Predicting Future South African Refined Copper Consumption Using the Intensity-of-Use Theory

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A nation's intensity of use (IoU) of a mineral product has been conventionally defined as the consumption of that particular product divided by its gross domestic product (GDP) per capita. A nation's intensity of consumption of a material or metal is expected to increase to a certain level, then plateau before tapering downwards, forming an inverted U shape, whilst GDP per capita increases. In contrast, a country's IoU of refined copper (intermediary product) is defined as the domestic consumption by first industrial users (firms) divided by its GDP. The resultant shape over time as GDP per capita increases is expected to be an everted U. It is in this respect that this paper models future consumption of refined copper in South Africa using the IoU theory. The model is based on data series from 1998 to 2016. During this period, the IoU in South Africa had a downward trend and was estimated that it will reach the zero level when the GDP per capital is USD 11,000, based on 2010 constant prices.

INTRODUCTION

Every sustainable market economy thrives on the basic concept of supply and demand. Supply refers to the quantities that the market can offer and demand represents the quantity and quality of a product desired by buyers; however, a good measure of usage is consumption, rather than demand, and good measures of quantities supplied are production output and inventory levels.

In the world of copper and when recycled copper is ignored, the entry point into the global market is the primary mine production, followed by refined copper production, then fabricated products, and finally end-consumer products. Each of these stages has their own sub-market dynamics driven by supply and demand.

When considering primary production, the copper data released by the International Copper Study Group (ICSG) (2017) showed that in the first seven months of 2017, the global mine copper production declined by approximately 2%. In the same time period, the concentrate production and solvent extraction–electrowinning output (processes leading to production of refined copper) also declined by 1.5% and 4.5%, respectively. Certain countries were highlighted as being responsible for the decline. For example, declines of 22% in Canada and 19% in Mongolia were due to lower grades in planned mining sequence; a ban on concentrate exports in the Indonesia from January to April resulted in 10% decline in its production; the world's biggest copper mine producing country (Chile) was badly affected by strike action at the Escondida and Codelco mines. These declines were offset by a 3% and 5% rise in Mexican and Peruvian concentrate output, respectively. A further decline was recorded on a regional basis that included a 3% reduction in Africa, 5% in America and 2% in Oceania, resulting in a 4.5% net global decline, despite a 3% and 2.5% increases in output in Asia and Europe, respectively.

On the global scale, mine production of copper in South Africa is relatively small, representing only 0.4% of global production in 2015. Although there are several smaller copper mining operations in South Africa, the significant primary producer of copper is Palabora Mining Company (PMC).

Notwithstanding, the essence of this paper is to cast a light on Africa as a significant global producer of primary copper, while it is an insignificant player in follow-up downstream activities, in particular refined copper consumption. For this purpose, the paper further provides insights in terms of growth trends using the Intensity of Use (IoU) hypothesis for South Africa, Zambia and the whole of Africa (inclusive of South Africa and Zambia), while using Chile and China as benchmarks.

COPPER VALUE CHAIN

It can be argued that there are three phases to the copper supply chain. The first stage consists of mined production, driven predominantly by mining of ores, then processing to produce copper concentrates from ores, and lastly followed by pyrometallurgy or hydrometallurgy to produce refined copper or primary copper for first-tier industrial consumers. The second stage consists of the conversion of refined copper into intermediary articles. The third stage consists of processed articles for input into high-end products for final consumption, characterised by markets shown in Figure 1.

According to the ICSG (2017), the estimated global reserves of copper stood at 720 million tonnes in 2016 while the global copper production was 20 million tonnes in the same year. This was a 5% increase from the 2015 global copper production.

For centuries copper has played an important role in the world economy and its consumption is expected to continue to rise. Copper is mainly consumed in the generation and transmission of electricity and in the transmission of information. As the global economy grows, with more people having access to electricity, electronic equipment and devices, the final consumption of copper is expected to rise by 22% within five years from 2017, according to the chairman of the Aditya Birla Group, due to increasing usage in electric vehicles, solar and wind power generation. The consumption is expected to continue growing beyond the five years to reach the level of 28 million tonnes in 2014 from 23 million tonnes in 2017 (Chaudhary & Afonso, 2017).

According to the ICSG (2017) and the Copper Development Association (CDA) (2017), the final consumption of copper in 2016 was attributed mainly to building and construction, manufacturing of electrical and electronic products, industrial machinery and equipment, transportation equipment and consumer and general products, as shown in Figure 1.

