes that are less competitive. Another mechanism is through project cancellations, mine closures, exploration

and capital cuts or reserve depletion, they might find their positon improving over time (Venmyn Deloitte, 2016).

2.4.2 Cost

Costs are all expenditures related to an operation in the normal course of current or future production. Measuring costs and revenues for accounting purposes treats them as incurred as soon as the work is done, while cash costs are only considered once payment is made for the work done. While the difference is subtle, timing differences between payments and receipts result in potentially a large difference between the accounting state of the business and the cash balance. With regards to business survival, it is ultimately the cash state that is critical for operations.

Costs dependant on external factors, such as royalty payments, taxes, fuel or electricity unit costs, are uncontrollable. Controllable costs, related to mining, processing or transport on the mine property are more directly related to choices that the company can make. Costs may also be classified as fixed or variable (i.e. related to production), depending on how they are expected to change if production levels change, with platinum mining typically 75% fixed (Impala Platinum Holdings, 2018a). In deciding whether costs are controllable or not, or fixed or variable, the timeframe under consideration is critical: over a long enough timeframe all controllable costs are related to production and hence variable, while

some uncontrollable costs may be influenced by choice to operate and thorough lobbying those that do control them (Surujhlal, et al., 2014).

Uncontrollable costs

Taxes include royalties that are generally paid on revenue, income tax paid on accounting profit as well as dividend and withholding taxes paid to shareholders or overseas shareholders respectively (Birch, 2015). Royalties are costs that relate to accessing and mining the resource and may be paid to local communities or the government, or occasionally private holders of the resource. They may be time based, production volume based or profit based. In the latter case it behaves more like an income tax. In the case of South Africa, a small (0.5%) portion is fixed, with the largest proportion behaving effectively like a profit tax. For the platinum industry, where a refined metal is sold, royalty to be paid is calculated using Equation 2.1 (Birch, 2015):

Royalty paid = Gross sales excluding non-mining income x Royalty %

……...2.1

Where: *Royalty % = 0.5% + (EBIT/(Aggregate gross sales x 12.5))*

Income taxes are a function of accounting profit and are imposed by governments, hence considered uncontrollable. As a marginal operation will not be paying any income tax, income tax is excluded from industry

cost curves. Arguably it may need to be included when considering relative attractiveness across countries for more cash positive operations. Withholding and dividend taxes are another form of income tax (Birch, 2015).

Unit fuel costs (mostly diesel for mining) are considered uncontrollable, with approximately half of the cost of fuel resulting from a government fuel levy. The cost of production is based on the cost of oil used to produce the fuel and is priced internationally. South Africa consumes the second largest amount of oil in Africa, behind Egypt. It imported around 80% of the c. 700 thousand barrels a day worth of oil required in 2016 (up from 60% in 2008) with 86% of local production coming from coal/gas to liquids and produced mostly by Sasol, with some from PetroSA (U. S. Energy Information Administration, 2017).

Unit electricity costs are regulated in South Africa by the National Energy Regulator (NERSA), with 90% of production by Eskom and the remainder form independent power producers (U. S. Energy Information Administration, 2017). Between 2013 and 2015 there were several power cuts, with industry and economic growth negatively affected. From 2016, in South Africa, weaker electricity demand and new capacity commissioned resulting in power surplus.

Controllable costs

Controllable costs are controllable to some extent by choices the mining company makes with regards to resource development or operation. *Mining costs* by process include cost to access the ore, remove the ore from the seam and the initial crushing and classification to facilitate transportation from underground or from the mining area. It also includes the cost of transporting or conveying it to the beneficiation plant and on-going rehabilitation as a part of normal operations. It may include an allowance for final closure of the mine, however this is generally separated out as it may be an accounting provision in some countries rather than a cash payment. Mining costs tend to mostly consist of labour, both on-mine and contracting, and stores costs (spare parts and other consumable costs), utility cost (electricity, explosives, fuel), and sundry costs (other) (Anglo American Platinum, 2013).

Labour cost as a proportion of total cost is likely to be countercyclical, as labour costs are diluted when volumes are driven up in a market upturn (Mazumder, 2010). The marginal cost of labour, however, is pro-cyclical. Hours of work are adjusted more readily than the number of employees, making the fixed portion of labour costs not perfectly flexible in the near term.

Most PGMs are mined using underground methods, with only Lac Des Illes (Canada) and Mogalakwena (South Africa) being significant open pit mines (Zientek, et al., 2017a). Underground mining cost, both for accessing and removing the ore, is related to host rock type, depth, technology selected for mining, energy supply and cost, and the construction methods selected to access the ore. When mining a metamorphic host rock, like schist, it requires c. 70% greater support cost to be incurred relative to a more competent host rock, like those associated with a lead/zinc mineralised system (Doneva, et al., 2015).

For underground mining, a significant cost, both in terms of initial and sustaining capital, is associated with the development of travelling ways and tunnels (40 – 60%, according to Doneva et al. (2015)). While costs to develop shafts and pump stations are considered initial capital, other development costs are classified as sustaining capital and behave more like operating costs.

Development costs have been found to be largely a function of host rock type and the cross section chosen, rather than other factors such as construction technology and energy (Doneva, et al., 2015). The majority of costs are associated with drilling and blasting, support and loading and hauling. The split between them varies mostly due to host rock type, with more competent rock requiring more drilling and blasting (c. 45% of total in

a lead/zinc mineralised system, versus c. 19% for a schist host rock type), but requiring less support (c. 20% for a lead/zinc mineralised system, versus 61% in a schist). The host rock associated with South African PGM mines tends to be of the more competent type.

Beneficiation costs are those underlying what is normally commercially termed “treatment and refining”. In the PGM industry, these consist of costs associated with further classification and milling, followed by concentration through froth flotation (where reagents provide a technology advantage due to increased recovery, at a significant cost). Smelting occurs in electric furnaces, with subsequent air or oxygen enriched blown conversion and finally refining by hydrometallurgy. For smelting and conversion, the most significant cost is associated with utilities (electricity), while for refining it is consumables (presumably chemicals associated with hydrometallurgy) (Anglo American Platinum, 2013).

Transport of the product to the point of sale may be as far as the mine gate or end customer, with the latter being particularly relevant to high volume low value (“bulk”) materials rather than for PGMs. It is controllable to the extent that choices can be made with regards to transportation type and the level of beneficiation/concentration of the product being transported.

General and administration costs include support functions such as management, accounting, marketing and exploration. Where multiple sites are run centrally, central costs tend to be allocated to mine sites where they are related to direct support provided, or to shareholders if they are not clearly related to a specific site. (e.g. exploration in areas not near existing operations would normally be allocated to shareholders, rather than brought into consideration for a particular mine site) (S&P Global Market Intelligence, 2017).

Rehabilitation and closure costs are those costs related to restoring a mine site to an acceptable state after the end of the productive life of mine. While it may be an accounting provision, some countries (including South Africa) require a cash provision held in a trust, while the allocation occurring is dependent on production and approved by government (Birch, 2015).

2.4.3 Cost control

On a macro level, production cost inflation is better explained by labour and output production, with a fixed portion of both, than considering labour alone (Matheron & Maury, 2004). The Phillips curve (Blanchard, 2011) has been used to relate inflation in an economy to employment and hence production output. The traditional formulation finds that high inflation results from high employment and is backward looking, implying that

higher production results in higher inflation. The New Keynesian formulation, as used by Whelan (2005) suggests that this relationship should be *forward* looking, i.e. that the *expectation* of higher production results in cost inflation. Empirically, evidence suggests a mixture of both, with the expectation of higher output explaining about half of the inflation experienced. (Roeger & Herz, 2012) The implication for mining is that both an actual increase in production as well as an anticipated increase in production leads to higher input costs.

Another factor to consider is industry capacity compared to current outputs, according to the Calvo pricing formulation used by Whelan (2005). When production is high relative to capacity, there is more competition for production factors, resulting in higher real costs. Price assumptions play a critical role in terms of project approval and the extent to which effort is put into cost control. The platinum mining industry has used planning assumptions materially above spot prices for an extended period (Venmyn Deloitte, 2016).

The selected systems matter to the effectiveness of cost control. Responsibility costing may be good for accountability, but it masks overheads and hence cost control effects may be diluted. In one study, stoping and support was found to be 39% of costs on responsibility costing, but 64% when considered on an activity based costing basis.

i.e. responsibility costing may lead to misdirection, particularly when looking at process improvements (Scott-Russell, 1993).

Cost reduction approaches may use a top down or rolled over budgeting approach, but a more effective approach is to sum up costs based on detailed fundamentals - so-called “zero based budgets” (Borthwick, 1991). Cost developments over time as well as deferrable costs can be identified from the start, with permanent cost reductions put through sustainably. Greater information accuracy is required when margins reduce and better cost control is required: good cost control relies on having long term plans, with short term quantitative budgets to deliver on cost reductions. Costs are all variable over the longer term and well specified zero based budgeting ensures that all activities add value.

The approach to cost control proposed by PricewaterhouseCoopers (2015) is to first establish a cost reduction environment by laying out the need for it, agreeing on cost ownership before challenging plans. They suggest checking for contract leakage (potential for recoverable claims, cost avoidance areas, off-contract savings), checking performance by looking at results, controlling all spending, and lastly stabilising controls used to more clearly see effects over time (PricewaterhouseCoopers LLC, 2015).

Optimising costs also results in better cost control. This can take the form of reducing labour, process or consumables wastage, time lost due to high frequency of change in production methods or poor placement of equipment, and reducing stock (Borthwick, 1991). Optimising and controlling costs may also be achieved through restructuring the company: seeking economies of scale may help to reduce costs by spreading fixed costs over a broader production output base. Building experience over time and identifying efficiencies in processes is a more incremental approach. Monitoring profitability of each process allows the key value driver to be identified and given priority, while those processes that are less important may be eliminated or reduced. Reducing and removing complexity, reducing peripheral sales, identifying obsolescence of processes or equipment due to changing technology are other methods of controlling costs (PricewaterhouseCoopers LLC, 2015).

Specific to mining, overall costs can be reduced by cutting overhead costs, better short-term execution planning, or implementing a business improvement programme that considers production, process and cost management (Surujhlal, et al., 2014). Costs may be optimised by changing the metals mix in production to one that is better suited to market expectations, particularly with regards to by-products and product form. While not related to costs, capital decisions affect cash, with capital rationalisation, optimisation of farm fence boundaries and managing the

portfolio to rationalise, close, or re-size mines leading to a more optimal size and lower capital intensity.

2.4.4 Productivity

Productivity was the third highest risk for mining in 2016, according to Ernst & Young Global Limited (2016b), after sustainable cost reductions and unlocking working capital. It affects the unit cost of production and competitiveness. In order to optimise productivity, it requires a systems focus on mining assets and the flow of material end to end (mine to customer), pursuing all loss (including revenue, cost and capital streams), as well as supporting people to optimise systems and processes (Ernst & Young Global Limited, 2016b). Step changes are required to create a truly modern, safe, productive environment on the mine. This extends across all phases and requires increased rigour prior to feasibility stages, efficiency in mine planning, and collaboration across the mine when operating (Drinkwater, 2017).

Regarding scale, a study (Anon., 2017) looking at Australian hard rock mines found that there was little to gain for most mines when larger than about 0.5Mt of rock or ore was moved for most mines. Looking at this in more detail, it was found that pursuing economies of scale was not enough to reduce unit costs significantly; optimising processes and systems were also needed not to lose the gains from scale.

Productivity improvements on-mine are achieved through carefully designed and executed operations strategies and on-mine planning. Typical methods include selecting high grade pockets of the reserve, increasing production to dilute fixed costs or ramping up volumes from lower cost operations in the portfolio. There is a question of sustainability of these options, with them seen generally as short-term solutions in times of a cash squeeze only (Venmyn Deloitte, 2016).

Productivity cannot be pursued in isolation. Diseconomies of scale occur where systems are not interlinked and dispersed, resulting in duplication of systems and support for these multiple systems, with associated costs (Ernst & Young Global Limited, 2017a). Other considerations should be that existing technology may hamper the introduction of new technology and that a more digital environment in a wider company portfolio, where productivity improvements may need more focus in some areas, may be to the detriment of other parts of the company.

In an underground mine, productivity improvements can be achieved by reducing stope widths, potentially through mechanisation (Scott-Russell, 1993). Improving stope advance, thereby reducing the time between blasts, as well as the development ratio, thereby reducing non-productive material removal, potentially improve profitability c. 25% according to one

study. The advent of the “intelligent mine” has been discussed since the 1990’s, with data acquisition systems, underground communications, computerised information, communications with public networks and even robotics having been discussed.

The “end to end” model, where oversight is kept of the whole value chain from exploration, production, beneficiation, logistics to sales to customers, is suggested by Ernst & Young Global Limited (2017b) to improve productivity. It ensures that the process is efficient by producing what the customer needs, rather than what a site can deliver or what has been found by exploration. Digital strategies involve using available computing, networking and sensing inputs to help in reducing variability in the organisation for decision making, resulting in higher productivity while reducing variability. It reduces complexity while going back into the detail of processes.

Implementation of digital and networked systems, phased in with a clear organisational plan, provide opportunities to achieve further cost control and productivity benefits. Simulation and planning for implementation, optimisation during roll-out and monitoring and control once implemented are required to achieve the full benefits of the selected system (Ernst & Young Global Limited, 2017b).

Ernst & Young Global Limited (2016b) have specified the ten highest risks to mining. The highest risk is seen as being cash optimisation, as preservation remains key in on-going market volatility. The second highest risk is capital access, with seeking alternative sources resulting in greater risk of default. The third highest risk is productivity, with an asset focus, an end-to-end view as discussed previously and supporting people recommended to reduce risks. The fourth highest risk is related to the social licence to operate which impacts productivity by increasing stoppage times. Accidents, onerous rehabilitation requirements and protests impact productivity (Ernst & Young Global Limited, 2016b).

2.4.5 The level of capital expenditure

Capital spent on building or expanding mines is financed by obtaining and maintaining debt and equity. While the size of capital outlay is controllable by the business, interest paid on debt and the return expected by shareholders is considered uncontrollable and dependant on external factors. The interest paid for debt is not controllable, however the business has the choice of using either debt or equity to finance the initial outlay. Optimising the cost of capital is covered extensively in Lumby and Jones (2004).

Although not related to long term survival or industry cost curve competitiveness in the near term, capital spending does relate to the net

cash position of a company and company survival. Mechanisms to free cash spent on capital include capital austerity, deferral and marginal operation closure (Venmyn Deloitte, 2016).

Deep level mining is capital intensive relative to other methods and exposed to related issues: as technology matures, diminishing returns are achieved as deeper orebodies are accessed over time (Scott-Russell, 1993). The extent of mechanisation is site specific for the mining method employed. Capital intensity overall is lower for more mechanised mines: while it is higher for equipment (c. 20%), less capital is required for development (- 40%) and less for personnel accommodation (-30%), resulting in c. 30% lower capital overall. Additional benefits result from being more flexible to design changes and requiring less infrastructure.

Capital productivity improvements start well before building the mine. It starts from the initial business case and investment proposals, process solution design (where higher capital is weighed against higher operating expense and value is weighed against flexibility), and in the engineering design and commercial delivery (PricewaterhouseCoopers LLC, 2015) .

Sustaining capital expenditure blurs the lines between operating cost and capital cost, as it is incurred to sustain future production but does not increase productive capacity. It includes both maintenance of capital

equipment as well as extending access to the mineral resource. As it is necessary to maintain production and long-term competitiveness, it is included in calculating all-in sustaining costs and is also included in costs as used for industry cost curves in this research report (S&P Global Market Intelligence, 2017).

2.4.6 The level of debt in a company

Debt should not influence cost curve position, however payments and access influences *cash* position, hence survival and competitiveness. In 2016, access to traditional capital sources (loan finance, equity) was increasingly difficult for mining companies after low global economic growth and an extended period of low prices led to poor company performance (Ernst & Young Global Limited, 2016b). With default risks up over 2016, non-traditional sources were increasingly used: streaming, alternative royalties and private equity are some of the mechanisms used. This form of financing tended to be expensive and influenced long term competitiveness while providing near term cash flow.

Ernst & Young Global Limited (2016) cited cash optimisation as their top risk. For short term survival, optimising working capital is an effective way to free up cash. Reducing debtors (accounts payable to the company) while increasing creditors and hence increasing debt levels is one way to do so. The risk is that levels are dropped too far, resulting in customers

being lost, under-investment, inefficiency and ultimately production being affected (Ernst & Young Global Limited, 2016a). Reducing accounts receivables not only improves cash flow once, but also reduces the cost of management of debtors. Other less essential costs that may be sought to be reduced include insurance, distribution, selling and finance charges (Borthwick, 1991).

Default risk

Short term survival may come at the price of increased default risk. Common measures used to test for the risk of default on debt include financial statement ratio analysis. They are relevant as they are often dimensionless and used for comparison of a company to other firms, competitors and its own past performance (Reilly & Brown, 2006). While there are several ratios that could be applied, this study only calculated one liquidity ratio and one debt ratio.

A liquidity ratio was used in order to test if the company would run into cash issues and be unable to service its debts, leading to insolvency. The Quick ratio as per Reilly & Brown (2006) was used, and is calculated using Equation 2.2:

Quick ratio = (Current Assets - Inventory) / Current Liabilities…..……..2.2

The ratio indicates how easily short-term liabilities can be serviced from cash or cash equivalents, as inventory generally takes longer to convert to cash (Reilly & Brown, 2006).

As a test of how indebted a firm was, the Total Debt to Capital ratio as per Reilly & Brown (2006) was used in Equation 2.3, where:

Total Debt to Capital ratio = Total Debt / Total Assets……2.3

The ratio indicates how much of the assets are financed by debt and hence how high the risk is should debtholders recall or not renew their loans. It is also an indicator of the risk if cash flows are volatile (Reilly & Brown, 2006).

To quantify default risk, analysts also use various balance sheet measures that have been empirically derived by looking at sets of data and relating them to financial default. One widely used measure, applied by Acharya et al (2013) in a study considering the risk of hedging in commodity companies is the Zmijewski score. The measure was developed by determining balance sheet variables empirically that would indicate if a company will default or not. Suitable constants were determined by multi-factor regression using US stock exchange information. While it is specifically forward looking, it is applicable to more companies than only those in the mining industry.

The Zmijewski score is calculated using Equation 2.4 :

Zmijewski score = - 4.3 – (4.5 x Net Income / Total Assets) + (5.7 x Total Debt / Total Assets) – (0.004 x Current Assets / Current Liabilities)……2.4

2.4.7 Commodity price volatility

Volatility is defined as the deviation of a value from an expected or measured average. Commodity prices, being key revenue drivers, are of particular interest to miners, though they are present in costs too. One example would be fuel for operating vehicles in a mine, the cost of which is linked to the price of oil. Volatility tends to increase when there is low inventory of a product in a particular market: price fluctuates increasingly as there is uncertainty around availability of a product (Symeonidis, et al., 2012). As a result, spot prices tend to be higher than future ones, even after accounting for storage costs. i.e. markets are backwardated.

Commodity price volatility makes it difficult to forecast revenue over the life of mine, requiring increased responsiveness, productivity and higher margins to provide a greater buffer to costs. The full value of the product to the market needs to be understood, with an ability to respond more quickly to demand changes an advantage. Volatility does not influence the cost competitiveness of a company directly, but it does affect the ability to continue through price fluctuations and hence survival.

An example of commodity price volatility affecting survival is in 2015, when iron ore production was added to the low-cost end of the cost curve, resulting in low iron ore prices. Iron ore prices went even lower than expected from looking at marginal production and were thought to result from an expected return to future higher prices (derivative market transmitting stress to the spot market). Higher cost producers could continue even though their marginal costs were not being covered, as investors and financiers were more tolerant of poor performance, due to being able to transfer risks. Large fixed costs associated with permanent or temporary closure resulted in more operations willing to continue. Only if a longer downturn had been expected would more operations have shut. This resulted in excess supply remaining in the market, further depressing iron ore prices, exacerbated by non-competitive intervention in the market. These were thought at the time to include Chinese government backing of enterprises and Indian export bans (Donovan & Hartley, 2016).

Methods to control and limit the negative effects of commodity price volatility include reducing costs and increasing productivity, as larger margins result in lower volatility in cash flows (Ernst & Young Global Limited, 2016a). Working capital may be reduced in downturns even at the expense of reliability, as cash is freed up. Greater capital effectiveness, resulting in larger margins after accounting for capital repayments, provide a buffer to default risk in more volatile periods. A more flexible financing approach, considering hedging and flexibility in

operations and portfolio strategy, including investing counter cyclically, may provide further insulation against the negative effects of volatility.

The increased use of derivatives in commodity markets ("financialisation" of markets) may be a means by which volatility in commodity spot prices has increased in recent years. Theoretically, derivative markets should increase price visibility and hence price discovery, thereby reducing volatility. Market financialisation has led to the transmission of stress to commodity markets through derivative positions, resulting in movements in the physical market (spot price). A study by Buyuksahin and Robe (2014) found that it is not derivative positions that have necessarily increased volatility of the markets, but the type of owners of the derivative positions and how they are used do matter. Speculators, hedge funds and particularly the latter with both equity and commodity exposure tend to increase volatility due to pro-cyclical behaviour. Non-speculative swaps/index traders, those hedging a physical position or expecting delivery do not increase volatility (Buyuksahin & Robe, 2014).

2.4.8 Inventory level

Inventories are necessary for more efficient short run production, as well as in setting commodity prices. Where a commodity is storable, producers balance the cost of changes in production levels, versus the cost of bearing inventory, as reflected in the pricing of futures. In a low or normal

price environment, inventory in the production process helps smooth processes (Pindyck, 1990). In a high price environment, inventory prevents stock outs from occurring, and facilitates production and delivery scheduling. A higher convenience yield exists in a high price environment (high interest rates and a high cost of holding stock), where the cost of stock running out is high, resulting in high futures prices. The converse is true when interest is low. The convenience yield is greater for energy and perishables, as the inventory carrying cost is higher than for precious metals (Symeonidis, et al., 2012).

2.4.9 Hedging

Hedging occurs when a firm tries to limit a change in future realised prices, interest rates or exchange rates by setting them in advance by buying or selling derivatives ("options"). The theory of storage results in backwardation of futures prices (i.e. lower future than spot prices) when inventory is low, or contango (i.e. higher future than spot prices) when inventory is high (Symeonidis, et al., 2012). This influences a firm's decision to make a use of hedging instruments at a particular time.

In general, interest rates and exchange rates are hedged more than commodity prices. Low returns on hedging have been achieved on commodity price hedging (e.g. gold), while only exchange rate has resulted in benefit for companies at a larger scale. A study looking at the

cost of hedging versus the impact on stock value indicated an uplift of 4.3% on stock values for those companies that do hedge, mostly on exchange rates, though the study was based on the period 1995 to 1999 in the USA (Nelson, et al., 2005).

Non-financial firms don't hedge significantly, though larger firms tend to hedge more. This is thought to be due to the cost of implementing a programme requiring a large enough scale to warrant the cost of the programme. In non-financial firms that do hedge, financial exposure relative to market capitalisation is also relatively small; hedging is used to fine tune risk and is used for specific transactions, with it being rarely speculative in nature. Most hedges are held for less than one year, with operational hedging already occurring through diverse locations (Guay & Kothari, 2003).

Hedging positions have an impact on producers. When producers are capital constrained, with hedging requirements in order to obtain funding, hedging costs increase through price pressure in futures. This affects producers supply decisions, and they hold less inventory. As a result, current hedging decisions are affected by the future (Acharya, et al., 2013). Hedging is used as a mechanism for limiting the finality of loss in bankruptcy. It is used more widely by firms that are higher leveraged in more highly concentrated industries (Purnanandam, 2008).

2.5 Chapter Summary

This chapter looked at the theoretical background to industry cost curves. Macroeconomics influence the environment that mining takes place in, affecting both demand and supply. The minerals industry uses industry cost curves, based on ranked individual producer costs and cumulative volumes, for competitor and price analysis. A number of factors were discussed that affect competitive position on an industry cost curve directly (e.g. mining cost and productivity) as well as indirectly (e.g. volatility, hedging). The next chapter gives some background to the mining industry in general and the platinum industry specifically, as it is the subject of this report.

3 MINING INDUSTRY BACKGROUND

3.1 The Global Mining Industry

Natural resources, and hence mining, play a significant role in 81 countries, together accounting for c. 25% of global GDP and half the world's people (World Bank, 2018). Over the 2010 – 2017 period covered in the report, there have been significant changes in the fortunes of the mining industry. While the recovery from the global financial crisis in 2008 was fairly rapid, PWC in 2015 talked of a "race to the bottom", where Chinese demand reduced significantly, commodity prices (including platinum) dropped 25% and return on capital reduced to a low of 4% while dividends halved or were even eliminated. 2015 saw a few mining companies having their market capital reduced below their net asset values, driven by a spot price and short term focus (PricewaterhouseCoopers LLC, 2016a).

As a result, the following year, 2016, was more cautious, with investment inertia, restraint and debt shedding. Capital was reduced and safe jurisdictions preferred for operations and projects. Towards the end of the year, planned disposals were called off due to better conditions prevailing and better future conditions expected. Eleven Chinese companies were in the top forty companies, as others dropped out. China was shown to be more patient than most other companies and appeared to invest through

the cycle. Depletion, resulting from underinvestment over the prolonged down-turn, started resulting in operational issues at some producers.