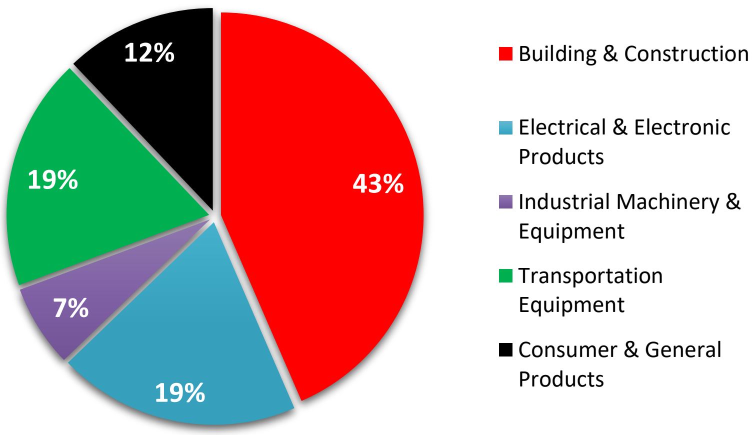


Figure 1: The distribution of global copper end-user market in 2016. Source: CDA (2017).

The participation of Africa in this supply chain is relatively low compared with other regions. For example, in 2016, the total African production of primary copper was 9% of the total global production. During the same period, Africa was a net exporter of refined copper, with very little consumed in the continent, as shown in Figures 2 and 3. Similarly, the copper end-user market in Africa is small, amounting to only 1% of global consumption (ICSG, 2017).

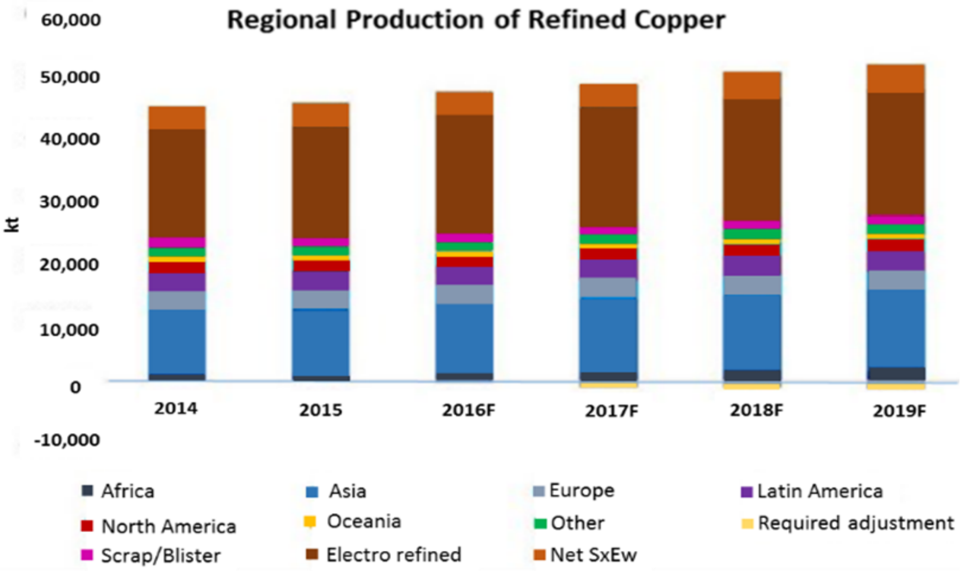


Figure 2: Regional actual and forecast production of refined copper. Source: Araneda (2017).

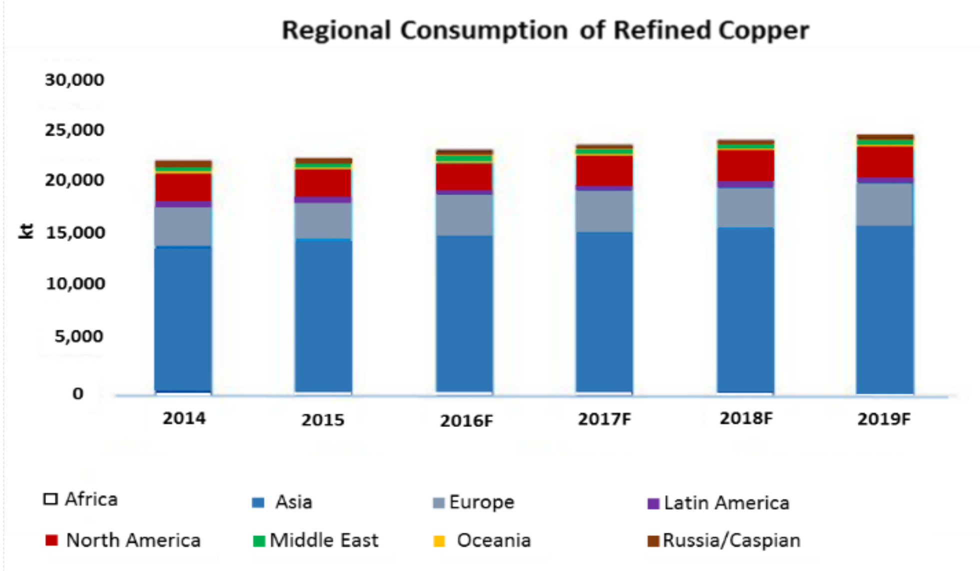


Figure 3: Regional actual and forecast consumption of refined copper. Source: Araneda (2017).

OVERVIEW OF COPPER MINING IN AFRICA

The mine production of copper in Africa has improved. With Zambia having re-privatised its mines and with a relatively more stable political environment emerging in the Democratic Republic of Congo (DRC), there have been extensive investments in the Copperbelt region to take advantage of the rising global demand for copper. Zambia was for a long time Africa's top producer of copper but in 2013 it was surpassed by the DRC and the latter in 2014 became the first African country to produce more than 1 million tonnes of copper. Figure 4 shows the relative dominance of DRC and Zambia on the African continent with respect to primary copper production (Sikamo *et al.*, 2016).

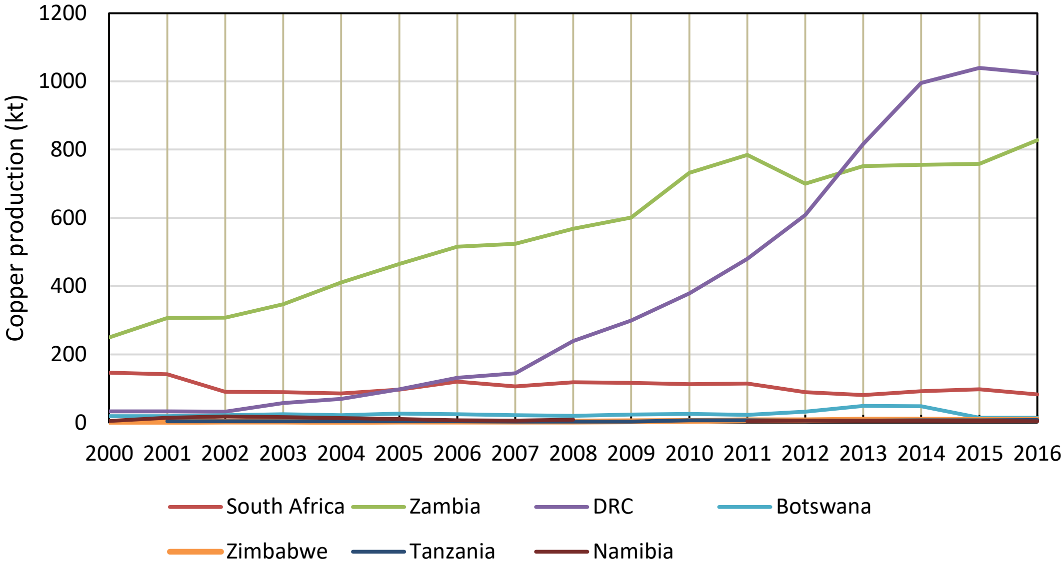


Figure 4: Africa mine copper production from 2000 to 2016. Data sources: Cochilco (2007, 2016).

According to Sikamo *et al.* (2016), Zambia first commercially produced copper in 1908 from Kansanshi mine, which led to a rise in exploration and subsequent copper production in the country. Copper production rose steadily peaking at 720 000 tonnes in 1969 shortly before the nationalisation of mines and thereafter decreasing to approximately 200 000 tonnes in the year 2000. Following the re-privatisation of the copper mines, production increased considerably to 763 800 tonnes in 2013; however, there was a marginal drop thereafter to 708 300 tonnes and 710 600 tonnes, respectively, in 2014 and 2015 due to reasons mentioned above (Sikamo *et al.*, 2016). In 2016, copper production reached 827 700 tonnes (Cochilco, 2016).