While 2016 was challenging, with China's economic outlook softening, activism rising, governments intervening and new players disrupting the industry, it was overall positive for producers. The aggregate profit of the top 40 companies was US$20Bn, versus an aggregated loss of US$28Bn in 2015 (PricewaterhouseCoopers LLC, 2017a). Cash flow improved, resulting from asset sales and the issuance of fresh debt. Credit ratings improved, resulting in better interest rates on debt. Impairments reduced from US$54Bn in 2015 to US$19Bn in 2016. Capital cuts continued to be significant, with exploration spend reduced for the fourth year in a row, from 21 US$ Bn in 2012 to 7 US$ Bn in 2016. Africa attracted only 13% of global spending. Due to the downturn and deferral of costs, operations in 2016 suffered high maintenance costs, low reliability, reactive fixes and low utilisation of equipment, along with high safety costs.

In the years leading up to 2017, mining risks remained similar, being (in order of highest to lowest) commodity price volatility, the regulatory environment, socio-economic environment, labour relations and operating costs amongst others (PricewaterhouseCoopers LLC, 2017b). Africa started to close again to mining investment from 2016; in Nigeria this was before mining activity had increased. In 2002 the Democratic Republic of

Congo (DRC) put in place a new mining code to attract investment. According to PricewaterhouseCoopers LLC (2017b), it played a large part in increasing the number of mining rights issued in 2002 from 35 to 482 in 2016. In 2016, the DRC started increasing control of mining profits through accounting, legal and tax measures, resulting in an uncertain future for mining production.

A similar issue was seen in Tanzania, where a significant taxation change was implemented, with all agreements opened and “unconscionable terms” reviewed. Changes were put through that allowed for free carry favouring government, increasing royalties, restricting VAT recovery and increasing local content requirements (PricewaterhouseCoopers LLC, 2017b).

South Africa continued to show the signs of a mature industry, with safety stoppages impacting significantly: they cost the industry ZAR4.8Bn in 2015. Given that depletion results in greater complexity and depth, technology solutions will be required (PricewaterhouseCoopers LLC, 2017b).

3.1.1 Mining boom

In the 2000’s, China’s demand of a number of commodities increased rapidly, with an initially limited supply response resulting in elevated

commodity prices. This was referred to as the “mining boom”. With the inevitable cooling following in 2009, the impact on various economies has been investigated. Notably this has been in Australia, due to a high exposure to both mining and China’s demand for minerals.

In Australia, the boom altered the composition, not the absolute level of economic output. It raised the level of national expenditure and widened the trade deficit, both as a result of short term commodity gains. There were some long term gains in the form of immigration and investment facilitating other growth, positive influences on purchasing power parity and the general standard of living, despite the non-commodity sectors of the economy contracting (Makin, 2014).

Costs increased in Australia as a result of the mining boom, resulting mainly from resource depletion and the lag in supply ramp up. As mining uses its own inputs/products too, some of the cost increases were found to be circular (Connolly & Orsmond, 2011). Revenue in mining increased rapidly to match underlying costs, while volumes increased only modestly. Productivity (both labour specific and multi-factor productivity) was found to have fallen from 2003 as reserve depletion required accessing lower grades, requiring relatively more inputs. Lagged investments and slowly ramping up production were other reasons for cost and price increases.

Recent improvements in productivity appear to be a result of ramping up production.

Refining and smelting benefitted less from the boom: value added by the sector remained flat, with processed metals exports reducing from Australia as capacity increased in Asia. The impetus for higher prices due to ramp up requirements was not there (Connolly & Orsmond, 2011).

3.2 The South African Mining Industry

3.2.1 History of the industry

South Africa's mining history started with the discovery of alluvial diamonds in 1867 at the Orange River. With the first diamond mines starting in 1868, attention quickly moved to gold, with gold discovered at Pilgrims Rest and Barberton (Mining in Africa, 2017).

After the discovery of the world's largest gold resource in the Witwatersrand, Johannesburg area in 1884, the first gold mining companies were established in 1886. With new beneficiation methods found in 1890 to extract gold, production increased rapidly to make South Africa the world's largest gold producer by 1898 (Minerals Council South Africa, 2018a). Over time, depleting reserves have resulted in the deepest

mines in the world at c. 4000m and 50 ºC temperature, and in 2017 only produced 4.2% of global output.

Coal was discovered not long after gold, near the gold mines, at Springs. With coal initially used to serve the gold mines, it eventually expanded towards Witbank (now Emalahleni) and powered South Africa's industrialisation (Minerals Council South Africa, 2018c). In 1976, the Richards Bay Coal Terminal was established by coal companies, with an initial capacity of 12Mt, in order to export coal. This has increased over time to 76Mt of the 252Mt produced in 2017, with the balance going to power stations and other domestic users.

Platinum Group Metals (PGMs) were discovered only later in South Africa, with nuggets found in 1924. Subsequently, Hans Merensky found the world's largest deposit in the Bushveld Complex, spanning from Rustenburg (Western Limb) to Steelpoort (Eastern Limb, discovered 1925), to Polokwane (Northern Limb) (Minerals Council South Africa, 2017a).

3.2.2 Challenges facing the South African mining industry

The gold mining industry, representative of most of deep level mining in South Africa, has faced a number of challenges. These include commodity price volatility, escalating cost of production due to ore grade

decline, exponential increases in energy, reagent and water consumption, as well as general input cost increases, particularly power. Increasing depth as a result of depletion has resulting in higher ventilation and cooling costs, with greater seismicity and narrower reefs, while there has been an increasing difficulty in mechanising mining due to geological discontinuities. Labour issues go beyond depth related issues (which include availability and low utilisation due to travel times resulting in late starts and early finishing) and extend to relations with management and lack of education, resulting in low skills and a poor understanding of business and productivity (Tholana & Neingo, 2016).

The Mine Health and Safety Act was introduced in 1996, with the mines inspectorate included in the Department of Mineral Resources. The Chief Inspector was granted extensive powers and may prohibit certain work, with stoppages potentially extending to entire operations (so-called "section 54" stoppages). The industry has been incentivised to take more extensive safety measures, including roof nets and proximity detectors for mobile equipment (Chamber of Mines South Africa, 2017). Fatalities in mining reduced by 88% over the period 1993 to 2016, however there were still 73 fatalities in 2016 and 86 in 2017. The number of fatalities in the platinum industry had always been fairly low relative to the gold industry. There has been a strong focus on addressing the underlying reasons for fatalities, with fall of ground now at similar frequencies to machinery and general since 2012.

Regulatory uncertainty has become an issue for investors. The Mining Charter was launched in 2004, with subsequent revisions enacted or proposed (Minerals Council South Africa, 2017b). Recently, amendments were proposed in April 2016, with a court order to review the Charter in December 2017. This culminated in a June 2018 announcement to increase the target on black ownership of new mining rights to 30%, a 5% free carried interest for labour and the same again for communities, with 1% of Earnings Before Interest, Tax, Depreciation and Amortisation (EBITDA) allocated to labour and communities, before being scrapped on the 23rd of August 2018 (Minerals Council South Africa, 2018b).

A discussion of the South African mining industry is not complete without a look at the tragedy that occurred at Marikana, 12th to 16th August 2012 (Minerals Council South Africa, 2018d). Several people died, numbering 44 in total: 10 policemen, security guards and miners were killed and 34 from police firing on protesting miners. The incident highlighted the socio-economic challenges faced by the industry and the complex interactions between different actors, including mine owners, government, labour unions, civil society, and the mineworkers themselves. The Farlam Commission of Inquiry into the tragedy highlighted broader issues concerning the industry and South Africa, particularly labour issues such as union rivalry. Others include legacy migratory labour issues, high levels of employee indebtedness, limited capacity for local government service

delivery and poor housing conditions (South African Institute of Race Relations, 2014).

3.2.3 Contribution of the mining industry to the economy

Mining's contribution to the South African economy increased from the early days of the discovery of gold, to peak at 21% of GDP in 1980 (with only manufacturing larger, at 22%), employing c. 760 000 people in 1987 (Minerals Council South Africa, 2017b). Mining's contribution has declined to 7% in 2017 with the increase in tertiary industries, with finance the largest contributor at 20% of total GDP in 2016, from 11% in 1980. Direct employment was at c. 465 000 people in 2017, with more people employed in platinum than gold mining operations from 2006 (Statistics South Africa, 2017). Despite GDP and employment contribution declining, mining has a disproportionate contribution to export income, at 27% of exports in 2017.

Apart from the contribution to the broader economy, a study by the South African Institute of Race Relations (2012) has found that every person working directly in the mines supports themselves and three other non-working people. (This was 2.8 in 2012 and has reduced from 3.8 in 1994). For Africans, this has reduced from 6 people in 1997 to 3.2 in 2012 (South African Institute of Race Relations, 2013). Given the c. 460 000 people directly employed in mining in South Africa in 2017, if the same applied to

indirect employment estimated at 1.6 million jobs (Minerals Council South Africa, 2017b), this would result in potentially over 5.5 million people dependant on the industry.

Despite the industry issues and challenges, the mining industry nevertheless plays an important role in the country. In analysing who gets the benefit of the mineral resources, one study estimates that employees take 40%, the government 19% (through tax, payroll and royalties) and shareholders only 2% (PricewaterhouseCoopers LLC, 2017b). Capital expenditure has been at a 10 year low. In PGMs mining, 24% and 22% of total industry revenue was re-invested over 2016 and 2017 respectively, however still resulted in a 4% decrease in production.

3.3 The Platinum Group Metals Industry

3.3.1 History

While platinum and associated metals have been used for millennia, platinum was first identified in modern times by the Spanish Conquistadors in South America when panning for gold (Minerals Council South Africa, 2017a). Due to most PGMs corrosion resistance and high temperature melting points, they were difficult to separate out. It was only in 1782 that the metal was able to be melted by adding oxygen, though it took another 25 years to be more widely used, and then mostly for decoration. Palladium and rhodium were separated out only shortly after this, with an

understanding of platinum's catalytic properties leading to the first fuel cell being devised in 1842. P.N. Johnson and G. Matthey in England formed a partnership in 1851 that survives as a company to today. They perfected techniques at separating out PGMs and casting into ingots that are still used at industrial scale today.

Various PGMs have excellent catalytic, electric, thermal, chemical and wear resistance characteristics. They are considered indispensable for some critical industrial applications, leading to them being declared a strategic material in the first world war (amplifiers, munitions, primers) and of greater importance in the second world war (a platinum-rhodium alloy is used to produce nitric-oxide for explosives and fertilisers) (Zientek, et al., 2017b).

In the 19th century and the early part of the 1900's, supplies of PGMs came mostly from Colombia and Russia. Canada ramped up its production alongside nickel in the 1900's and became a significant producer until the discovery of the Bushveld Complex by Hans Merensky and the ramp up of South African production (Minerals Council South Africa, 2017a).

Mining in the Bushveld started in 1931, as technology in processing and use (market demand) evolved (Surujhlal, et al., 2014). Over time,

processing technology including single pass mill floatation, double pass mill flotation and ultra-fine grinding technology allowed increased recovery of metals. Initially, mining was focused on the higher platinum containing Merensky reef, with the higher chrome content in UG2 also resulting in operational difficulties. Technology has allowed there to be an increased focus on UG2 from the 1990s. Smelting technology has advanced from blast furnaces and converters, to electric arc furnaces and PGM specific conversion processes. Refining base metals and precious metals evolved over time, with resultant higher extraction and recoveries and reduced environmental issues. Other improvements and hence cost reductions over time have included shared air and water, refrigeration, tailings disposal, training and workshops infrastructure across mines (Surujhlal, et al., 2014).

3.3.2 Demand for platinum group metals

Today, the predominant use for PGMs is in autocatalysts on vehicle engines in order to reduce exhaust emissions, for both diesel and gasoline vehicles (Carbon monoxide, sulphur and nitrogen oxides and particulates.) Other critical industrial applications include catalysts used to manufacture nitrous oxides (explosives, fertilisers, nitric acid) from crude oil, and various other intermediate compounds for chemicals and synthetic materials. They are used in the manufacturing of glass fibres, both for telecommunications and structures, as well as glass screens, and a myriad of other electronic, healthcare and gas applications (Zientek, et al.,

2017b). There is an emerging use for both producing hydrogen from water, as well as the reverse, in order to produce energy in a fuel cell (Johnson Matthey, 2017).

Over the period to 2012, demand has stagnated: there was 5.2% demand growth over 1982 to 2007, while it was only 0.6% from 2007 to 2012 (Surujhlal, et al., 2014). Demand growth has reduced due to loadings reducing in autocatalysts in vehicle exhaust systems, while jewellery demand has stagnated over the same period, particularly in the large Chinese market. Supply has not been actively managed, with unit costs, capital intensities and depths increasing over time, while new entrants from 2001 have resulted in greater fragmentation. Secondary sources (recycled material) have quadrupled since 2001. Wages, electrical components, electricity, explosives, support, reagents and diesel costs have all increased above inflation for the period 2000 – 2012, while at the same time head grade reduced by 1.8% p.a. 2005 – 2012.

The period 2012 to 2017 appears to have been better, at 10% gross demand growth in the industry to 2017. As shown in Figure 3.1 for platinum and Figure 3.2 for palladium, the view is starkly different between metals: platinum demand contracted by c. 5% to 2017 from 2013, mostly due to Chinese jewellery demand reducing, while palladium grew by 22% due to increased Chinese automobile sales (Johnson Matthey, 2017).

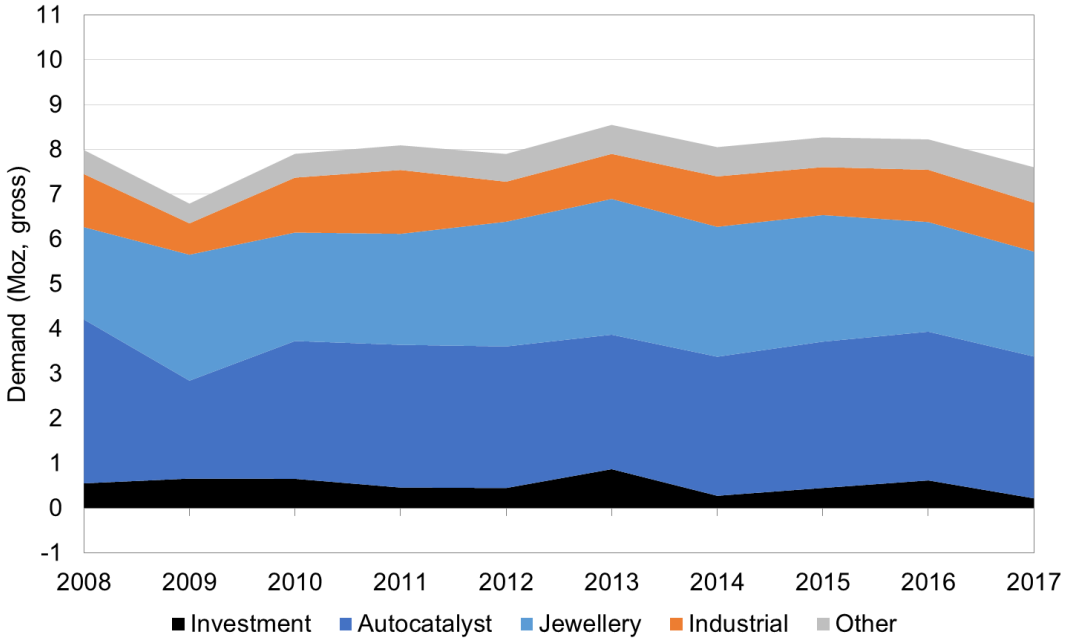


Figure 3.1: Demand for Platinum (2008 - 2017). After Johnson Matthey (2017)

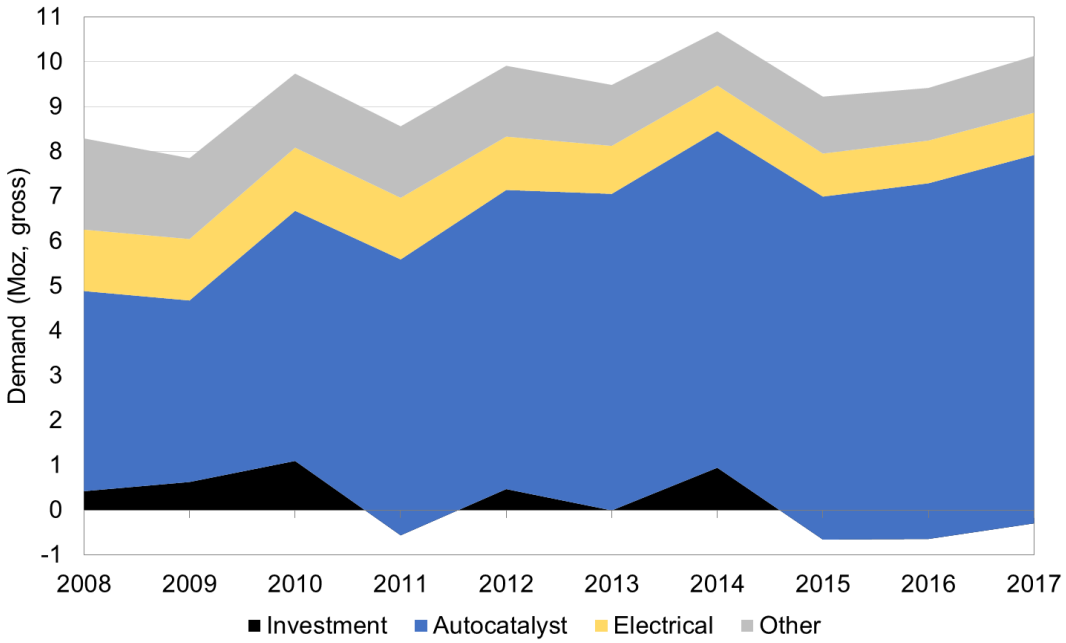


Figure 3.2: Demand for Palladium (2008 - 2017). After Johnson Matthey (2017)

There have been positive long term fundamentals for emerging markets, both in terms of demand (vehicles in China need PGMs) as well as supply (South Africa and Russia remain relatively stable). Cancelled projects and cuts to capital expenditure, decreasing costs overall and a more positive economic outlook were directionally positive, despite an increase in geopolitical risk with China shifting away from the West and an apparent oversupply in the industry (Venmyn Deloitte, 2016).

3.3.3 Supply of platinum group metals

Platinum Group Metals (PGMs) are both rare and highly concentrated in few locations, predominantly Russia and Southern Africa, with South Africa's Bushveld Complex accounting for most of the world's resources, as shown in Figure 3.3 below.

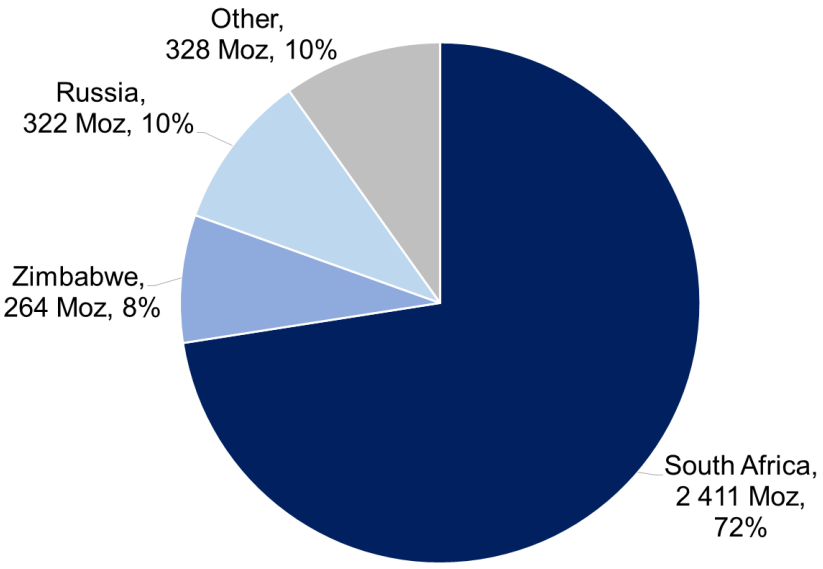


Figure 3.3: World PGM (incl. gold) resources. After ***(Zientek, et al., 2017b)***

In South Africa, PGMs are found in the Bushveld complex north of Johannesburg, as seen in Figure 3.4, stretching between Rustenburg, Polokwane and Middelburg and found in the Merensky, Upper Group 2 (UG2) , and Platreef reefs. The occurrence of the various PGMs (Platinum, Palladium, Rhodium, Osmium, Iridium, Ruthenium and gold) and associated metals (Chrome, Nickel, Copper, Cobalt and Silver) varies both between the reefs significantly and to some extent within a reef (Zientek, et al., 2017b).

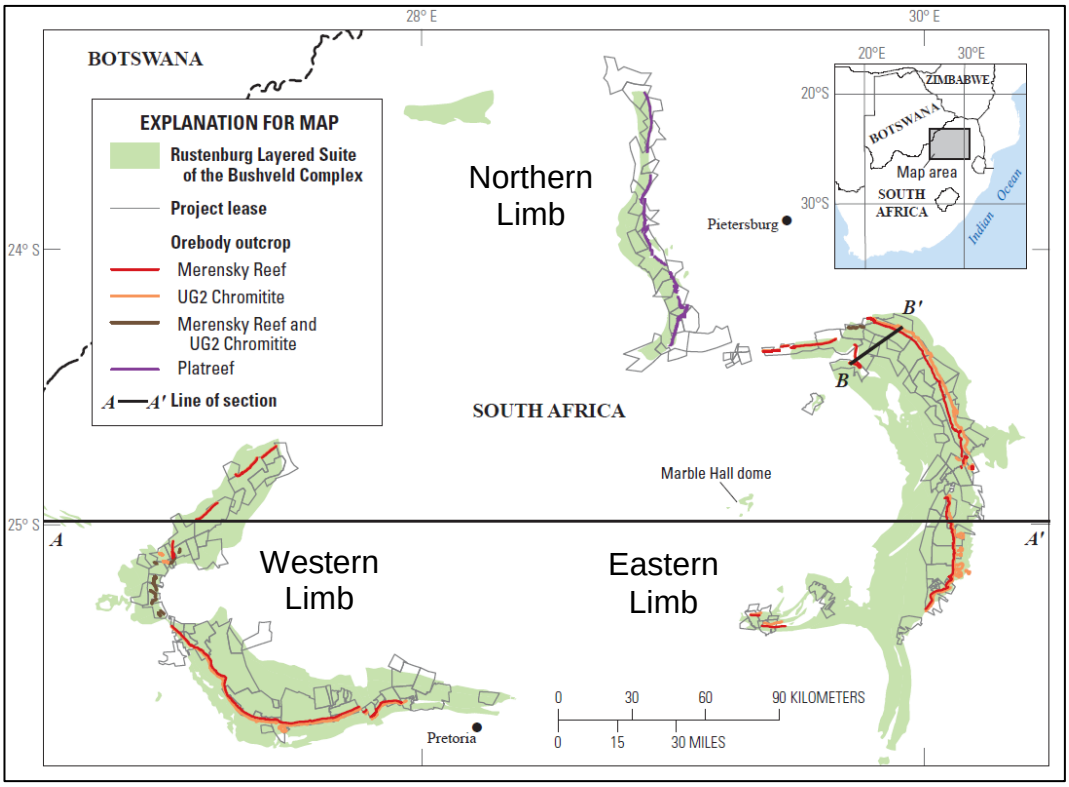


Figure 3.4: Map of Bushveld Complex, South Africa. After Zientek, et al.(2017b)

Co-extraction of both Merensky and UG2 reefs, mechanised mining and trackless mining has slowly been implemented due to the need to reduce costs, as seen at Bathopele mine, a part of Rustenburg mines now owned by Sibanye (Surujhlal, et al., 2014). Over the last decades mining has changed, from 27% of all ores extracted in 2000 being UG2, to 80% in 2012. An increase in depth and a 36% lower grade occurred over the same period, with vertical shafts supplemented by sub-declines.

Production of PGMs in 2017 still predominantly came from Southern Africa with c. 60% of all platinum, c. 30% of all palladium (Johnson Matthey,

2017), as can be seen in Figures 3.5 and 3.6. Russia has been well known for producing palladium, with significant sales from stocks (estimated at 1 Moz in 2008) ending around 2013. Recycling of autocatalysts from scrapped vehicles has increased in importance as an alternative source of PGMs, making up around a quarter of all supply in platinum and palladium in 2017.

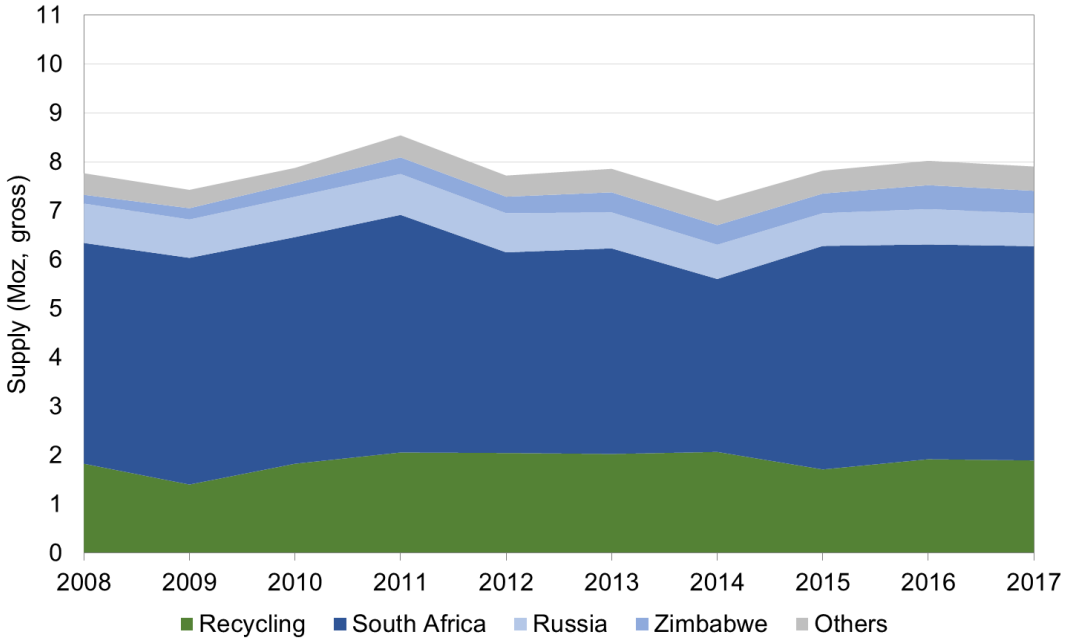


Figure 3.5: Global Platinum Supply. After Johnson Matthey (2017)

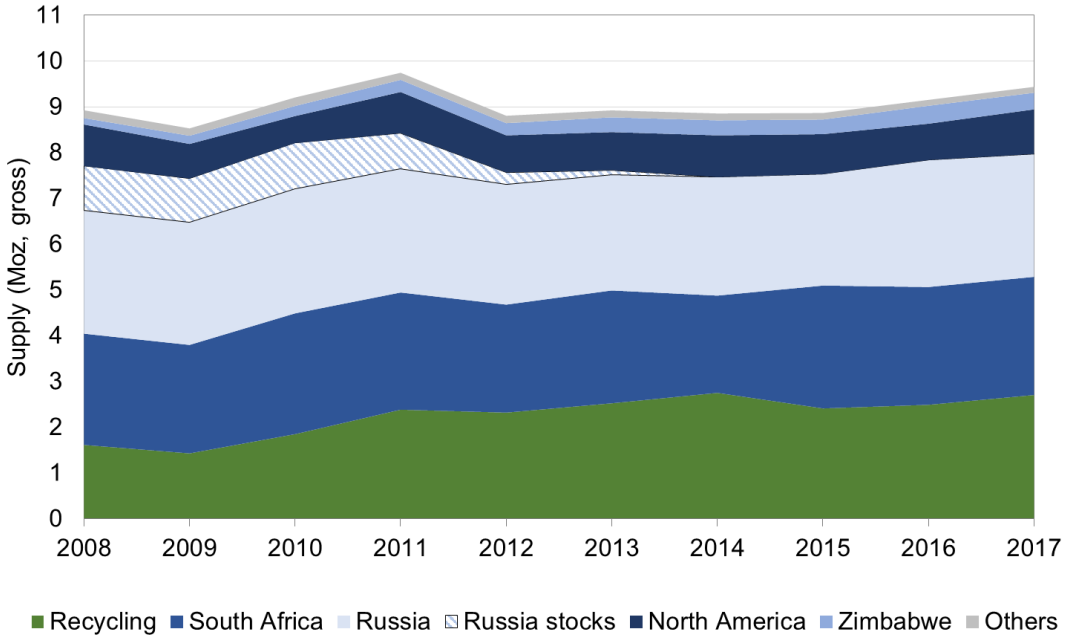


Figure 3.6: Palladium Supply. After Johnson Matthey (2017)

As PGMs are precious metals, they are able to be stockpiled in significant volumes. Stocks are estimated to have increased due to concerns around supply from South Africa and at the end of 2012 they were estimated by Steve Forrest Associates (2015) to be 4.1Moz, though the World Platinum Investment Council reduced their estimates to less than 2.4Moz by the end of 2015.

Input costs have grown at greater than inflation for a number of years prior to 2016, with the period to 2008 characterised by producing volume at any cost, while wages and electricity costs grew at well above consumer price inflation. Over the period 2012 – 2014, costs were higher due to industrial action and fixed costs being significant. From 2015 to 2016, some

marginal production was shut, and production increases saw overall costs decreasing again (PricewaterhouseCoopers LLC, 2016b).

Figure 3.7 compares indices of mining related input costs, as published by Statistics South Africa (2018). In Rand terms, electricity cost shows the greatest seasonality (prices in winter to producers are higher) and has increased by 10% p.a. over the period 2008 to 2017, while labour cost has increased steadily at 5% p.a. and diesel cost has *decreased* at 1%p.a. in real terms (i.e. after adjusting for inflation).

Figure 3.8 compares indices of mining related input costs, but in US Dollar terms, in order to make them more comparable to US Dollar denominated prices. In US Dollar terms, the change in input costs has been much smaller, with a 7% p.a. Increase for electricity, 2% for labour, and a 4% decrease on diesel.

The bigger issue is that the “basket price” of a polymetallic producer with metal ratios similar to Lonmin (59% Pt, 25% Pd, 10% Rh, 2% Au, 4% Ni, and 1% Cu by revenue) had decreased by more than 50% (8% p.a.) over the same period, severely squeezing margins (Lonmin, 2018; Johnson Matthey, 2018). Thanks to a weakening Rand, in US Dollar terms the cost increase (and hence margin squeeze) has not been as severe as drop in the basket price (-40% over the period, or -5% p.a.)

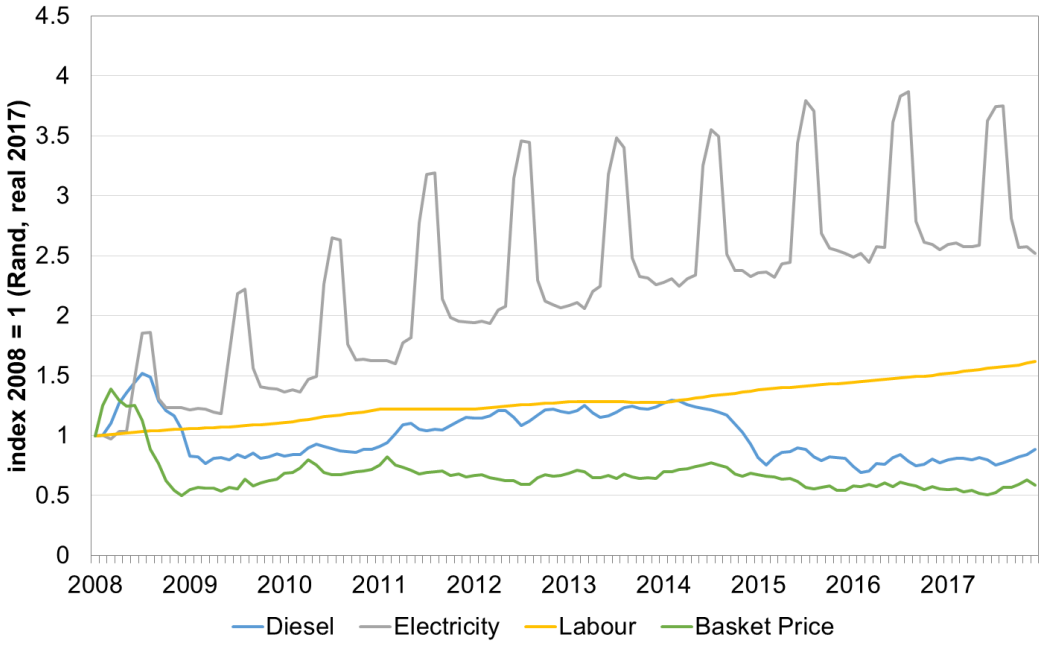


Figure 3.7: South African Mining Cost and Basket Price Index (Rand). After Statistics South Africa(2018); Johnson Matthey(2018); Lonmin(2018)

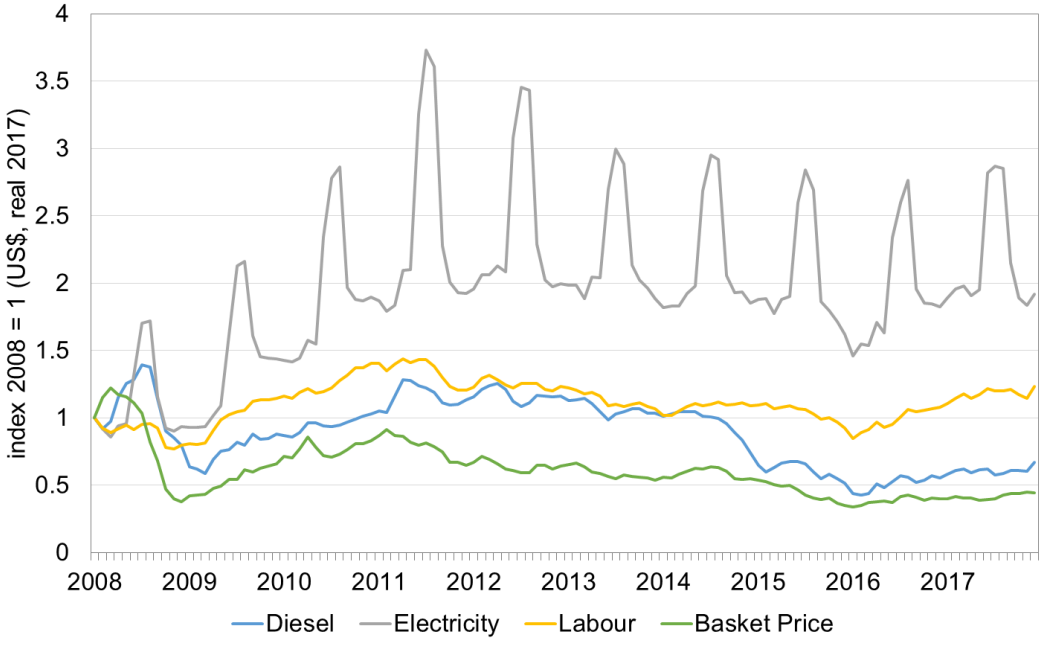


Figure 3.8: South African Mining Cost and Basket Price Index (US$). After Statistics South Africa(2018); Johnson Matthey(2018); Lonmin(2018)

PGM producer's sustaining capital spending has been low in recent years. By way of example, Impala has been unable to fund the required expansions (7.7Bn Rand, or c. 450 US$M for 17 shaft), and Lonmin has difficulties in obtaining the 540 US$M required for K4, based on current cash flows (Hatch, et al., 2017). This results in either industry production cuts becoming permanent, or companies being faced with raising capital with little chance for this to be paid back, or for supply and demand to balance.

The Platinum industry in South Africa has seen its debt restructured, reducing gearing from 15% to 11% over 2016 to 2017 (PricewaterhouseCoopers LLC, 2017b). While this has not been ideal, as prices reduced over the same period, it has been necessary. The acid ratio for most companies has been kept to greater than 1.0.

3.3.4 Companies producing PGMs

Significant South African Platinum producers in the 20th century were Gencor (with roots in Union Corporation), Johannesburg Consolidated Investments (JCI)I and Lonrho (originally the London and Rhodesian Mining and Land Company). These now existing in some form as Impala Platinum, Anglo American Platinum and Lonmin (Minerals Council South Africa, 2017a). The only significant change has been Sibanye, an offshoot

of Goldfields, taking over Anglo American Platinum's Rustenburg mines in 2016 and potentially set to take over Lonmin in December 2018.

Impala Platinum produced around 1.3 Moz of platinum in 2017 from five mines. In South Africa in the Bushveld Complex, the Impala Lease Area is on the Western Limb, Marula and Two Rivers are on the Eastern Limb. In Zimbabwe, Zimplats and Mimosa are on the Great Dyke. Both Impala Lease Area and Marula made losses, with the former significantly so (Impala Platinum Holdings, 2018a). Plans were announced in August 2018 to rationalise mining and close or sell loss making shafts (Impala Platinum Holdings, 2018b).

Anglo American Platinum produced around 1.4 Moz of platinum in 2017 from seven mines located in the Bushveld Complex, apart from Unki which is located on the Great Dyke in Zimbabwe. Mogalakwena, located in the Northern Limb, is a large open-pit operation. Union, Rustenburg, Kroondal and others were/are located on the western limb, with Modikwa and Mototolo located on the eastern limb (Anglo American Platinum, 2018). Rustenburg mines was no longer a part of the group in 2017, having been acquired by Sibanye-Stillwater in late 2016, and produced around 0.7Moz of platinum. Margins were at 16% on an all-in-cost basis (Sibanye-Stillwater, 2017a).

Lonmin produced around 0.7Moz of platinum from the Marikana mine, situated in the Western Limb over eleven shafts. The company was loss making in 2017 (Lonmin, 2018). The only other significant producer in 2017 was Norilsk, producing around 0.7Moz platinum as a by-product of nickel (225kt) and palladium (2.8Moz) production (PJSC MMC Norilsk Nickel, 2018)

3.4 Chapter Summary

This chapter gave some background to mining generally and platinum mining more specifically. For platinum mining, the supply of metals is in a ratio of 1.1 units palladium for every unit platinum, while autocatalyst demand in vehicles is 2.3:1. This is unsustainable; either excess platinum must be produced, only to go to stock, or autocatalyst demand must shift back to using more platinum. Apart from this, other future demand issues include jewellery, as it fills in demand rather than fundamentally supporting it, and electric vehicles, as they increase in market share and displace internal combustion engines and hence PGM based exhaust autocatalysts.

Supply in the industry is likely to be increasingly constrained due to underinvestment and rising real costs, with resulting inventory down 50% since 2012 according to Allsop et al. (2017). At the same time, recycling, as an alternative source of supply, has been increasing due to higher

scrap steel prices allowing for viable recovery of autocatalysts from exhaust systems. Future substitution of platinum for palladium will be price dependant (Allsop, et al., 2017). This makes competitive analysis using cost curves, as detailed in the next chapter, increasingly relevant.

4 DEVELOPING PLATINUM INDUSTRY COST CURVES

Cost curves for the PGM industry were developed for the period 2008 to 2017, in order to:

- Identify which method is most suitable to indicate competitiveness in a multi-product industry, as found in PGMs.
- Show how cost curves developed over time relate to commodity prices.
- Identify marginal producers that appear to have been loss making on a cash basis for a number of years for further investigation (i.e. that have been cash negative but have continued with operations).

4.1 Data Sources and Research Assumptions

Annual reports were used as the primary source of data about individual mines. While global accounting standards exist and “earnings” and “cash generated” have specific meanings at a corporate level, the detail disclosed behind this and the internal consistency of what is reported varies widely. This has been found not only between companies, but in the same company across time, with later reports not necessarily resulting in more complete disclosure. A tacit adherence, as in the gold industry, to a non-Generally Accepted Accounting Principles (GAAP) measure such as All-In-Sustaining-Cost (AISC) is not seen.

In compiling the data for this research report, detailed data was found to be missing or incomplete in official company reports. Without contacting the companies directly, two alternative approaches could be used, either to omit information not explicitly given, or to infer what was missing. While both approaches result in error (omission or estimation error), the approach in this study has been to err on the side of estimation error.

As the details behind the accounting basics are not required to be disclosed, production volumes are often not reported, particularly for by-product metals. The primary/major metal may not be reported either, with only an aggregated “4PGE” (four platinum group equivalent, often consisting of Platinum, Palladium, Rhodium and Gold) reported instead. This gives an indication of overall volume, however is not an indicator of revenue related to products, as the price of the different constituent metals is not equivalent and can vary over time, as can the production volumes. Milled volumes, as an indicator of cost, are reported by most producers, if not in the summary statistics then at least in the commentary.

The volumes and sites were disaggregated to the level given in the reports for the full period. While it is recognised that some companies could be disaggregated further to a mine or shaft level internally, this was not done in this study. Internally this may be possible, however internal information has not been used nor requested.

Due to reporting periods being different for different companies, there is potentially a mismatch when comparing information. Costs and volumes were adjusted to calendar years by simple fractional allocation, rather than by seeking underlying quarterly reports.

Where the volumes were not available, estimates were developed based on prior production, prill splits from the reserves statement, or estimates based on production from adjacent or similar operations. Production volumes were scaled based on milled tonnes, or vice versa.

In order to estimate the other volumes or those that may be missing in the data, the aggregate of the information available was compared to country totals as reported by Johnson Matthey (2017), an industry commentator. The balance was then allocated to “other” for a particular country. In general, this was less than 10% of the volume reported for a particular country in any one year. The exception is 2011, where c.12% of the volume of Platinum produced in South Africa could not be accounted for. This is also a year where the production volume as reported by Johnson Matthey (2017) reduced by 750koz in 2012, before returning to previous levels in 2015, and maybe the result of both strikes and a lag in information being reported.

The definition of cost, the detail provided and allocation of overheads (administration, marketing costs) to site varies significantly by company. As a result, the cost captured and represented as cash costs may not be complete and therefore under-represented. For this study, as close a representation to cash cost related to the site has been attempted. The costs represented in this report are on a cash basis, include mining, benefaction, transport, marketing, royalties and other overheads. They exclude tax (also cash tax payments), interest or finance charges, purchase of third party ore (where these are separable from own production volumes) and once-off payments, for example waste removal.

Sustaining capital costs are included where information is available. These are capitalised payments that are needed in order to sustain operations at current levels, for example development costs, and replacement of equipment. Unlike normal operating costs, replacement of equipment is easier to defer or replace with maintenance cost. As they may be large, periodic expenditures, sustaining capital expenditure tends to be less constant when observed over an annual period. It has been considered as a part of normal operations and hence operating cost for this study.

Where not available, costs were estimated based on other sites. Where sustaining capital was not given, it was estimated from total capital

expenditure, or at a level related to operating costs and a value representative of sustaining capital expenditure for the industry. (c.10% for most years and operations.)

4.2 Method Selected

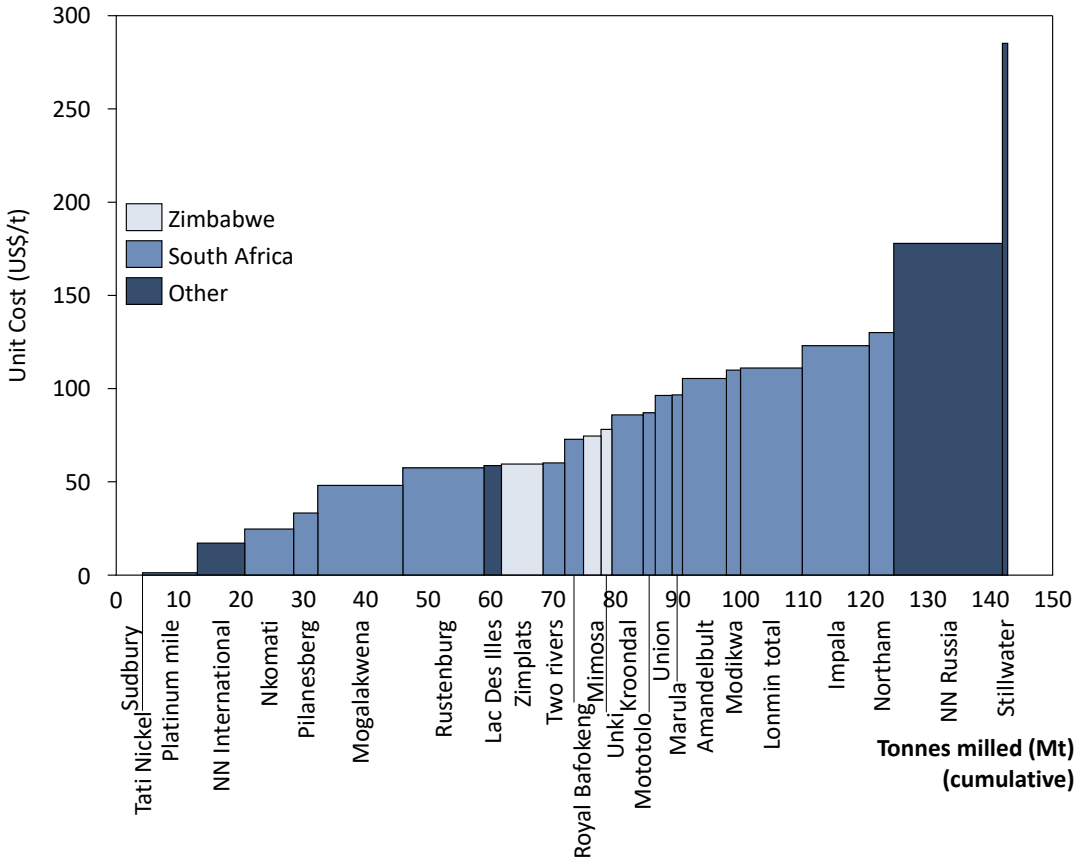
Various alternative methods to represent cost curves were tested in order to find a method that is most suited to finding the marginal producers in the PGMs industry over 2008 to 2017.

4.2.1 Cost per tonne milled

As a starting point, cost per milled tonne was used. It was suggested by Tholana (2012) as a way to work around the issue of co-production of metals. It is calculated by using the milled volume produced by a mine or company as the width of each bar, with the height represented by the total cash cost plus sustaining capital, divided by the milled volumes. It reflects competitive position effectively, when ore grade and by-products contained are similar. This is the case where only the platinum industry in South Africa, or in a particular region is being compared. It is also applicable where a primary metal is not clear, or where multiple products are shown, as is the case in the South African platinum industry. The prill split should, however, be similar. Lastly, it is applicable when mining costs are being compared or benchmarked.

The limitations discussed above also mean it is less suitable where ore grade and by-products are not similar. This is the case when comparing *global* platinum producers, some of which have very high costs but a high grade of ore with a significant by-product component, such as in Norilsk's Russian division. It has limitations even when only mining costs are being compared. Care should be taken that this is not a view of the mining process only, excluding the systems impact that mining decisions make on the product delivered to customers. (e.g. fragmentation impacting process recoveries.)

The representation using milled tonnes, as in Figure 4.1, is not able to capture the effect of by-products from other industries or recycled material, unless converted to an equivalent milled volume that is back-calculated from industry averages. If a reference to revenues were needed, prices would need to be indicated on the curve in a less recognisable form (i.e. price per tonne milled rather than prices per unit sold product). If shown as a basket price, the contribution of individual metals is unable to be disaggregated.



Note: Sudbury considered by-product at no cost for illustrative purposes only.

Figure 4.1: 2017 PGM Cost Curve per tonne milled. After Appendix 8.11

To illustrate one of the limitations of an industry cost curve on the basis of tonnes milled in Figure 4.1, consider that Norilsk Nickel in Russia ("NN Russia") is indicated as the highest cost large producer. This is correct, but does not consider that the revenue achieved from a milled tonne (c. US$600/t) is almost ten times higher than an equivalent tonne from Rustenburg at the bottom of the cost curve.

To overcome some of the limitations and make the producers more comparable on the basis of competitiveness, a curve indicating margin per

milled tonne may be used, as per Figure 4.2, however it is difficult to identify which company is at the margin (visually, margin = 0). In addition, the relation to industry demand for underlying products is unable to be presented.

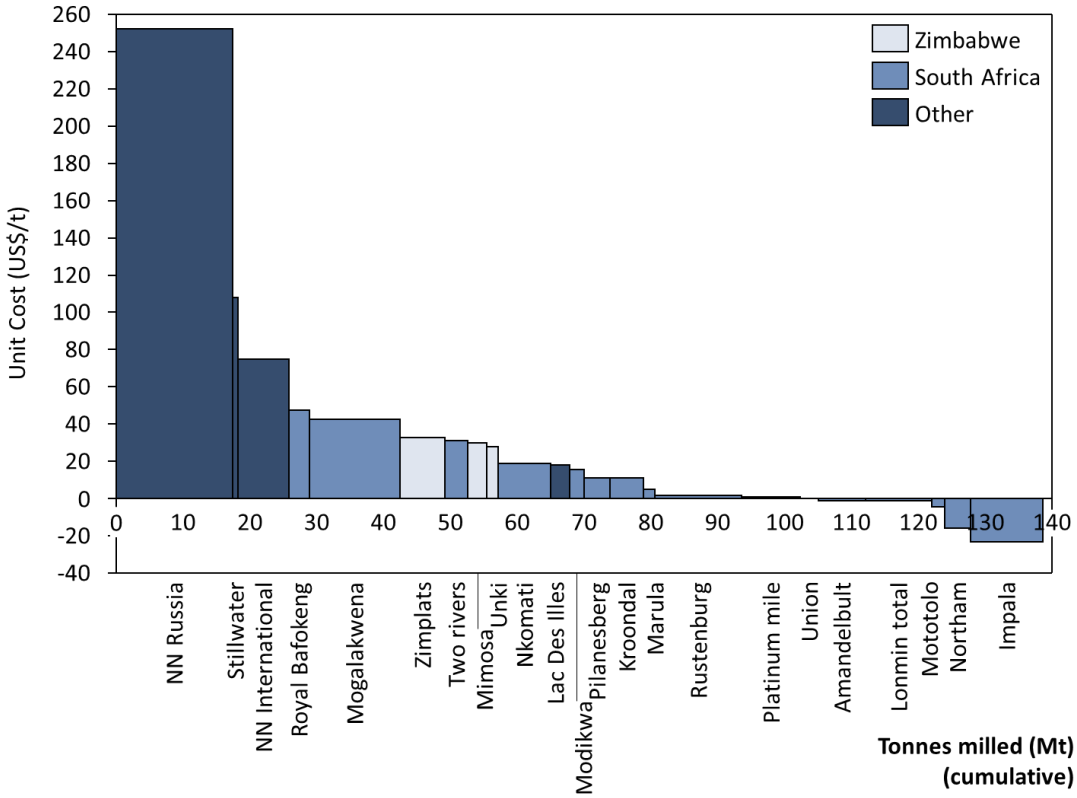


Figure 4.2: 2017 PGM Margin Curve per tonne milled. After Appendix 8.12

Margins may be presented in this way for all other methods too, with the same limitations, hence are not discussed further in each section.

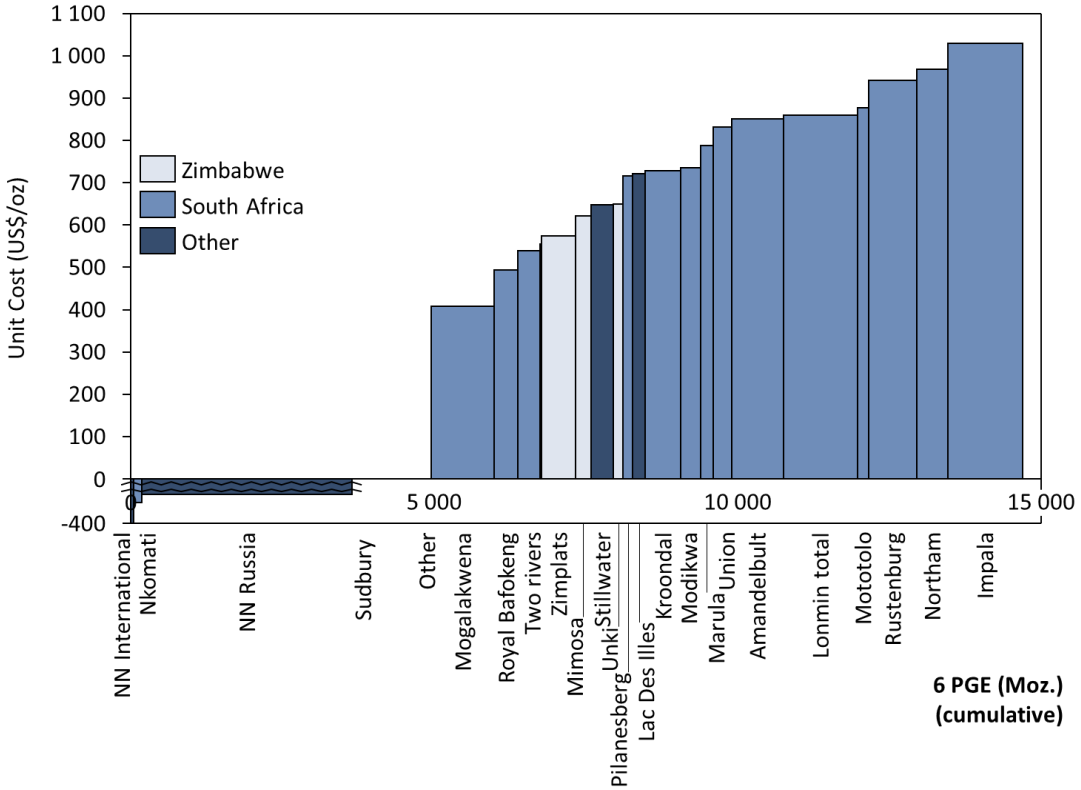
4.2.2 Cost per 6PGE

A cost curve with six Platinum Group Elements (PGE), as shown in Figure 4.3, is represented by:

- The width of each bar for the operation as the sum of the production by mass of platinum, palladium, rhodium, iridium, ruthenium and osmium.
- The height of each bar as the total cash costs (including sustaining capital), divided by the volume calculated. Other by-products, such as nickel, cobalt, silver and gold, are normally subtracted from the total cash costs calculated.

It is useful in order to show competitive advantage, as it accounts for metal recoveries from the ore and for the chosen process. The effect of commercial terms can also be shown by using sales volumes rather than mined volumes. This has the added advantage of showing the positive or negative effects of commercial and sales functions, despite losing the ability to show the fundamental potential of the producing assets. It also has the benefit of not trying to value the constituent metals. They are considered equal in terms of contribution to revenue, which is useful when underlying markets may be in very different situations. By netting off the other metals, the effect of high value by-product metals (e.g. nickel, in the case of Norilsk) is accounted for, versus other producers that may have less by-products. Other production, recycling, or sales from stock can be shown on the cost curve, as it is an alternative to primary production.

Disadvantages are similar to the milled tonne approach, in that the 6PGE product split by underlying metal needs to be similar to be comparable. If this is not the case, the competitive position may be different to what is shown. In addition, the prevailing price per unit 6PGE for the constituent metals cannot be shown on the cost curve, as it is a weighted average of price and volume for each individual producer, with each having a different product mix. At best, an industry "basket price" can be shown, which is only comparable where producers have a similar product split.



Note: Sudbury considered by-product at no cost for illustrative purposes only.

Figure 4.3: 2017 PGM Cost Curve per 6PGE. After Appendix 8.13

Comparing Figure 4.2 and Figure 4.3, Norilsk Nickel in Russia has shifted to the left when compared to the per tonne milled cost curve, with it now being shown, more correctly, as significantly more competitive. It is also shown as having a negative cost, due to the value of non-6PGE products being netted off. This ascribes the full value of non-6PGE products to their competitiveness, which is also not perfectly represented: the 6PGE would not be produced if one had to pay someone to remove them from site. While the contribution of metals other than 6PGE are shown in proportion, the effect of a different product mix across the 6PGE is still not correctly indicating competitiveness for an operation in this method either.

4.2.3 Cost per 2PGE

A cost curve per 2PGE volumes, as per Figure 4.4, is built up on a similar basis to the 6PGE curve. The width of each bar for an operation in this case is shown as the sum of the production by mass of platinum and palladium (2PGE) only, with the value of all other metals subtracted from cash costs and represented per 2PGE volume as the height/ of the bar.

It is a useful representation, as platinum and palladium are co-produced, with a certain amount of inter-changeability in vehicle autocatalysts and hence demand too. As a result, prices may be somewhat interdependent and this representation allows for the marginal platinum plus palladium

volume to be found, if product volume splits are similar. Disadvantages are similar to those issues described in the 6PGE cost curves.

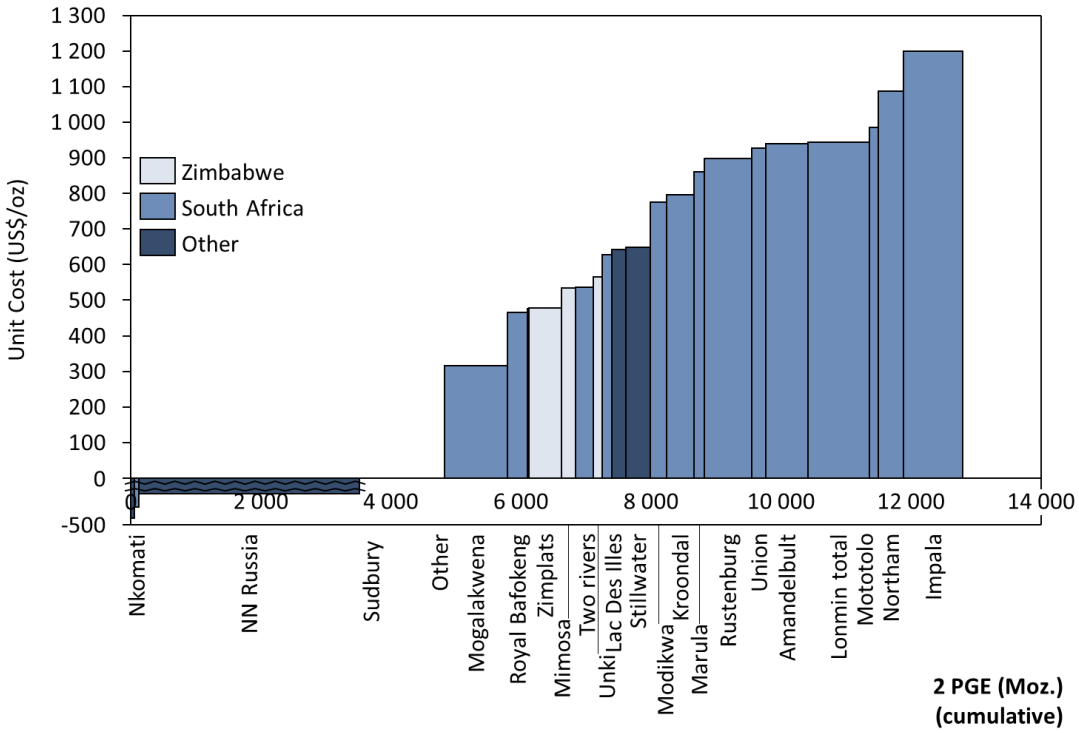


Figure 4.4 :2017 PGM Cost Curve per 2PGE. After Appendix 8.14

Note: Not all producers labelled.

As the relative contribution of non-2PGE metals may be considerable, notably nickel and copper in the case of Norilsk, it may result in some producer's cash costs appearing to be significantly negative. This is a result of allocating the full cost and revenue, hence margin, of the by-products to the 2PGE and skews the view on the operation's competitiveness severely for producers where 2PGE are by-products, such as for Norilsk Nickel in Russia.

4.2.4 Cost per platinum (net)

Cost curves are often shown by the primary product only, net of by-products, as shown in Figure 4.5. In the case of platinum, the width of each bar for an operation is the production by mass of platinum, with the revenue of all other metals subtracted from the total cash costs plus sustaining capital, divided by the volume of platinum only.

This allows a direct comparison against the price of the product being shown. For the primary product, this allows the marginal producer to be found. As for the 2PGE case, a significant drawback is that the full benefit of by-products is ascribed to the primary product.

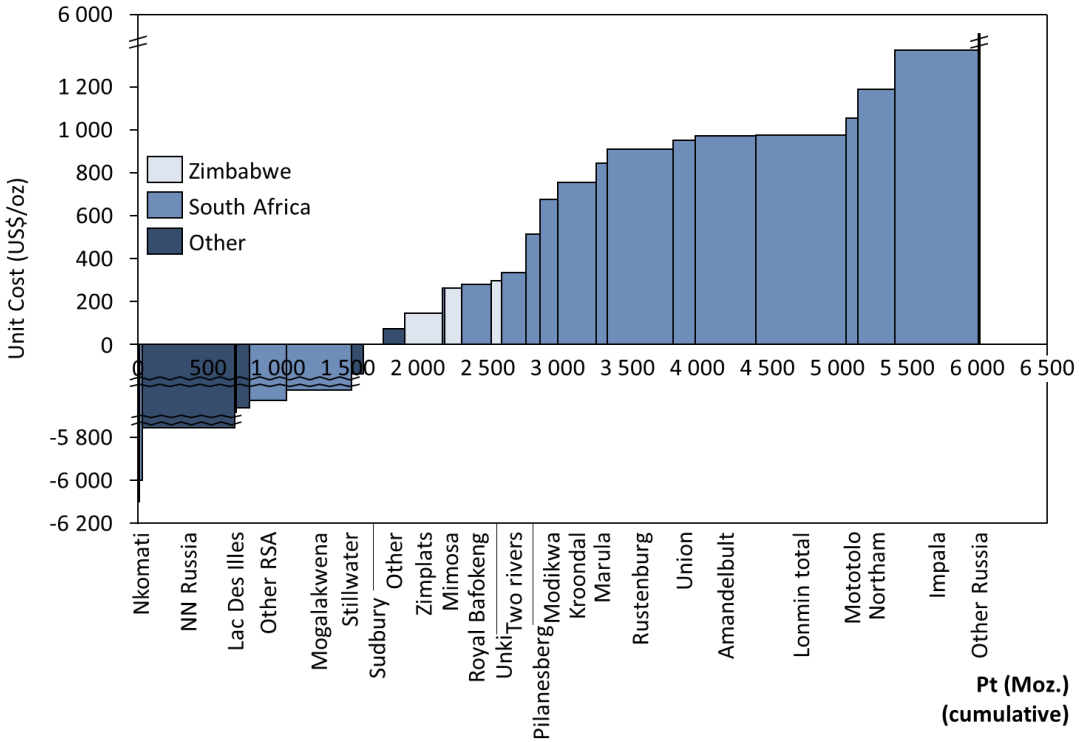


Figure 4.5 : 2017 PGM Cost Curve per ounce Platinum (net). After Appendix 8.15

This representation is somewhat problematic for the platinum industry, as palladium has increased in price to be close to that of platinum. For South African producers, this has meant that those with higher palladium production have moved disproportionately down the cost curve into a more competitive position.

As an extreme example, North American Palladium's mine, Lac Des Illes, with negligible by-product platinum production, is one of the producers at the far left of the curve in Figure 4.5. This indicates it is highly competitive in platinum production and would continue to produce even if it had to pay to do so. This is clearly not the case, as it were to incur a penalty for stopping. (Environmental limitations have resulted in this having happened in salt and acid production, but it is not generally applicable.)

The other more significant example is Norilsk Nickel, where on platinum, palladium, nickel or copper individually it appears to have a low cash cost on a net basis. There is thus *no* consistency across cost curves for individual products, as it cannot be low or cash negative in all cases. The cost curve drawn for the particular product is not mutually exclusive and using this approach it would not be possible to compare the position of Norilsk on a nickel, copper or palladium cost curve at the same time. As shown by the cost per milled tonne, it has significant costs and this should be shown when considering overall competitiveness.

4.2.5 Cost per platinum (co-product)

An extension to the cost per platinum volume cost curve where by-products are netted off is to ascribe equal *value* to all products for a particular producer. This is applied as an equal margin, on a proportionate basis, that is assumed for each product. While some products may "carry" others, when the production site becomes cash negative on a total basis across all products, it starts using cash reserves and should be considered "marginal".

A simple approach to do this is by proportioning cost to each product by the proportion of revenue for the operation, as shown in Figure 4.6. Following the logic that a particular product line, if separable, may be shut down, a more correct method would be to ascribe costs that are applicable to a particular product to that product and then only divide the remaining costs on a revenue weighted basis. Due to a limitation on information and for simplicity, this research paper assumes all costs are inseparable and does not allocate costs to a particular product other than on a revenue weighted basis.

The width of each bar representing a producer is thus the mass of platinum produced, with the height of the bar being cost per platinum ounce, where cost is total cash cost and sustaining capital proportioned by platinum's contribution to total revenue in Figure 4.6

This method appears to correctly capture the contribution of the product being considered, even if it is a by-product for that operation. It allows for comparison with other producers where the by-product is the major product for that producer. The method is mutually exclusive across products and does not double count costs or revenues. By way of example, a platinum, palladium and nickel cost curve would consistently indicate competitiveness in a particular market, even when positions in platinum, palladium and nickel were compared at the same time.

The method does not, however, show the contribution of the selected product relative to other products from the operation. It also does not take into account that price for one particular product may be unusually high due to, for example, low stocks, thus potentially skewing the allocation of costs and the view on competitive position.

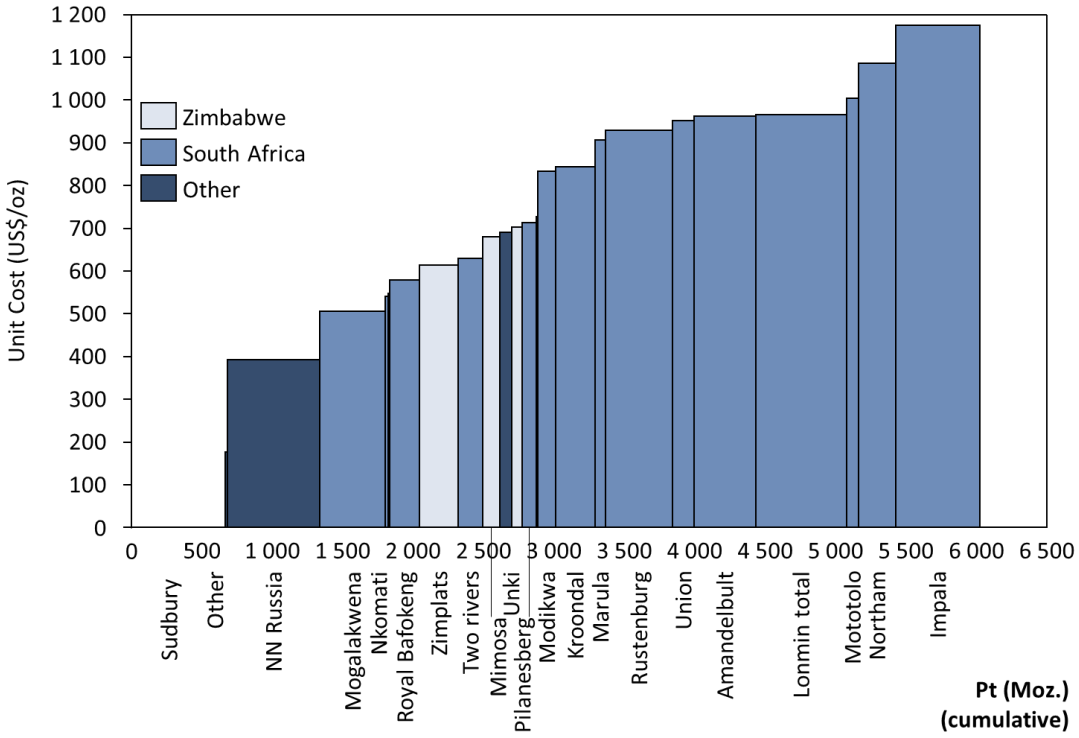


Figure 4.6 : 2017 PGM Cost Curve per ounce Platinum (co-product). After Appendix 8.10

From the above, negative costs are removed, making it intuitively easier to understand. The zero costs indicated at the left of the curve are due to lack or omission of information rather than due to an oddity of accounting method. Vale Sudbury, on the far left, has not separated out the divisions accounts from other division's accounts, and the contribution is very small relative to others; zero seemed a reasonable approximation. Other volumes are balancing numbers for operations that make up the difference between a country's production according to the Johnson Matthey (2017) industry view, and the sum total of published information.

On balance, as summarised in Table 4.1, this method appears to have the least inconsistencies across products relative to others. While more cumbersome to apply than a “net” approach, it gives a better reflection where by-products contribute significantly to an operation and an industry. A summary of various methods to produce industry cost curves can be found in Table 4.1 in Chapter 4.5.

4.3 PGM Cost Curves over Time

Using the co-product method described in Chapter 4.2.5, a cost curve was produced for the PGM industry for every year from 2008 to 2017, with a focus on platinum. Detailed year on year charts and the associated data are shown in Appendix A.

Firstly, a comparison of the start and end of the period is shown in Figure 4.7 in order to illustrate that despite similar cost curves, market prices may be very different. Secondly, developments over time are considered to see if there is anything that can be learnt from the cost curves in Figures 4.9 to 4.11. Derived from this, ways to represent changes over time are shown in Figures 4.12 and 4.13.

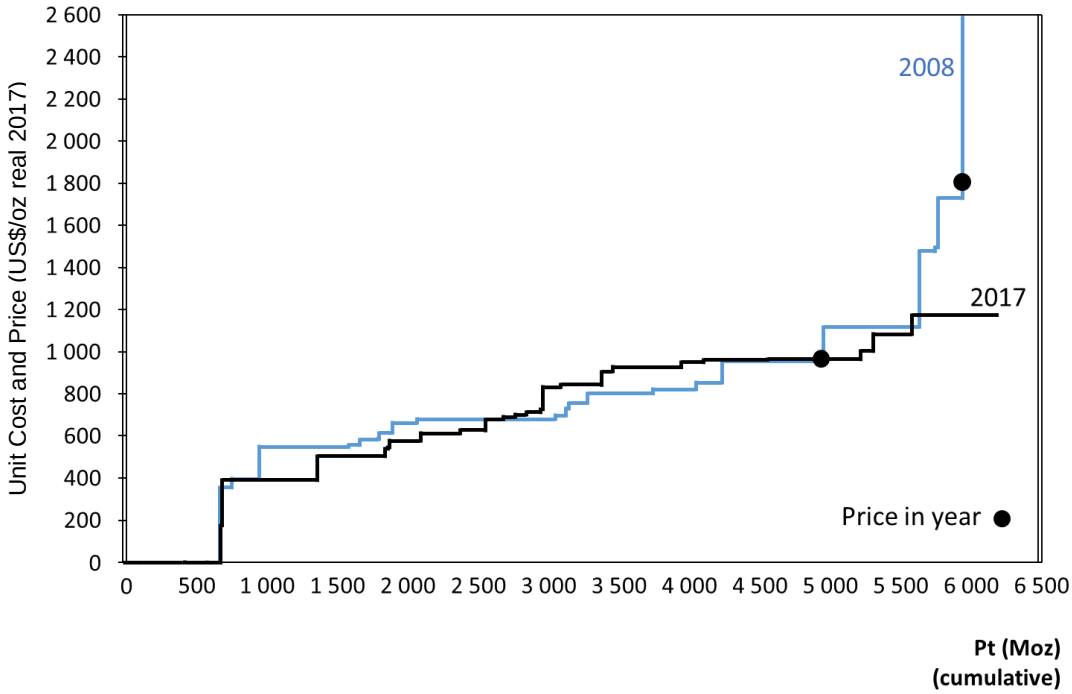


Figure 4.7 : 2017 and 2008 PGM Cost Curve per ounce Platinum (US$/oz Pt, real 2017, co-product). After Appendix 8.1 and 8.10

When comparing the cost curve for 2008 to the cost curve for 2017, despite the cost curves being fairy similar up to about 5 Moz platinum, the price in 2017 is significantly lower. (Around US$1800/oz in 2008, versus about US$950/oz in 2017 according to Johnson Matthey(2018), adjusted for inflation using U.S. Bureau of Labor (2018) data.) This is despite palladium being relatively low priced in 2008 (US$400/oz real 2017) versus 2017 (where it was US$875/oz real 2017), hence being allocated less of the cost using this methodology.

The difference in the market between 2008 and 2017, as in Figure 4.8, is likely due to stocks: 2008 saw platinum in slight deficit, according to

Johnson Matthey (2017), while in 2017 it was in surplus. More important is the accumulation of platinum in the market for the period 2008 to 2017. While Johnson Matthey (2017) shows deficits accumulating for the period, if investment is excluded as banking analysts and market analyst SFA do, then a significant stock build has occurred.

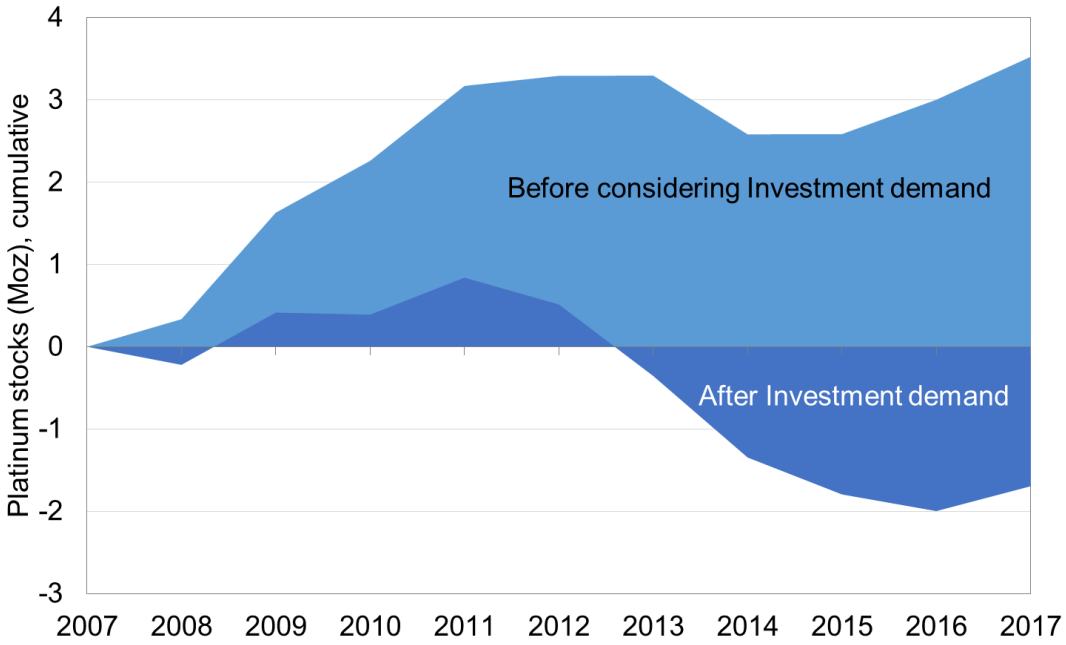


Figure 4.8 : Accumulated stocks of Platinum, 2008 to 2017. After Johnson Matthey (2017)

Accumulated stocks are expected to have a negative effect on price, with prices cutting into the cost curve. The year 2017 has approximately 3.5 Moz more stock available relative to 2008 and hence prices would be expected to be lower, as seen in practice. As a result, a high production volume is no longer cash positive in 2017, whereas in 2008 the price was well above the marginal producer's cost.

While looking at 2008 and 2017 in isolation, the path taken resulting in a particular outcome is at least as important. In order to see how industry cost curves progress over time, one alternative is to plot them on the same graph. (They have been converted to real 2017 terms for comparability.) There appear to have been three distinct periods over 2008 to 2017, as shown in Figure 4.9 below. Over 2008 to 2012, as shown in Figure 4.9, costs increased in US Dollar terms for most incumbents on the cost curve, particularly those between 2.5 Moz and 5 Moz. While not directly observed in any one year in the resultant price, it is expected to have contributed.

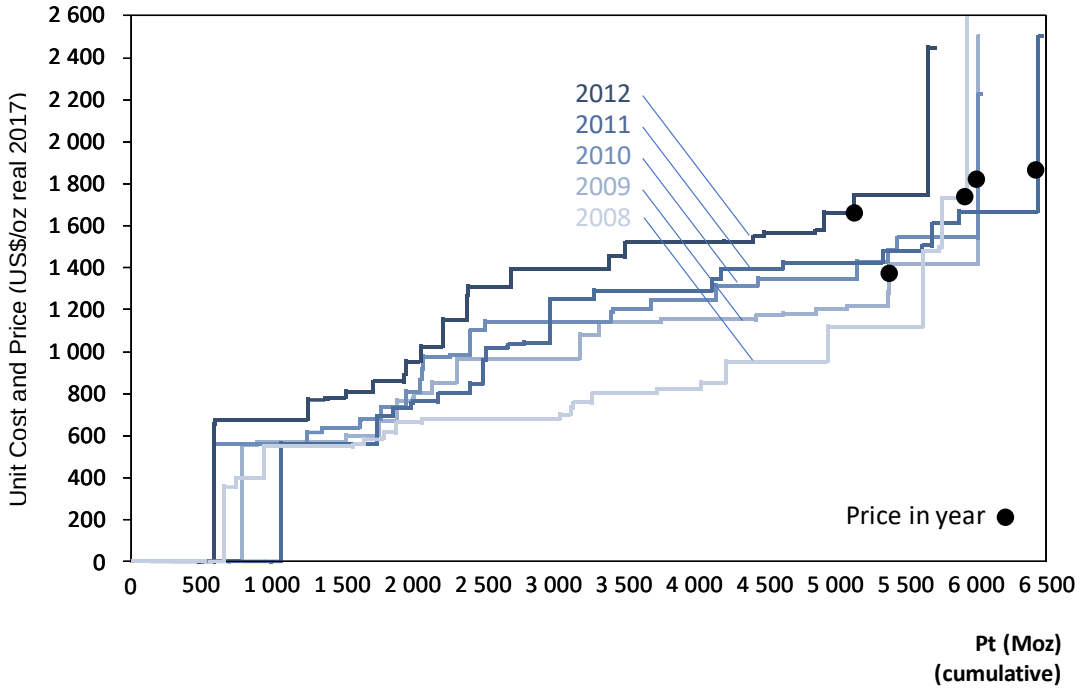


Figure 4.9 : 2008 to 2012 PGM cost curves and price points.
After Appendix 8.1 to 8.5

In the second period shown in Figure 4.10, costs started decreasing in 2013, before significant strikes occurred in 2014 that curtailed production at major producers, notably Lonmin by more than 40%, resulting in both a shortened cost curve (5 Moz produced, versus 6 Moz the year before. This resulted in significantly elevated unit costs for producers due to high fixed costs, particularly at the margin.

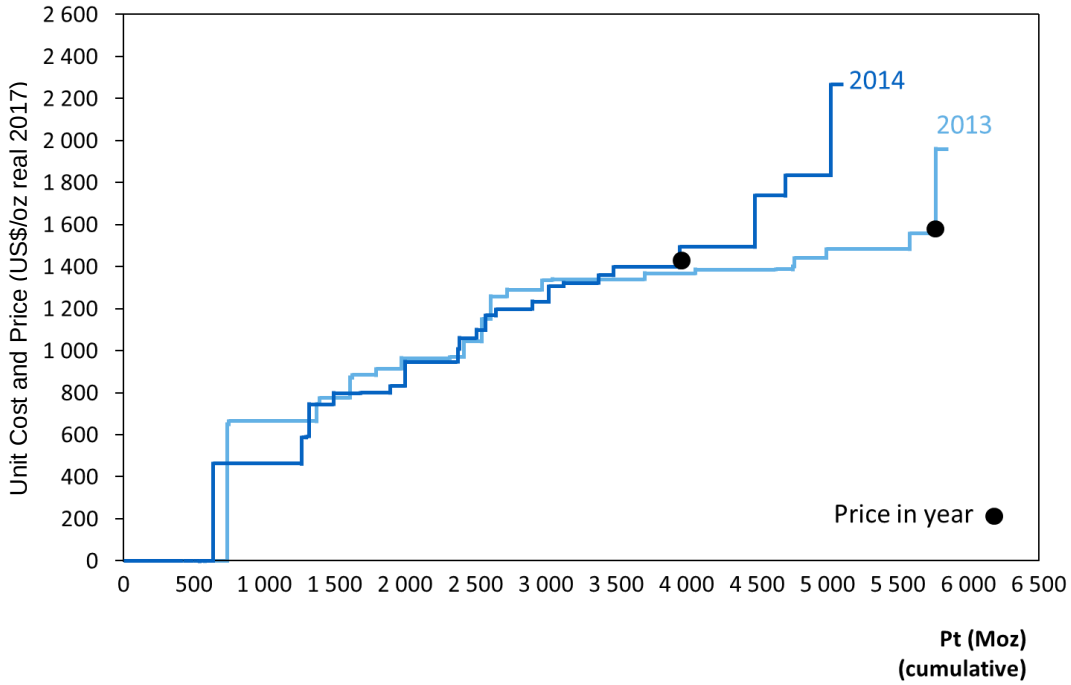


Figure 4.10 : 2013 to 2014 PGM cost curves and price points. After Appendix 8.6 and 8.7

Subsequent to this, costs continued to decrease over the period 2015 to 2017 as shown in Figure 4.11. Producers were responding to higher inventories and a worsening market with reducing prices. In any of the years, 1 to 1.5 Moz of platinum production and the associated producers

were cash negative. Given the methodology, these producers would also be shown as cash negative on any other products too.

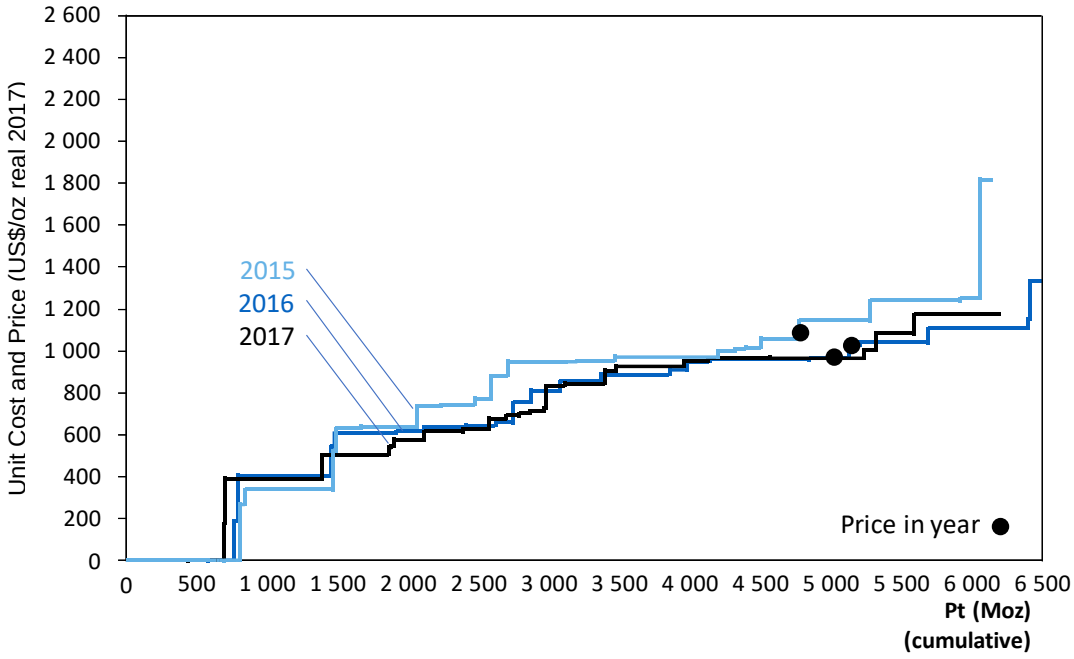


Figure 4.11 : 2015 to 2017 PGM cost curves and price points. After Appendix 8.8 to 8.10

While all cost curves could be plotted on one chart, this is not readable and difficult to interpret. An alternative is to show a summary of the cost curves in each year as a vertical bar. The progression over time can then be shown for the industry, though individual producers are no longer able to be identified in the summary. The first alternative shown in Figure 4.1.2 indicates the cost at which a volume percentile intersects. (For example, in 2008 there is 25% of the supply volumes provided below about 550

US$/oz in real 2017 terms.) This is useful to relate costs to prices, however does not show information related to volumes in absolute terms.

From Figure 4.12, the years 2008, 2010, 2011 and 2013 have prices elevated above the cost curve. The year 2009 was unusual due to after-effects of the financial crisis and 2012 saw the Marikana disaster affecting production (with fixed costs unable to be offset by higher production.) The strike in 2014 is clearly visible in increased costs. Over the period 2015 to 2017 costs above the 25th percentile decreased by 200 to 300 US$/oz platinum in real 2017 terms. Unfortunately prices decreased by around 400 US$/oz over the same period for platinum, resulting in close to a quarter of the industry being loss making for the period.

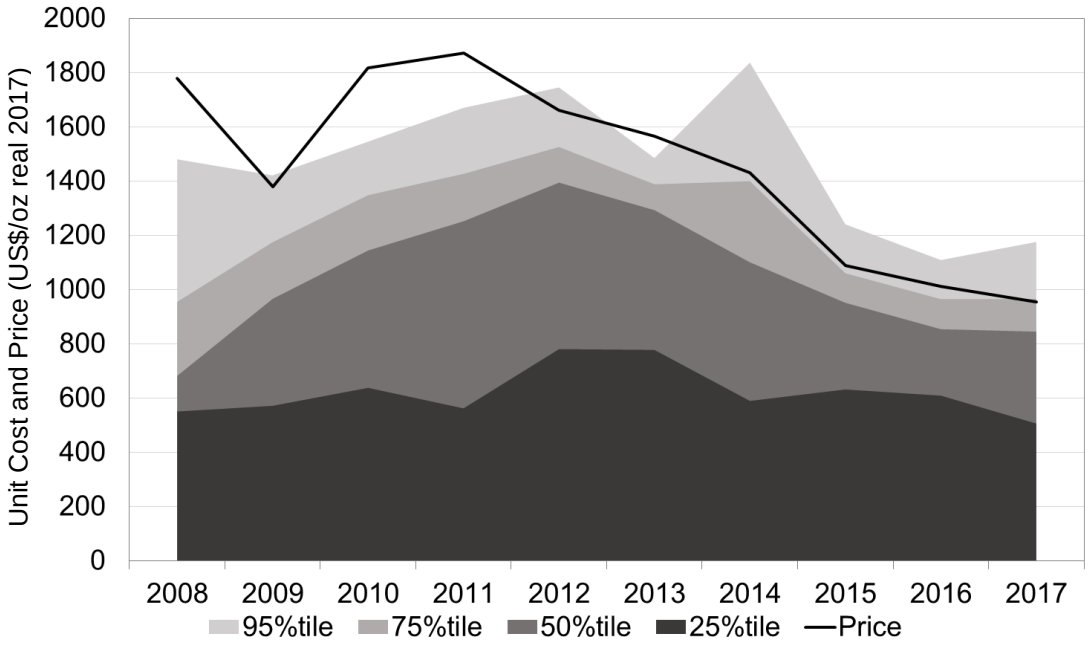


Figure 4.12 : Summary PGM cost curves 2008 – 2017 (cost percentile). After Appendix 8.1 to 8.10

A second, alternative presentation is shown in figure 4.1.3., where volumes are shown on the vertical axis, as they are for each year's cost curve on the horizontal axis. The colour shading then represents the cost range for a particular volume. (For example, in 2008, between one and three Moz cumulative platinum production in the industry, the cost of production was in the range US$501/oz to US$750/oz Platinum in real 2017 terms.) The price can then be plotted as a function of the volume where it intersects the industry cost curve. While it is more difficult to see costs and prices, it is well suited to seeing how steep a cost curve is, as well as the industry volumes that have negative cash margins.

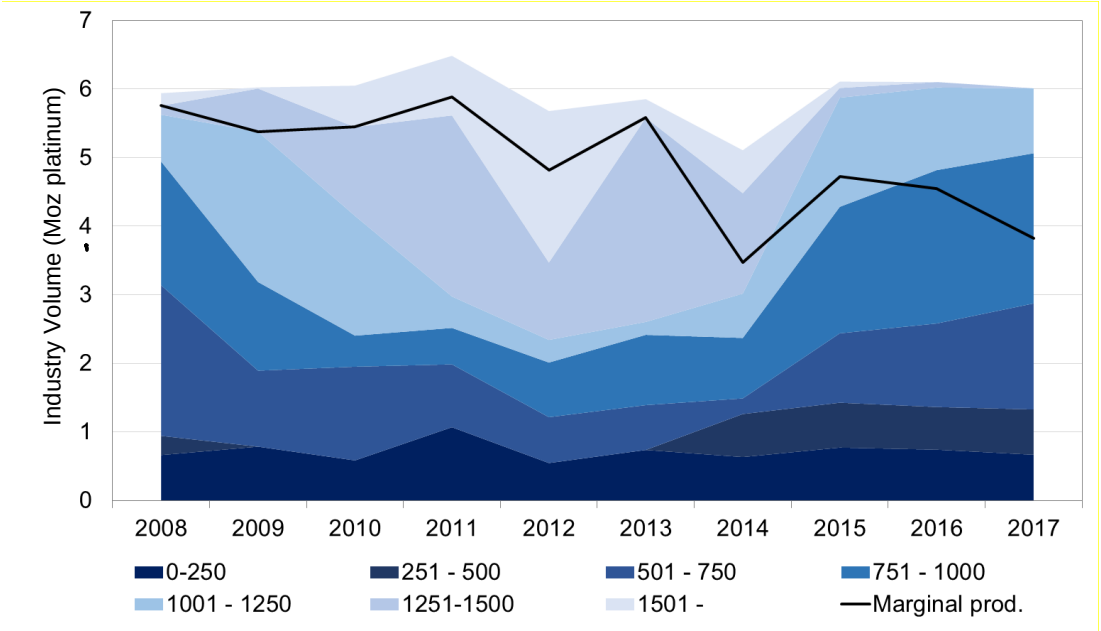


Figure 4.13 : Summary PGM cost curves 2008 – 2017 (volume/cost). After Appendix 8.1 to 8.10

From Figure 4.13, costs increased for most of the industry over 2008 and 2009, as prices remained high. In 2014 prices reduced, with costs reducing significantly over 2015 to 2017 in real 2017 terms, with 1000 to 2000 koz platinum production having negative cash margins.

4.4 Identifying sub-economic producers

From Chapter 4.3, the more difficult years for producers were 2014 to 2017, where 20-30% of the industry was cash negative according to the cost curves. In order to identify the marginal producers for further investigation, the individual cost curves for the years 2014 to 2017 (Figures 4.14 to 4.17) were analysed. The producers in each year that were cash negative were identified, with the percentage of cost that was not covered by price calculated. The region where marginal producers are expected is highlighted with a red circle, with recurring marginal producers selected for further investigation indicated in bold. The advantage of the cost curve used means that this same percentage applies to all by-product metals and ultimately the producer being considered.

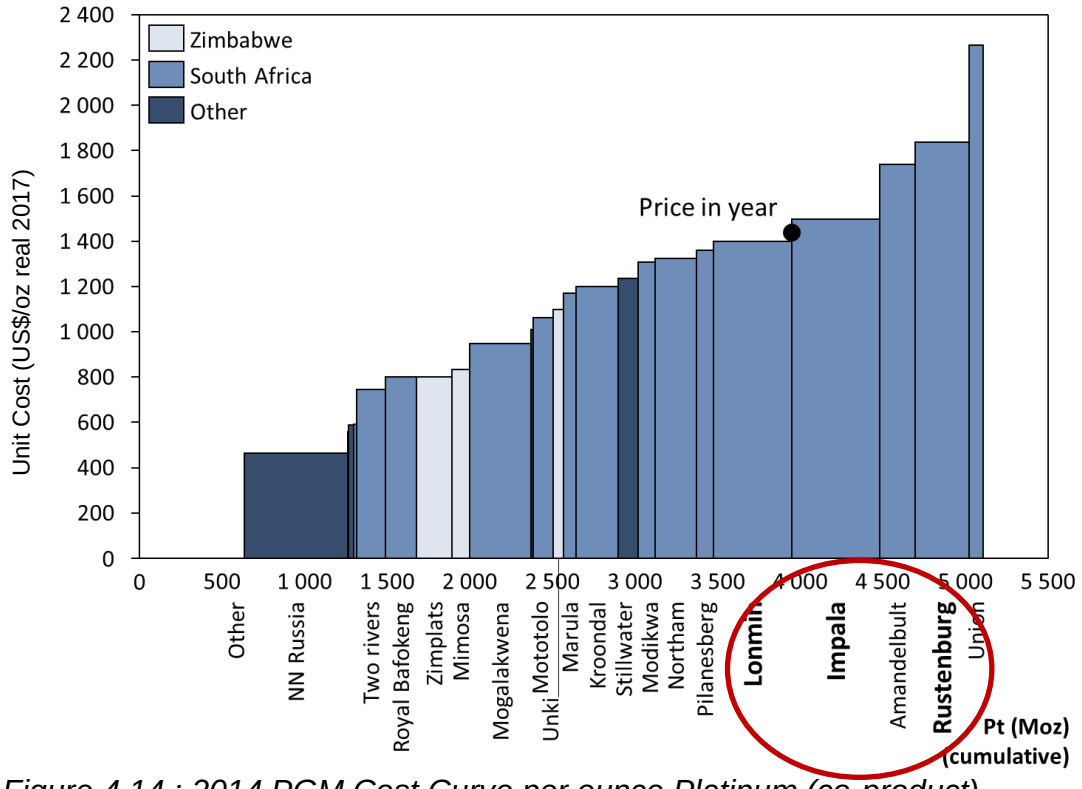


Figure 4.14 : 2014 PGM Cost Curve per ounce Platinum (co-product). After Appendix 8.7

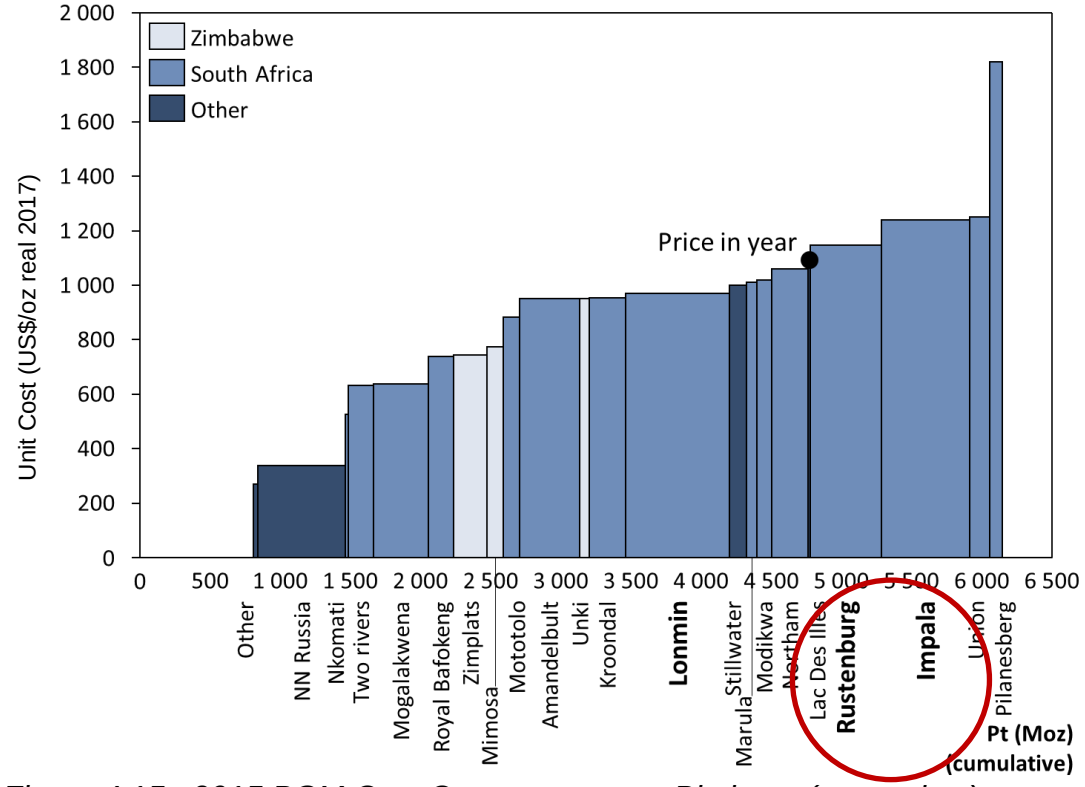


Figure 4.15 : 2015 PGM Cost Curve per ounce Platinum (co-product). After Appendix 8.8

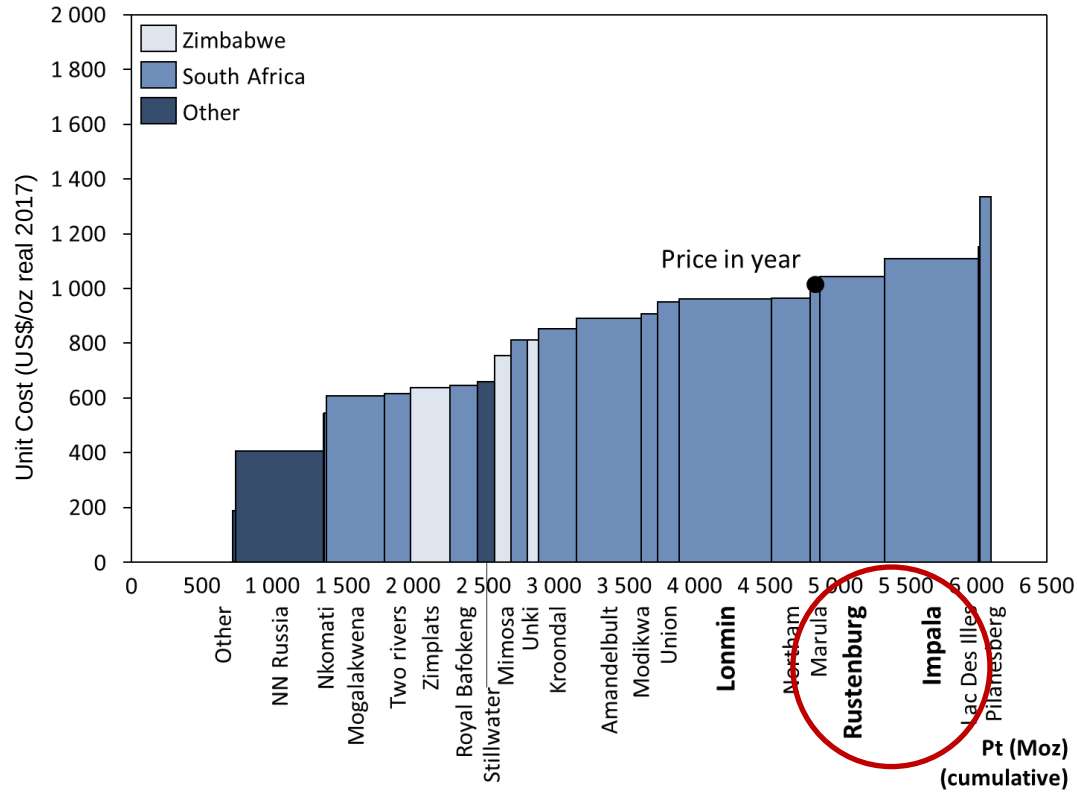


Figure 4.16 : 2016 PGM Cost Curve per ounce Platinum (co-product). After appendix 8.9

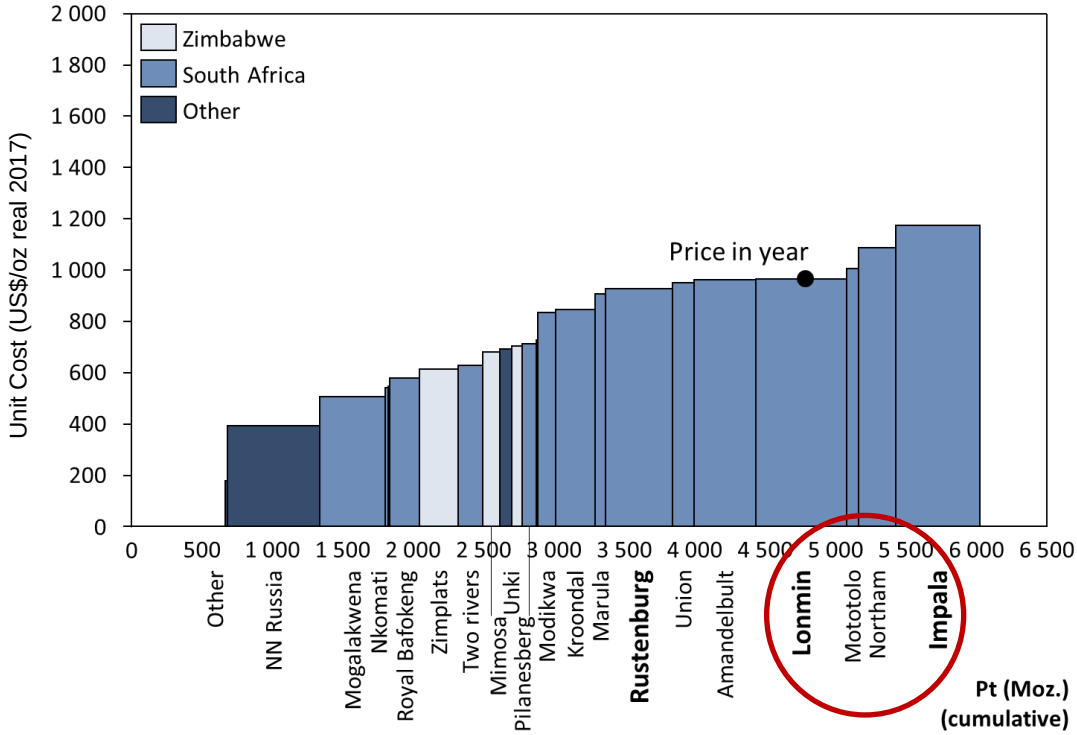


Figure 4.17 : 2017 PGM Cost Curve per ounce Platinum (co-product). After Appendix 8.10

While a number of producers were above the price in each year, only Impala seems to have been substantially cash negative for the full period and hence was selected to investigate further. Rustenburg mines, from Anglo American/Sibanye, was cash negative for three consecutive years. Lastly, Lonmin has had significant cash issues and was expected to be one of the producers to be significantly cash negative. It is included on the list of producers to investigate as a check. Other producers that might have been included are Union, also from Anglo American Platinum, as well as Pilanesberg, however they have been more cash positive over the period under investigation. Union moved to a more competitive position over time by closure of uneconomical shafts and optimising the mine plan (Anglo American Platinum, 2013).

4.5 Chapter Summary

Various representations of cost curves were tested, with the advantages and disadvantages summarised in Table 4.1. For this report, cash cost curves shown on a per ounce platinum on a co-product basis were selected to identify sub economic producers. This representation allows for significant by-product production to be accounted for, while not ascribing too much value to by-product production. It is a reasonable way to compare producers with very different product outputs, as is the case for global platinum production. As it is revenue weighted, it may still result in some misrepresentation if by-products have prices that are significantly different to “normal” levels.

Using the co-product method, the period 2008 to 2017 was investigated, with 2014 to 2017 being particularly relevant as the industry was found to have close to a quarter of all volumes cash negative over this period, despite significant reductions in costs.

Looking at each cost curve over the 2014 to 2017 period, Impala lease area and Rustenburg mines were identified as being cash negative for all or three of the selected years. Lonmin was selected in addition, having experienced cash flow issues over the same period.

Table 4.1 : Advantages and disadvantages of cost curve methods

Cost Curve	Advantages	Disadvantages
Tonne milled	• Competitive position representative, if primary product is unclear • Useful for benchmarking e.g. Mining costs	• Variable product splits across operations skews results • Varying by-products skews results • Individual metal prices not shown • Product demand not shown
6PGE	• Customer viewpoint • Metal recovery included • Commercial terms • Non-mining volumes included, e.g. recycling	• Variable product splits across operations skews results • Product information needed • Individual metal prices not shown • Product demand not shown
2PGE	As above, and useful where: • Metals are co-produced • Interchangeable demand in some sectors	• Variable product splits across operations skews results • Product information needed • Individual metal prices not shown • Product demand not shown
Platinum (net)	As above, and: • Price is able to be indicated • Demand can be indicated	• Production with large by-product contribution shown as negative • Value ascribed to one product (not mutually exclusive)
Platinum (co-product)	As above, and: • Equal margin (%) is shown across metals • Is mutually exclusive • No counter-intuitive "negative costs"	• More complex calculation, if precision is required • Product information needed • More detailed information on processes required for precision
Margin (all methods)	• Shows competitive (operational) position	• Product information needed • Difficult to indicate margin

5 MECHANISMS USED BY SUB-ECONOMIC PRODUCERS FOR SUVIVAL

With marginal producers identified, specifically those that appear to have been significantly cash negative over the period, cash flows of the selected operations were checked to see that what appears to be the case on the cost curve is reflected in the financial statements. Each one was checked to see, for the period in question, how they survived, by looking at measures not directly related to costs or productivity.

Cross subsidisation from other sites or the parent company was considered by looking at the cash flows, cash reserves and financial position of the parent company.

Sustaining capital deferral was sought in annual reports. While a clear reduction is difficult to identify in the time horizon used and to some extent is subjective, as increased operating costs may be an acceptable substitute, reductions were looked for in the financial information given or the discussions.

Cash reserves were looked at to see if losses could be sustained. Specifically, the rate of change and depletion was looked at.

Working capital optimisation, notably changes in inventory indicating that stock had been monetised, was evaluated. Shortening accounts receivable and lengthening accounts payable time has a similar effect. While carrying less stock is an indicator of financial efficiency, this is also an indicator of a greater willingness to carry operational risk and transfer financial stress to operations. Lower pipeline stocks in particular results in less operational flexibility, higher risk of failure and lower operational efficiency.

Financial position was looked at using a few basic debt and liquidity ratios, in order to check if a company's financial position was compromised. If not immediately distressed, it was checked to see if financing was used to cope with a period of low or no cash flow, whether through loans or equity issue (re-capitalisation).

Hedging of commodity prices, currency, or interest rates was sought in the annual reports, to see if it might have helped in the survival of the company in question, or perhaps even resulted in financial distress.

Exit costs, as a mechanism to avoid closure of an operation, were looked for in reports.

5.1 Impala Lease Area

The Impala lease area in South Africa was uncompetitive for every year in the period 2014 to 2017, from the cost curves generated. This is reflected in the overall cash flow for 2014 to 2016. In 2017 this is only seen in the operating cash flow, as financing was used to both extend maturity of debt and obtain R 2 Billion for “general corporate purposes” (Impala Platinum Holdings, 2018a). The contribution to the parent company has been relatively small in comparison to, and more negative than, other sites (c. 40% of total cash flow). Given that the Impala lease area makes up more than half of the total volume produced by the company and hence the overall productive effort, this is likely to have been of concern to management.

Inventory has remained fairly stable over the period, despite the acid ratio being low (32 to 11%). After significant impairments to the balance sheet in 2017 of R 10 Billion, the debt ratio became significant, at 73%. Hedging, using cross-currency interest swaps on US$ denominated convertible bonds, was employed by Impala. In most years, except 2017, this had a positive impact on financial position.

The parent company has been in a significantly stronger position than the impala lease area, including cash flow and debt position. Despite this, the Impala lease area has a number of separate operating units, and the

holding company was proactive in managing them. In August 2018, at the time of writing this report, Impala announced significant restructuring of its operations in the lease area near Rustenburg. (Impala Platinum Holdings, 2018b) This approach is supported by the historical cost curves, though a clear view on the decision would require their view of forecast market conditions.

Overall, the cost curves support the conclusion that Impala has been in an extended downturn. It has been able to survive thus far thanks to cash reserves and by delaying paying bills, helped by having a reasonably strong balance sheet. This has given Impala time to implement portfolio improvements, including shutting or potentially selling unprofitable shafts.

5.2 Rustenburg Mines

Rustenburg was a part of Anglo American Platinum that was sold to Sibanye-Stillwater in 2016. The Anglo American Platinum annual report for 2016 describes the sale of “less competitive” assets, of which Rustenburg was one. According to the cost curves, the operation was close to neutral for every year 2015 to 2017 (negative in 2015 and 2016), and significantly negative in 2014.

When looking at cash flows, this is not reflected in all periods: despite both operating and total cash flow being fairly small, 2014 in particular is quite positive, the opposite of what is shown on the cost curves. On closer inspection, this is due in part to the additional by-product chrome that was sold, where revenues are captured but volumes are not reported. On the cost curves developed, revenues are derived from volumes, resulting in under estimating by-product revenues. Another under-estimate is due to significant tailings revenues that are included in cash flows.

Production volumes were significantly lower in 2014 (c. 325koz Pt, versus c. 550koz Pt in most other years) due to a significant strike in 2014 and operational issues. In 2015, with the return of the mine to normal operations from the strike, the East and West mines were consolidated in order to reduce costs and improve competitiveness. Like Impala, Rustenburg consists of a number of separate mines. From the detail given in the 2013 report, only Khuseleka shaft was cash positive, after final cessation of maintenance and mining of the less productive Khuseleka 2 shaft.

Information regarding the financial position of Rustenburg was not available in the Anglo American Platinum annual reports. At a parent company level, cash reserves were very low in 2014, only increasing by 2016. The level of cash and cash equivalents held was substantially lower

than Impala platinum, averaging c. ZAR2.8Bn versus Impala holding ZAR4.5Bn for the period 2014 to 2016 (Impala Platinum Holdings, 2018a). The debt ratio for the parent company (Anglo American Platinum) was also surprisingly high, at c. 49% when Rustenburg was sold. The new owners, Sibanye-Stillwater, have driven the inventory even lower and have lower cash reserves, while having a higher debt ratio at c. 69% in 2017. There is less room for error and some hedging, notably of debt instruments, was used.

Overall, Rustenburg has been close to marginal for an extended period. This resulted in some operational improvements (combinations and closures), but ultimately led to the sale of the mine to Sibanye-Stillwater. Anglo American Platinum was not in a strong position, though was able to support the mine through cash reserves and a reasonable debt position. The new parent company, Sibanye-Stillwater, was in a worse position, hence highly incentivised for operational improvements.

5.3 Lonmin

Interpreted from the cost curves, Lonmin was *not* one of the sites that was expected to be significantly cash negative, apart from 2017. Based on published information however, Lonmin *did* undergo a rights issue in 2015 due to liquidity and capital structure issues and plans to sell to Sibanye-Stillwater end 2018 (Sibanye-Stillwater, 2017a).

Looking at Lonmin's cash flows, operating cash flows are negative in 2014, but fairly positive over the period 2015 to 2017. Total cash flows are quite negative, apart from 2016. On closer inspection, this is largely due to capital expenditure consisting of sustaining capital investments. Expansion capital projects were deferred in earlier years. The Bulks Tailings Treatment facility was built towards 2017, to focus on producing near term value.

Unexpectedly, Lonmin's working capital was negatively affected by accounts receivable reducing less than accounts payable. This is likely due to the rights issue and the financial difficulties that Lonmin found itself in. As trade credit was less likely to be extended, this resulted in an increase in the working capital requirements, likely opposite to what would be ideal.

At first glance, Lonmin's debt and acid ratios look acceptable. Looking at the balance sheet over time, however, indicates a reduction in non-current liabilities. Presumably the reduction over 2014 to 2015 occurred as a result of access to finance reducing after the strikes in 2014 and liquidity issues. Debt covenants, where debt will be withdrawn if certain criteria are not met and in Lonmin's case keeping the company value above a threshold agreed with particular debtors, have had to be waived in order

for finance not to be withdrawn in 2017. Lonmin has a clear policy of not hedging price or exchange rate.

Lonmin's coping strategy and some of the mechanisms leading to the company turning cash negative are described in more detail by Brown (2016). These include re-engineering the business for operating at a lower cost and a rights issue, where additional funding was secured by the board in 2012 in order to address debt as a result of strikes occurring while capital was being spent.

Overall, Lonmin has had reasonably positive operating cash flows, but these have been negative when including sustaining capital. Sustaining capital has not been deferred in the period under investigation, with it being critical for having access to reserves and equipment in operating condition. Lonmin's issues related more to debt covenant and liquidity concerns than an absolute negative year on year position and serves as an example of where the other producers were headed.

5.4 Chapter Summary

For the three PGM producers identified as unsustainably marginal for an extended period, plans have been initiated to maintain the business. These range from closure/sale of marginal shafts (Impala), selling marginal mines (Anglo American Platinum, Rustenburg), to selling the whole business for value for stakeholders (Lonmin). This agrees with the

view from the cost curve analysis and has been taken as empirical evidence that they provide a reasonable tool to estimate competitive position.

Differences between the position indicated on the cost curves and the company information were found, including:

- Sales of minor products such as chrome, some other metals or some parts of the operation (tailings recovery) were not captured on cost curves, as volume information was not available and unable to be inferred. Specifically, the sale of chrome may become material in later years and may need to be requested from companies or back-calculated from “other revenue” cash flows.

- Costs were not always cash costs. The matching principle in accounting might lead to a different cash position being shown if true cash flows are used. As cost curves tend to be used in discussing the fundamental position of the business, this should be less of an issue and may well be improved by costs matched to revenues.

- Sustaining capital is not always specified. Whether due to the difficulty in defining or measuring it, or perhaps due to its irregular nature, it is not always given in reports. As a result, it may need to be inferred, influencing competitive position.

Various mechanisms were observed enabling the companies identified to remain producing while attempting to increase productivity and reduce costs. For all, this resulted in various changes having to be made to the way the company was operated. The various mechanisms are described and compared below:

- *Cross-subsidisation* in some form was used by all companies. This either was with a diversified parent (Sibanye-Stillwater), a larger company with various producing sites (Impala, Anglo American Platinum) or at least across various shafts in the same mine (Rustenburg mines, Lonmin).

- *Deferral of sustaining capital* appeared to be used in all companies. In the case of Lonmin, this eventually could no longer be deferred and the company had to go as far as a rights issue to maintain operations due to the requirement of cash for sustaining capital.

- *Cash reserves* appeared to be used in all companies, though not specified for Rustenburg mine itself. Cash reduced by a third, or close to R 1.7Bn, for 2015 at Impala.

- *Working capital,* specifically with respect to Inventories, was reduced for Rustenburg and Lonmin. Presumably this was not necessary for Impala as the cash position was acceptable and there was no need to optimise working capital while risking operations.

- *Debt obtained or equity issued* was seen for Lonmin, where in 2015 another rights issues was required due to liquidity and debt concerns. Impala acquired some financing, ahead of re-financing requirements, and Rustenburg mines has not published the underlying information to be able to observe it (It has not been required at a parent company level).

- *Hedging* as a survival mechanism was not observed in any of the sites, with Lonmin specifying that it has a non-hedging policy. Hedging that was observed was generally associated with financing rather than directly associated with survival, in the form of currency swaps on debt (Impala) and required to meet debt covenants (Sibanye-Stillwater, once owning Rustenburg).

- *Exit costs* were not mentioned as a reason not to shut down. For all three companies, however, eventually sub-economic shafts were shut in an attempt to obtain a better average for the parent

company. From observations, exit costs are best considered as a reason to defer the shut decision using mechanisms described above, rather than enabling deferral.

The observations are summarised in Table 5.1 for the three companies that were considered.

Table 5.1 : Survival mechanisms: Impala, Rustenburg mines and Lonmin

	Impala Lease Area	Rustenburg Mine	Lonmin
Cross Subsidisation	Some: Marula, Zimplats	Extensive: Anglo Platinum, Anglo	None
Sustaining Capital Deferral	?	2013, 2015 much lower	Unable to defer further
Cash Reserves	Substantial; reducing	?	Low reserves
Working capital optimisation	Payables increased	Inventories reduced	*Decreased* due to difficulties
Debt obtained/ equity issued	Debt obtained (R2Bn)	Not needed	Ratios fine, debt covenant onerous
Hedging	Cross-currency interest swaps	Some; debt instruments	No hedging
Exit costs	?	?	?
Other	Shut and sell shafts	Chrome sales, shut shafts	Rights issue, sale of company

Note that green denotes evidence of employing the survival mechanism, orange some evidence, and red the opposite behaviour.

6 SUMMARY CONCLUSION AND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1 Summary Conclusions

Cost curves may be produced by various methods. The purpose for which they are being used should guide selecting the method to build them, the costs to include, and which companies/regions to cover. For this research report, various cost curves were tested before being compiled. Co-product costing, where equal margins are applied across all products, was seen as the most appropriate and representative. For this, costs were applied by ratio of revenue across all products, including mining, beneficiation, marketing and overheads where available.

Cash costs were used to the extent possible, i.e. depreciation, amortisation, interest, tax and extraordinary items (e.g. impairment charges) were excluded. Sustaining capital was included, as it is required to be spent to maintain longer term and future production. When compiling the cost curves, global production of platinum was considered. This included production outside of Southern Africa, where platinum is produced as a by-product in the case of Norilsk (Russia) and Stillwater (North America).

Cost curves for the platinum industry were produced for the ten years 2008 to 2017, along with summaries to show the progression against the price of platinum. The years 2014 to 2017 show significant industry production volumes (1 – 1.5 Moz, or a quarter of the industry) being cash negative. Given the method of drawing cost curves that was selected, the cost curves for other products would have indicated similar (negative) margins for the marginal producers. This allowed the producers that had costs exceeding prices for any of those four years to be identified for further investigation. Impala and Rustenburg mines were identified as being cash negative for four and three of the years respectively. Lonmin was selected in addition, as it has had to undergo a rights issue due to financial difficulties in 2015.

In order to survive while being uncompetitive and trying to become more productive and/or reduce unit costs, a number of measures were observed. All made a use of cross-subsidisation from other sites or a parent company in a better financial position, though the extent to which this was possible varied from significant (Rustenburg under Anglo American Platinum) to limited (Lonmin). Expansion capital and sustaining capital was deferred by most, with Lonmin providing an example of sustaining capital having to be spent, with no further possibility of deferral.

For all, cash reserves and working capital reductions were used to support near term cash requirements. In the case of Lonmin, re-capitalisation through a rights issue was required by Lonmin to solve near term liquidity concerns. This not only provided cash for survival, it also resulted in more stringent business discipline and control. Other than for meeting debt requirements (currency or covenants), hedging was not used as a way to reduce the risk of default at the marginal sites looked at in more detail.

Overall, cost curves produced using the co-product methodology were useful in correctly identifying marginal producers. In order to produce more precise analysis and for comparability, it would be useful if the industry would adopt a standard non-GAAP measure for costs, such as the All-In-Sustaining-Cost (AISC) measure used by the gold industry. More public information on a shaft/regional level would allow for better public analysis, as some areas are divisible and more or less profitable areas could be identified. This is particularly the case for Impala lease area and Lonmin. Lastly, specifying the production and sales volumes of all products would support analysis by clarifying the full value available to stakeholders. While commercial arrangements will determine price achieved and may not wish to be disclosed, volumes should be less contentious.

Regarding the use of cost curves to indicate competitive position, the research report has highlighted that they are useful but are strictly

operational indicators of the mine's performance in the broader market. They are suitable for indicating competitive *performance* (operational position), however financial balance sheets and the details behind them are still needed to indicate competitive *strength* (financial position) and hence ability for a business to continue.

6.2 Recommendations for Further Research

The research report highlighted that what is still needed is a mechanism to combine an endogenous resilience measure of the business (as provided by balance sheets) with an exogenous resilience measure (as provided by cost curves). A single, combined method may be a better indicator not only of current competitive position, but of future expected outcome. This would help in forward looking business decision making.

Specific balance sheet focussed further work may include determining a measure equivalent to the Zmijewski score for the risk of future business failure that is suitable for mining companies. The current constants have been determined from empirical analysis using all USA companies. Doing the exercise for mining companies specifically may be more useful and accurate in forecasting mining business failure risk. A method many then be found that combines this with the simplicity of suitable cost curves, giving a more complete view of the industry.

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8 APPENDIX A: 2008 – 2017 COST CURVES AND DATA

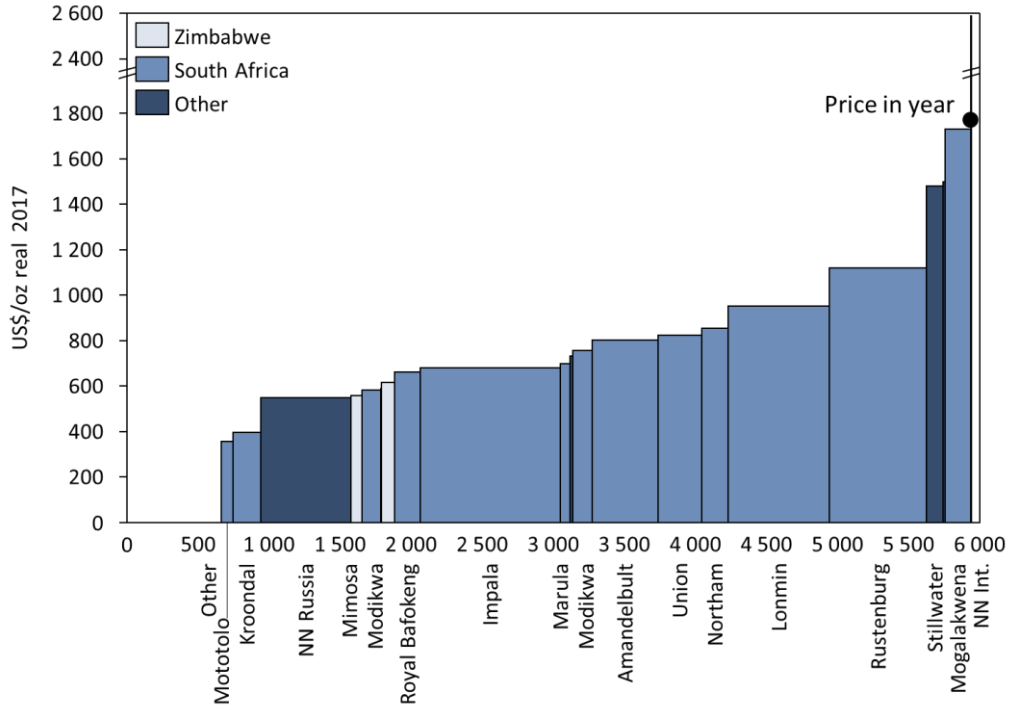

Figure 8.1 : 2008 PGM Cost Curve per ounce Platinum (co-product)

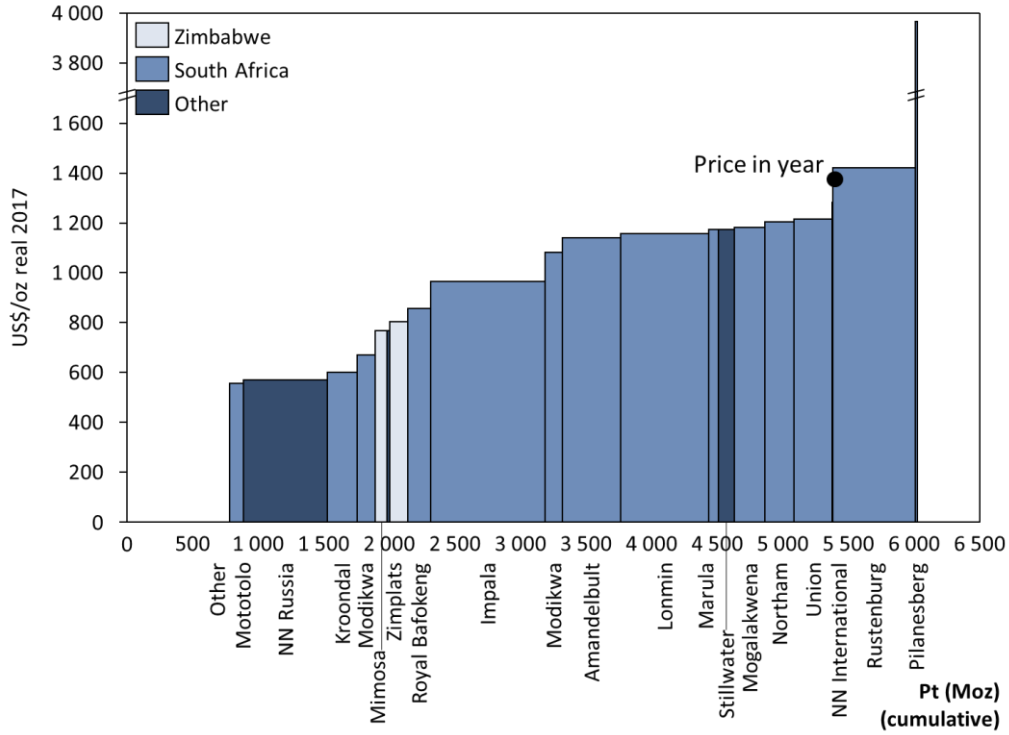

Figure 8.2 : 2009 PGM Cost Curve per ounce Platinum (co-product)

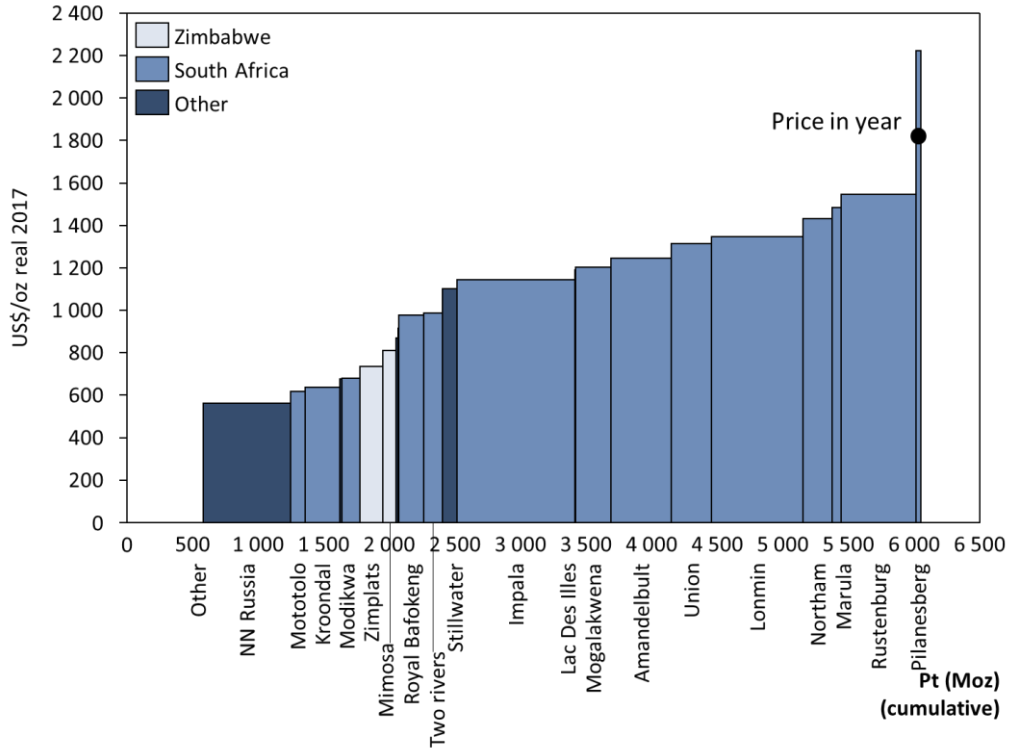

Figure 8.3 : 2010 PGM Cost Curve per ounce Platinum (co-product)

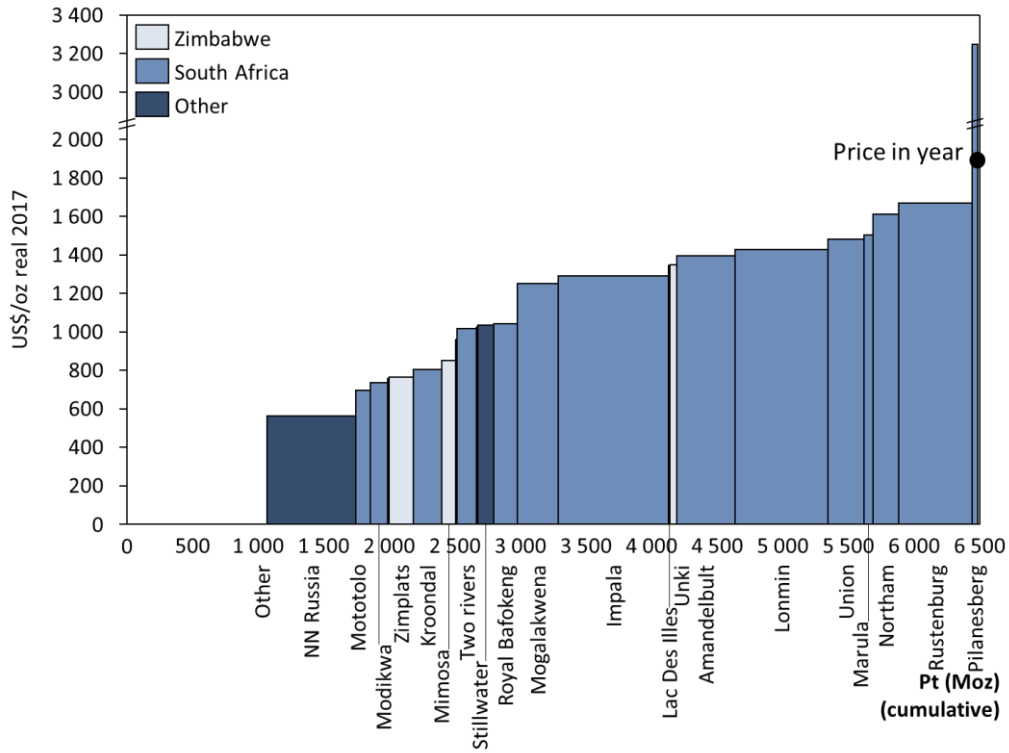

Figure 8.4 : 2011 PGM Cost Curve per ounce Platinum (co-product)

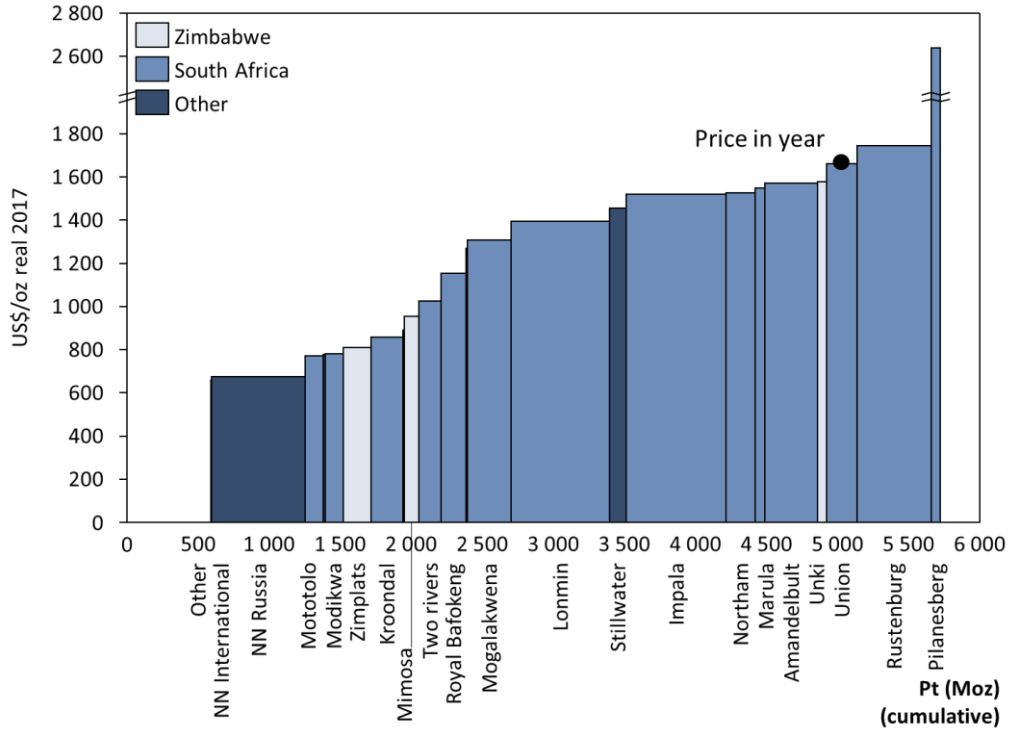

Figure 8.5 : 2012 PGM Cost Curve per ounce Platinum (co-product)

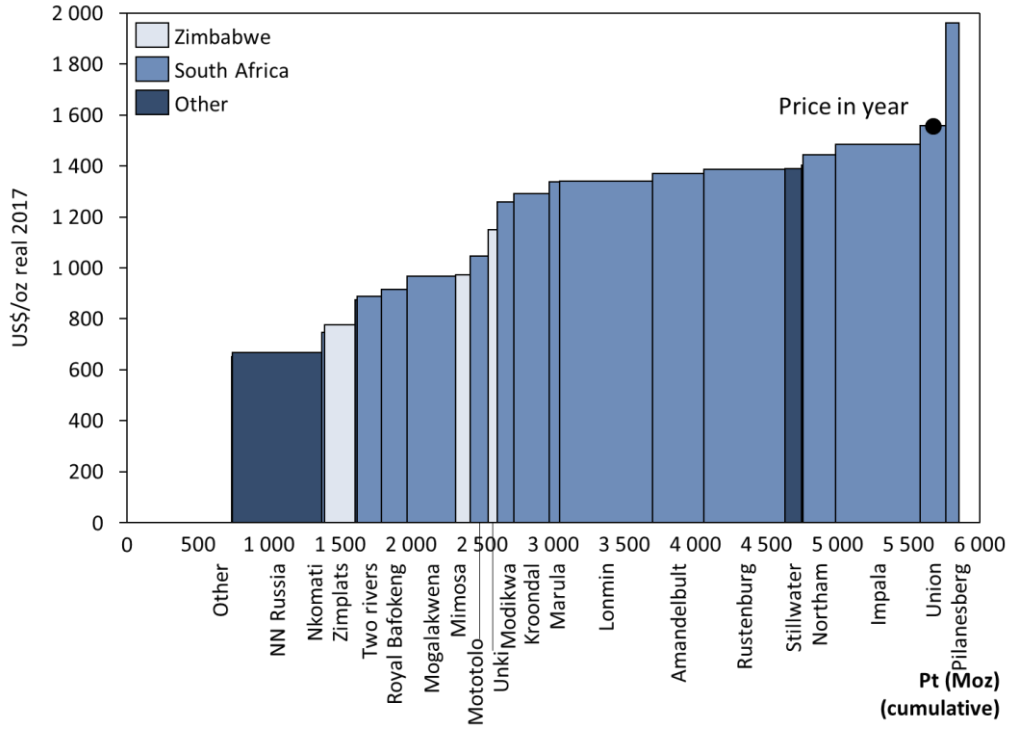

Figure 8.6 : 2013 PGM Cost Curve per ounce Platinum (co-product)

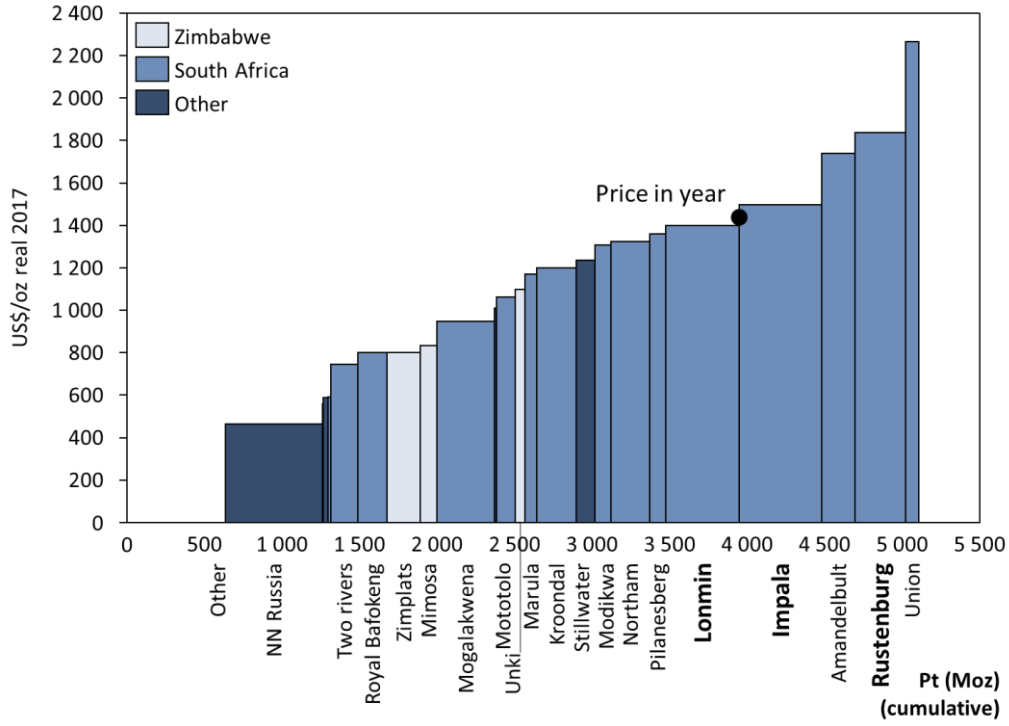

Figure 8.7 : 2014 PGM Cost Curve per ounce Platinum (co-product)

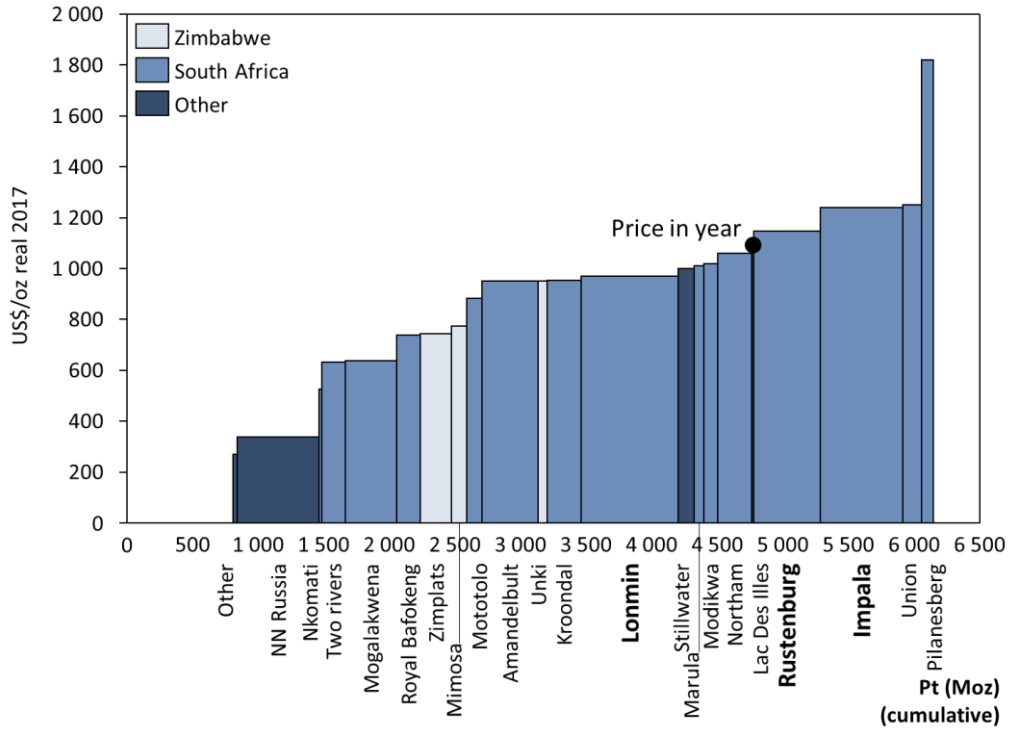

Figure 8.8 : 2015 PGM Cost Curve per ounce Platinum (co-product)

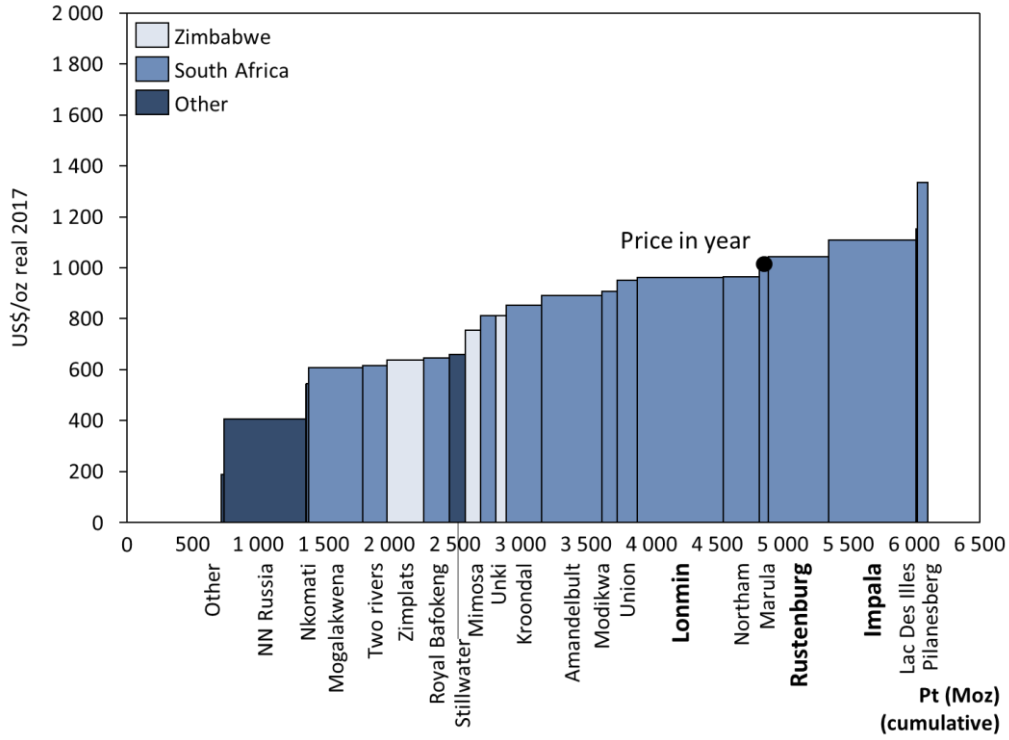

Figure 8.9 : 2016 PGM Cost Curve per ounce Platinum (co-product)

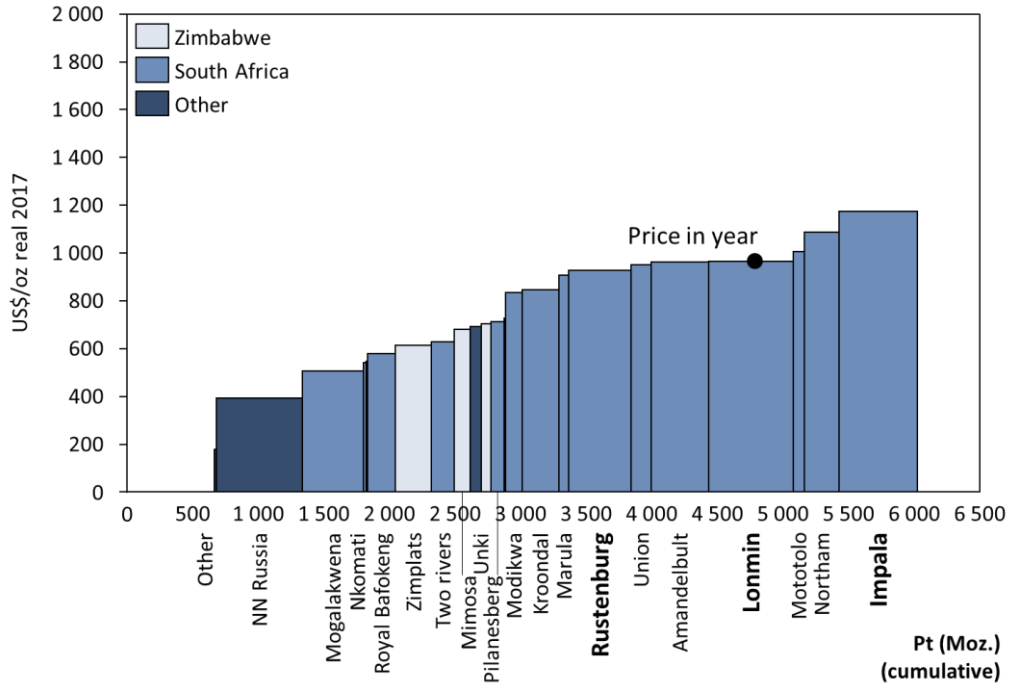

Figure 8.10 : 2017 PGM Cost Curve per ounce Platinum (co-product)

8.1 Data for 2008 Cost Curve

2008				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	166	0.0
RSA	OTH	Other RSA	200	0.1
RUS	OTH	Other Russia	173	0.2
ZIM	OTH	Other Zimbabwe	5	0.3
CAN	OTH	Other North America	28	0.4
OTH	OTH	Other	91	0.5
ZIM	APL	Unki	0	0.6
RSA	APL	Mototolo	84	317.5
RSA	APL	Kroondal	196	354.8
RUS	NN	NN Russia	632	490.3
ZIM	IMP	Mimosa	80	497.9
RSA	APL	Modikwa	131	520.5
RSA	ARM	Nkomati	5	525.4
ZIM	IMP	Zimplats	95	549.2
RSA	RBP	Royal Bafokeng	178	591.5
RSA	IMP	Impala	984	607.5
RSA	IMP	Marula	72	622.8
BOT	NN	Tati Nickel	19	652.3
RSA	ARM	Modikwa	135	675.2
RSA	APL	Amandelbult	461	715.1
RSA	APL	Union	309	733.3
RSA	NHM	Northam	186	762.3
RSA	LON	Lonmin	715	850.5
RSA	APL	Rustenburg	682	997.8
CAN	SWL	Stillwater Company	115	1318.6
CAN	NAP	Lac Des Illes	16	1334.7
RSA	APL	Mogalakwena	177	1542.3
FIN	NN	NN International	5	2306.2

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2010), (African Rainbow Minerals, 2013), (African Rainbow Minerals, 2010), (Impala Platinum Holdings, 2012), (Lonmin, 2011), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2009), (Northam Platinum, 2010), (Stillwater Mining Company, 2012), (Royal Bafokeng Platinum, 2011), (Sedibelo Platinum Mines, 2014), (Vale, 2011)

8.2 Data for 2009 Cost Curve

2009				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	103	0.0
RSA	OTH	Other RSA	401	0.1
RUS	OTH	Other Russia	149	0.2
ZIM	OTH	Other Zimbabwe	4	0.3
CAN	OTH	Other North America	34	0.4
OTH	OTH	Other	93	0.5
ZIM	APL	Unki	0	0.6
CAN	NAP	Lac Des Illes	0	0.7
RSA	APL	Mototolo	106	488.7
RUS	NN	NN Russia	636	502.7
RSA	APL	Kroondal	231	528.7
RSA	APL	Modikwa	135	591.0
ZIM	IMP	Mimosa	92	674.5
BOT	NN	Tati Nickel	17	676.0
RSA	ARM	Nkomati	3	685.8
ZIM	IMP	Zimplats	134	707.7
RSA	RBP	Royal Bafokeng	176	753.2
RSA	IMP	Impala	872	849.9
RSA	ARM	Modikwa	134	951.6
RSA	APL	Amandelbult	444	1004.4
RSA	LON	Lonmin	671	1018.1
RSA	IMP	Marula	72	1033.3
CAN	SWL	Stillwater Company	123	1033.7
RSA	APL	Mogalakwena	233	1040.9
RSA	NHM	Northam	222	1060.5
RSA	APL	Union	292	1070.8
FIN	NN	NN International	5	1127.3
RSA	APL	Rustenburg	626	1250.5
RSA	SED	Pilanesberg	17	3490.7

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2010), (African Rainbow Minerals, 2013), (African Rainbow Minerals, 2010), (Impala Platinum Holdings, 2012), (Lonmin, 2011), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2012), (Northam Platinum, 2013), (Stillwater Mining Company, 2012), (Royal Bafokeng Platinum, 2012), (Sedibelo Platinum Mines, 2014), (Vale, 2011)

8.3 Data for 2010 Cost Curve

2010				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	35	0.0
RSA	OTH	Other RSA	255	0.1
RUS	OTH	Other Russia	162	0.2
ZIM	OTH	Other Zimbabwe	1	0.3
CAN	OTH	Other North America	49	0.4
OTH	OTH	Other	81	0.5
ZIM	APL	Unki	0	0.6
RUS	NN	NN Russia	663	499.4
RSA	APL	Mototolo	111	550.3
RSA	APL	Kroondal	267	567.3
FIN	NN	NN International	15	602.4
RSA	APL	Modikwa	135	604.7
ZIM	IMP	Zimplats	177	654.5
ZIM	IMP	Mimosa	102	722.1
BOT	NN	Tati Nickel	14	773.9
RSA	ARM	Nkomati	7	814.9
RSA	RBP	Royal Bafokeng	187	870.0
RSA	ARM	Two rivers	143	877.3
CAN	SWL	Stillwater Company	111	981.3
RSA	IMP	Impala	900	1018.0
CAN	NAP	Lac Des Illes	5	1057.6
RSA	APL	Mogalakwena	272	1072.2
RSA	APL	Amandelbult	459	1109.2
RSA	APL	Union	304	1170.8
RSA	LON	Lonmin	701	1199.5
RSA	NHM	Northam	220	1274.4
RSA	IMP	Marula	70	1321.8
RSA	APL	Rustenburg	568	1375.1
RSA	SED	Pilanesberg	36	1980.1

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2014), (African Rainbow Minerals, 2013), (African Rainbow Minerals, 2010), (Impala Platinum Holdings, 2012), (Lonmin, 2013), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2012), (Northam Platinum, 2013), (Stillwater Mining Company, 2012), (Royal Bafokeng Platinum, 2012), (Sedibelo Platinum Mines, 2014), (Vale, 2011)

8.4 Data for 2011 Cost Curve

2011				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	174	0.0
RSA	OTH	Other RSA	608	0.1
RUS	OTH	Other Russia	163	0.2
ZIM	OTH	Other Zimbabwe	-1	0.3
CAN	OTH	Other North America	48	0.4
OTH	OTH	Other	76	0.5
RUS	NN	NN Russia	672	517.5
RSA	APL	Mototolo	115	640.7
RSA	APL	Modikwa	130	676.2
FIN	NN	NN International	12	697.8
ZIM	IMP	Zimplats	185	704.5
RSA	APL	Kroondal	218	740.2
ZIM	IMP	Mimosa	105	782.5
BOT	NN	Tati Nickel	12	884.1
RSA	ARM	Two rivers	148	938.2
RSA	ARM	Nkomati	9	944.2
CAN	SWL	Stillwater Company	119	952.9
RSA	RBP	Royal Bafokeng	183	960.4
RSA	APL	Mogalakwena	313	1152.8
RSA	IMP	Impala	841	1190.4
CAN	NAP	Lac Des Illes	9	1240.9
ZIM	APL	Unki	51	1241.3
RSA	APL	Amandelbult	446	1285.4
RSA	LON	Lonmin	709	1313.8
RSA	APL	Union	273	1363.8
RSA	IMP	Marula	70	1386.7
RSA	NHM	Northam	196	1484.5
RSA	APL	Rustenburg	561	1538.1
RSA	SED	Pilanesberg	42	2992.1

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2014), (African Rainbow Minerals, 2013), (Impala Platinum Holdings, 2012), (Lonmin, 2013), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2014), (Northam Platinum, 2013), (Stillwater Mining Company, 2016), (Royal Bafokeng Platinum, 2012), (Sedibelo Platinum Mines, 2014), (Vale, 2014)

8.5 Data for 2012 Cost Curve

2012				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	134	0.0
RSA	OTH	Other RSA	140	0.1
RUS	OTH	Other Russia	141	0.2
ZIM	OTH	Other Zimbabwe	-21	0.3
CAN	OTH	Other North America	43	0.4
OTH	OTH	Other	109	0.5
FIN	NN	NN International	9	616.9
RUS	NN	NN Russia	660	633.0
RSA	APL	Mototolo	124	722.2
BOT	NN	Tati Nickel	14	727.3
RSA	APL	Modikwa	130	730.6
ZIM	IMP	Zimplats	191	757.9
RSA	APL	Kroondal	223	802.6
RSA	ARM	Nkomati	12	833.9
ZIM	IMP	Mimosa	102	893.5
RSA	ARM	Two rivers	156	961.0
RSA	RBP	Royal Bafokeng	175	1080.2
CAN	NAP	Lac Des Illes	11	1187.3
RSA	APL	Mogalakwena	305	1225.6
RSA	LON	Lonmin	695	1305.3
CAN	SWL	Stillwater Company	118	1362.2
RSA	IMP	Impala	702	1424.9
RSA	NHM	Northam	204	1428.3
RSA	IMP	Marula	71	1449.9
RSA	APL	Amandelbult	369	1470.3
ZIM	APL	Unki	65	1478.0
RSA	APL	Union	213	1557.4
RSA	APL	Rustenburg	522	1633.7
RSA	SED	Pilanesberg	64	2469.9

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (Anglo American Platinum, 2014), (African Rainbow Minerals, 2013), (Impala Platinum Holdings, 2016), (Lonmin, 2013), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2014), (Northam Platinum, 2013), (Stillwater Mining Company, 2016), (Royal Bafokeng Platinum, 2014), (Sedibelo Platinum Mines, 2014), (Vale, 2014)

8.6 Data for 2013 Cost Curve

2013				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	145	0.0
RSA	OTH	Other RSA	251	0.1
RUS	OTH	Other Russia	109	0.2
ZIM	OTH	Other Zimbabwe	28	0.3
CAN	OTH	Other North America	43	0.4
OTH	OTH	Other	161	0.5
BOT	NN	Tati Nickel	7	619.9
RUS	NN	NN Russia	627	634.5
RSA	ARM	Nkomati	20	712.4
ZIM	IMP	Zimplats	215	740.2
FIN	NN	NN International	16	832.9
RSA	ARM	Two rivers	169	845.0
RSA	RBP	Royal Bafokeng	181	872.2
RSA	APL	Mogalakwena	341	920.5
ZIM	IMP	Mimosa	103	925.8
RSA	APL	Mototolo	125	995.2
ZIM	APL	Unki	64	1096.4
RSA	APL	Modikwa	118	1200.3
RSA	APL	Kroondal	246	1231.0
RSA	IMP	Marula	75	1272.9
RSA	LON	Lonmin	654	1277.7
RSA	APL	Amandelbult	361	1304.2
RSA	APL	Rustenburg	569	1321.8
CAN	SWL	Stillwater Company	120	1323.3
CAN	NAP	Lac Des Illes	10	1337.3
RSA	NHM	Northam	227	1374.9
RSA	IMP	Impala	597	1414.2
RSA	APL	Union	181	1484.9
RSA	SED	Pilanesberg	90	1868.9

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (Anglo American Platinum, 2014), (African Rainbow Minerals, 2017), (Impala Platinum Holdings, 2016), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2014), (Northam Platinum, 2018b), (Northam Platinum, 2013), (Stillwater Mining Company, 2016), (Royal Bafokeng Platinum, 2014), (Sedibelo Platinum Mines, 2014), (Vale, 2014)

8.7 Data for 2014 Cost Curve

2014				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	182	0.0
RSA	OTH	Other RSA	239	0.1
RUS	OTH	Other Russia	73	0.2
ZIM	OTH	Other Zimbabwe	17	0.3
CAN	OTH	Other North America	26	0.4
OTH	OTH	Other	96	0.5
RUS	NN	NN Russia	627	450.7
BOT	NN	Tati Nickel	4	542.6
FIN	NN	NN International	31	572.7
RSA	ARM	Nkomati	19	576.1
RSA	ARM	Two rivers	174	725.6
RSA	RBP	Royal Bafokeng	190	777.6
ZIM	IMP	Zimplats	212	778.6
ZIM	IMP	Mimosa	110	809.3
RSA	APL	Mogalakwena	370	921.8
CAN	NAP	Lac Des Illes	13	980.5
RSA	APL	Mototolo	122	1031.9
ZIM	APL	Unki	62	1069.3
RSA	IMP	Marula	76	1137.7
RSA	APL	Kroondal	256	1165.7
CAN	SWL	Stillwater Company	118	1200.6
RSA	APL	Modikwa	105	1270.8
RSA	NHM	Northam	248	1287.5
RSA	SED	Pilanesberg	106	1322.0
RSA	LON	Lonmin	473	1360.1
RSA	IMP	Impala	533	1453.7
RSA	APL	Amandelbult	214	1691.2
RSA	APL	Rustenburg	324	1785.1
RSA	APL	Union	88	2203.5

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (Anglo American Platinum, 2016), (African Rainbow Minerals, 2017), (Impala Platinum Holdings, 2016), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2016), (Northam Platinum, 2018b), (Stillwater Mining Company, 2016), (Royal Bafokeng Platinum, 2018), (Sedibelo Platinum Mines, 2016), (Vale, 2017)

8.8 Data for 2015 Cost Curve

2015				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	154	0.0
RSA	OTH	Other RSA	439	0.1
RUS	OTH	Other Russia	48	0.2
ZIM	OTH	Other Zimbabwe	-19	0.3
CAN	OTH	Other North America	32	0.4
OTH	OTH	Other	117	0.5
FIN	NN	NN International	33	261.9
RUS	NN	NN Russia	622	329.8
BOT	NN	Tati Nickel	1	491.2
RSA	ARM	Nkomati	20	511.7
RSA	ARM	Two rivers	180	614.8
RSA	APL	Mogalakwena	393	622.0
RSA	RBP	Royal Bafokeng	180	718.5
ZIM	IMP	Zimplats	238	723.2
ZIM	IMP	Mimosa	115	752.1
RSA	APL	Mototolo	115	858.8
RSA	APL	Amandelbult	430	925.9
ZIM	APL	Unki	67	926.1
RSA	APL	Kroondal	263	927.6
RSA	LON	Lonmin total	739	945.9
CAN	SWL	Stillwater Company	118	973.4
RSA	IMP	Marula	76	984.8
RSA	APL	Modikwa	105	991.0
RSA	NHM	Northam	262	1031.8
CAN	NAP	Lac Des Illes	12	1035.3
RSA	APL	Rustenburg	507	1115.4
RSA	IMP	Impala	631	1207.6
RSA	APL	Union	141	1218.0
RSA	SED	Pilanesberg	93	1772.1

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (Anglo American Platinum, 2016), (African Rainbow Minerals, 2017), (Impala Platinum Holdings, 2018a), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2016), (Northam Platinum, 2018b), (Stillwater Mining Company, 2016), (Royal Bafokeng Platinum, 2018), (Sedibelo Platinum Mines, 2016), (Vale, 2017)

8.9 Data for 2016 Cost Curve

2016				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	166	0.1
RSA	OTH	Other RSA	256	0.2
RUS	OTH	Other Russia	101	0.3
ZIM	OTH	Other Zimbabwe	17	0.4
CAN	OTH	Other North America	39	0.5
OTH	OTH	Other	139	0.6
BOT	NN	Tati Nickel	0	0.7
FIN	NN	NN International	22	185.1
RUS	NN	NN Russia	622	400.8
RSA	SGL	Platinum mile	9	532.8
RSA	ARM	Nkomati	15	537.0
RSA	APL	Mogalakwena	412	598.8
RSA	ARM	Two rivers	184	604.7
ZIM	IMP	Zimplats	281	627.3
RSA	RBP	Royal Bafokeng	196	636.1
CAN	SWL	Stillwater Company	122	647.5
ZIM	IMP	Mimosa	117	741.6
RSA	APL	Mototolo	117	798.2
ZIM	APL	Unki	75	798.6
RSA	APL	Kroondal	274	839.8
RSA	APL	Amandelbult	459	875.5
RSA	APL	Modikwa	115	893.4
RSA	APL	Union	151	935.5
RSA	LON	Lonmin total	659	946.7
RSA	NHM	Northam	272	948.7
RSA	IMP	Marula	73	1010.1
RSA	SGL	Rustenburg	456	1025.9
RSA	IMP	Impala	666	1090.5
CAN	NAP	Lac Des Illes	10	1133.7
RSA	SED	Pilanesberg	80	1312.5

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (Anglo American Platinum, 2017), (African Rainbow Minerals, 2017), (Impala Platinum Holdings, 2018a), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2018), (Northam Platinum, 2018b), (Sibanye-Stillwater, 2017b), (Royal Bafokeng Platinum, 2018), (Sedibelo Platinum Mines, 2018), (Vale, 2017)

8.10 Data for 2017 Cost Curve

2017				
Country	**Company**	**Site name**	**Production kOz Pt**	**Cost (Co-Prod) US$/oz Pt (nom.)**
CAN	VAL	Sudbury	144	0.0
BOT	NN	Tati Nickel	0	0.1
RSA	OTH	Other RSA	264	0.2
RUS	OTH	Other Russia	8	0.3
ZIM	OTH	Other Zimbabwe	-6	0.4
CAN	OTH	Other North America	94	0.5
OTH	OTH	Other	152	0.6
FIN	NN	NN International	10	177.2
RUS	NN	NN Russia	660	392.2
RSA	APL	Mogalakwena	464	505.8
RSA	ARM	Nkomati	20	540.7
RSA	SGL	Platinum mile	12	547.2
RSA	RBP	Royal Bafokeng	212	578.5
ZIM	IMP	Zimplats	273	614.4
RSA	ARM	Two rivers	174	628.7
ZIM	IMP	Mimosa	121	679.6
CAN	SGL	Stillwater	85	691.6
ZIM	APL	Unki	75	702.6
RSA	SED	Pilanesberg	99	713.6
CAN	NAP	Lac Des Illes	12	727.3
RSA	APL	Modikwa	127	834.1
RSA	APL	Kroondal	279	844.5
RSA	IMP	Marula	77	906.9
RSA	SGL	Rustenburg	473	928.5
RSA	APL	Union	155	952.3
RSA	APL	Amandelbult	438	963.1
RSA	LON	Lonmin total	643	965.4
RSA	APL	Mototolo	85	1004.7
RSA	NHM	Northam	265	1085.6
RSA	IMP	Impala	596	1175.2

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo SGL: Sibanye-Stillwater
NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (African Rainbow Minerals, 2017), (African Rainbow Minerals, 2018), (Impala Platinum Holdings, 2018a), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2018), (Northam Platinum, 2018b) (Northam Platinum, 2018a), (Sibanye-Stillwater, 2018) (Sibanye-Stillwater, 2017b) , (Royal Bafokeng Platinum, 2018), (Sedibelo Platinum Mines, 2018), (Vale, 2018)

8.11 Data for 2017 tonnes milled cost curve

2017				
Country	Company	Site name	Per Tonne Milled	
			Tonnes	Cost
			Mt	US$/t
CAN	VAL	Sudbury	4	0
BOT	NN	Tati Nickel	0	0
FIN	NN	NN International	8	17
RUS	NN	NN Russia	17	178
RSA	APL	Mogalakwena	14	48
RSA	ARM	Nkomati	8	25
RSA	SGL	Platinum mile	9	1
RSA	RBP	Royal Bafokeng	3	73
ZIM	IMP	Zimplats	7	60
RSA	ARM	Two rivers	3	60
ZIM	IMP	Mimosa	3	75
CAN	SGL	Stillwater	1	285
ZIM	APL	Unki	2	78
RSA	SED	Pilanesberg	4	33
CAN	NAP	Lac Des Illes	3	59
RSA	APL	Modikwa	2	110
RSA	APL	Kroondal	5	86
RSA	IMP	Marula	2	97
RSA	SGL	Rustenburg	13	58
RSA	APL	Union	3	96
RSA	APL	Amandelbult	7	105
RSA	LON	Lonmin total	10	111
RSA	APL	Mototolo	2	87
RSA	NHM	Northam	4	130

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo
SGL: Sibanye-Stillwater NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (African Rainbow Minerals, 2017), (African Rainbow Minerals, 2018), (Impala Platinum Holdings, 2018a), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2018), (Northam Platinum, 2018b) (Northam Platinum, 2018a), (Sibanye-Stillwater, 2018) (Sibanye-Stillwater, 2017b) , (Royal Bafokeng Platinum, 2018), (Sedibelo Platinum Mines, 2018), (Vale, 2018)

8.12 Data for 2017 tonnes milled margin curve

2017				
Country	Company	Site name	Margin	
			Tonnes	Cost
			Mt	US$/t
FIN	NN	NN International	8	75
RUS	NN	NN Russia	17	252
RSA	APL	Mogalakwena	14	43
RSA	ARM	Nkomati	8	19
RSA	SGL	Platinum mile	9	1
RSA	RBP	Royal Bafokeng	3	47
ZIM	IMP	Zimplats	7	33
RSA	ARM	Two rivers	3	31
ZIM	IMP	Mimosa	3	30
CAN	SGL	Stillwater	1	108
ZIM	APL	Unki	2	28
RSA	SED	Pilanesberg	4	11
CAN	NAP	Lac Des Illes	3	18
RSA	APL	Modikwa	2	16
RSA	APL	Kroondal	5	11
RSA	IMP	Marula	2	5
RSA	SGL	Rustenburg	13	2
RSA	APL	Union	3	0
RSA	APL	Amandelbult	7	-1
RSA	LON	Lonmin total	10	-1
RSA	APL	Mototolo	2	-4
RSA	NHM	Northam	4	-16

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo
SGL: Sibanye-Stillwater NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (African Rainbow Minerals, 2017), (African Rainbow Minerals, 2018), (Impala Platinum Holdings, 2018a), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2018), (Northam Platinum, 2018b) (Northam Platinum, 2018a), (Sibanye-Stillwater, 2018) (Sibanye-Stillwater, 2017b) , (Royal Bafokeng Platinum, 2018), (Sedibelo Platinum Mines, 2018), (Vale, 2018)

8.13 Data for 2017 6PGE cost curve

2017				
Country	Company	Site name	Per 6PGE	
			6PGE	Cost
			M oz	US$/oz
CAN	VAL	Sudbury	358	0
BOT	NN	Tati Nickel	0	0
RSA	OTH	Other RSA	369	0
RUS	OTH	Other Russia	-46	0
ZIM	OTH	Other Zimbabwe	-30	0
CAN	OTH	Other North America	361	1
OTH	OTH	Other	139	1
FIN	NN	NN International	52	-10048
RUS	NN	NN Russia	3466	-332
RSA	APL	Mogalakwena	1041	408
RSA	ARM	Nkomati	128	-426
RSA	SGL	Platinum mile	21	555
RSA	RBP	Royal Bafokeng	387	493
ZIM	IMP	Zimplats	565	574
RSA	ARM	Two rivers	371	539
ZIM	IMP	Mimosa	244	622
CAN	SGL	Stillwater	376	648
ZIM	APL	Unki	157	649
RSA	SED	Pilanesberg	157	717
CAN	NAP	Lac Des Illes	214	721
RSA	APL	Modikwa	322	734
RSA	APL	Kroondal	583	728
RSA	IMP	Marula	203	788
RSA	SGL	Rustenburg	793	942
RSA	APL	Union	307	830
RSA	APL	Amandelbult	853	850
RSA	LON	Lonmin total	1221	860
RSA	APL	Mototolo	183	877
RSA	NHM	Northam	513	967

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo
SGL: Sibanye-Stillwater NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (African Rainbow Minerals, 2017), (African Rainbow Minerals, 2018), (Impala Platinum Holdings, 2018a), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2018), (Northam Platinum, 2018b) (Northam Platinum, 2018a), (Sibanye-Stillwater, 2018) (Sibanye-Stillwater, 2017b) , (Royal Bafokeng Platinum, 2018), (Sedibelo Platinum Mines, 2018), (Vale, 2018)

8.14 Data for 2017 2PGE cost curve

2017				
Country	Company	Site name	Per 2PGE	
			2PGE	Cost
			M oz	US$/oz
CAN	VAL	Sudbury	358	0
BOT	NN	Tati Nickel	0	0
RSA	OTH	Other RSA	369	0
RUS	OTH	Other Russia	-46	0
ZIM	OTH	Other Zimbabwe	-30	0
CAN	OTH	Other North America	361	1
OTH	OTH	Other	139	1
FIN	NN	NN International	52	-10048
RUS	NN	NN Russia	3398	-413
RSA	APL	Mogalakwena	973	317
RSA	ARM	Nkomati	66	-1336
RSA	SGL	Platinum mile	19	476
RSA	RBP	Royal Bafokeng	308	465
ZIM	IMP	Zimplats	500	477
RSA	ARM	Two rivers	277	536
ZIM	IMP	Mimosa	217	535
CAN	SGL	Stillwater	376	648
ZIM	APL	Unki	139	566
RSA	SED	Pilanesberg	146	629
CAN	NAP	Lac Des Illes	214	643
RSA	APL	Modikwa	249	774
RSA	APL	Kroondal	426	796
RSA	IMP	Marula	155	860
RSA	SGL	Rustenburg	726	899
RSA	APL	Union	226	927
RSA	APL	Amandelbult	641	940
RSA	LON	Lonmin total	942	943
RSA	APL	Mototolo	138	985
RSA	NHM	Northam	394	1087

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo
SGL: Sibanye-Stillwater NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (African Rainbow Minerals, 2017), (African Rainbow Minerals, 2018), (Impala Platinum Holdings, 2018a), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2018), (Northam Platinum, 2018b) (Northam Platinum, 2018a), (Sibanye-Stillwater, 2018) (Sibanye-Stillwater, 2017b) , (Royal Bafokeng Platinum, 2018), (Sedibelo Platinum Mines, 2018), (Vale, 2018)

8.15 Data for 2017 Pt (net) cost curve

2017				
Country	Company	Site name	Pt(net)	
			oz	Pt
			M oz	US$/oz
CAN	VAL	Sudbury	144	0
BOT	NN	Tati Nickel	0	0
RSA	OTH	Other RSA	264	-347
RUS	OTH	Other Russia	8	5908
ZIM	OTH	Other Zimbabwe	-6	-3824
CAN	OTH	Other North America	94	-2482
OTH	OTH	Other	152	75
FIN	NN	NN International	10	-55924
RUS	NN	NN Russia	660	-5755
RSA	APL	Mogalakwena	464	-296
RSA	ARM	Nkomati	20	-6422
RSA	SGL	Platinum mile	12	262
RSA	RBP	Royal Bafokeng	212	280
ZIM	IMP	Zimplats	273	147
RSA	ARM	Two rivers	174	337
ZIM	IMP	Mimosa	121	264
CAN	SGL	Stillwater	85	-136
ZIM	APL	Unki	75	298
RSA	SED	Pilanesberg	99	513
CAN	NAP	Lac Des Illes	12	-3181
RSA	APL	Modikwa	127	676
RSA	APL	Kroondal	279	754
RSA	IMP	Marula	77	844
RSA	SGL	Rustenburg	473	911
RSA	APL	Union	155	952
RSA	APL	Amandelbult	438	971
RSA	LON	Lonmin total	643	975
RSA	APL	Mototolo	85	1053
RSA	NHM	Northam	265	1189

APL: Anglo American Platinum ARM: African Rainbow Minerals
IMP: Impala Holdings LON: Lonmin NAP: North American Palladium
RBP: Royal Bafokeng Platinum SED: Sedibelo
SGL: Sibanye-Stillwater NN: Norilsk Nickel VAL: Vale

Data compiled from company reports. (Anglo American Platinum, 2018), (African Rainbow Minerals, 2017), (African Rainbow Minerals, 2018), (Impala Platinum Holdings, 2018a), (Lonmin, 2018), (PJSC MMC Norilsk Nickel, 2018), (North American Palladium, 2018), (Northam Platinum, 2018b) (Northam Platinum, 2018a), (Sibanye-Stillwater, 2018) (Sibanye-Stillwater, 2017b) , (Royal Bafokeng Platinum, 2018), (Sedibelo Platinum Mines, 2018), (Vale, 2018)

8.16 Data for prices and exchange rates

		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
US CPI		4.9%	-1.2%	1.1%	3.5%	1.7%	1.7%	2.0%	0.2%	1.0%	1.6%
RSA CPI		6.8%	8.3%	4.8%	3.7%	4.8%	5.3%	5.7%	5.7%	5.8%	5.0%
Inflation factor US		1.12	1.14	1.12	1.09	1.07	1.05	1.03	1.03	1.02	1.00
Inflation factor RSA		1.61	1.49	1.42	1.37	1.31	1.24	1.17	1.11	1.05	1.00
Exchange rate nom.	ZAR/USD	8.25	8.44	7.32	7.25	8.21	9.65	10.84	12.75	14.71	13.31
Oil price nominal	US$/bbl Brent	72	97	61	80	111	112	109	99	52	44
Pt price nominal	US$/oz	1584	1212	1616	1725	1554	1490	1391	1060	994	953
Pd price nominal	US$/oz	357	266	532	736	645	727	810	696	618	875
Rh price nominal	US$/oz	6543	1596	2447	2022	1276	1066	1173	953	693	1105
Ir price nominal	US$/oz	485	425	650	1036	1070	826	556	543	576	897
Ru price nominal	US$/oz	323	95	199	166	112	75	65	47	42	75
Ni price nominal	US$/t	21111	14655	21809	22910	17548	15032	16893	11863	9595	10410
Cu price nominal	US$/t	6956	5150	7535	8828	7962	7332	6863	5510	4868	6170
Au price nominal	US$/oz	872	973	1225	1569	1670	1411	1266	1161	1249	1258
Ag price nominal	US$/oz	15	15	20	35	31	24	19	16	17	17
Co price nominal	US$/t	55000	44000	46200	37400	28471	27025	30675	28292	25675	57429
Exchange rate real	ZAR/USD	11.86	11.05	9.26	9.15	10.04	11.41	12.37	13.79	15.19	13.31
Oil price real	US$/bbl Brent	81	110	69	86	119	117	112	102	53	44
Pt price real	US$/oz	1777	1378	1816	1873	1660	1565	1431	1089	1010	953
Pd price real	US$/oz	400	302	598	799	689	763	833	715	628	875
Rh price real	US$/oz	7343	1813	2749	2195	1362	1119	1206	979	705	1105
Ir price real	US$/oz	544	483	731	1125	1143	867	572	558	585	897
Ru price real	US$/oz	362	108	223	180	120	79	67	49	42	75
Ni price real	US$/t	23690	16650	24503	24870	18738	15781	17381	12183	9753	10410
Cu price real	US$/t	7806	5851	8466	9583	8503	7698	7061	5659	4948	6170
Au price real	US$/oz	978	1105	1376	1703	1783	1482	1302	1192	1270	1258
Ag price real	US$/oz	17	17	23	38	33	25	20	16	17	17
Co price real	US$/oz	61720	49990	51908	40599	30403	28372	31560	29055	26098	57429

Note: Figures in red are estimates

(Johnson Matthey, 2018), (Index Mundi, 2018)

(Infomine, 2018), (Statistics South Africa, 2018)

(The Reserve Bank of South Africa, 2018),

(U.S. Bureau of Labor Statistics, 2018)

(U. S. Energy Information Administration, 2018)