The majority of the copper mined in the DRC comes from the Katanga Province which lies to the south of the country in the Copperbelt region. According to the International Trade Administration (ITA) (2017), the DRC boasts one of the highest quality copper reserves in the world, estimated to contain grades above 3%, significantly higher than the global average of 0.6–0.8%.

The unstable political environment in the DRC before the 1990s led to a low and declining copper production. Efforts by the government to privatise mines in 1995 and the emergence of political tolerance attracted foreign investment in the country. In 2001 copper production was at a low 38 000 tonnes (KPMG Global Mining Institute, 2014). Over the years, production increased substantially, reaching production levels of 1 039 000 tonnes and 1 023 700 tonnes in 2015 and 2016, respectively (Cochilco, 2016).

In South Africa, copper production has been declining due to some mines approaching the end of their production lives and lack of investment into new projects. As a result, the country's copper production declined from a peak of 116 973 tonnes in 2007 to 65 257 tonnes in 2016 (Cochilco, 2016). Majority of South African copper comes from PMC, situated in the north-eastern part of the country in Limpopo Province. In addition, smaller amount of copper is produced by platinum mines as a by-product (Breytenbach, 2014; Chamber of Mines of South Africa, 2017). The production from other African countries in comparison with the DRC, Zambia and South Africa is small, as can be observed in Figure 4.

INTENSITY-OF-USE THEORY

The intensity of use (IoU) of a mineral product is defined as the quantity of consumption per gross domestic product (GDP) per capita (Magee and Devezas, 2017). According to Crowson (2017), the hypothesis is widely used both as an explanation of trends in materials consumption over time and as a predictive tool.

The concept of IoU was first introduced in the 1950s by Harold J Barnett for the ratio of total energy inputs to national economic output (Roberts, 1985). In his work, Barnett (1950) separated energy uses into several homogenous industry groups and used their projected growth and energy consumption patterns to make energy consumption forecasts. Barnett (1950) realised that between 1918 and 1948, the British thermal unit (BTU), a measure of the quantity of energy equivalent to 1055 J, grew from the year 1918, fluctuated between the years 1918 and 1941, and thereafter rose again during the early years of World War II. To explain this effect, Barnett (1950) speculated that the movements in the different forms or energies per unit of national product are influenced by improvements in technology, substitutions among the finished commodities and changes in the product mix of national product. Although Barnett (1950) concluded that the aggregate amount of energy used is determined by the level of economic activity, he did not, however, use the IoU to forecast consumption directly but used time and economic growth in his forecasting model.

In the 1960s, using the disaggregated industry groupings, Schurr and Netschert (1960) (cited in Roberts, 1985) noticed the inverted U-shape pattern of the IoU. In line with Barnett (1950), they concluded that the country's IoU of energy increased rapidly during periods of industrialisation and declined during times of technical efficiencies, as observed in the rapid industrialisation of the 1920s and beyond.

The IoU theory was first formally introduced by the International Iron and Steel Association in the 1970s and it was Wilfred Malenbaum who popularised the theory after conducting empirical studies of IoU for multiple countries around the world (Roberts, 1985). The hypothesis is a simple model that can be used to make long-term forecasts for the demand for metal. The IoU hypothesis is a function of per capita income expressed as:

$$\text{IoU} = \text{Consumption}/(\text{GDP}/\text{capita}). \qquad [1]$$

The premise of the theory is that demand or use of metal increases as a nation transitions from an agricultural economy to an industrial economy, then the rate of intensity of use decelerates towards a vertex point during the industrial phase of the economy, and then declines as the economy moves into the services-dominated phase. The transition from an agricultural-dominated to a service-dominated economy correlates with an increase in per capita income of the nation.

The IoU theory has, over the years, been used in the consumption analysis of various metals, such as copper, aluminium, lead, zinc, nickel and steel. It is a measure that indicates the intensity of final consumption, which, in the case of copper, will be the end-user market, as indicated in Figure 1.

With respect to refined copper, the IoU is applied to measure the intensity of consumption thereof by first-tier or industrial producers that ultimately supply subsequent markets with fabricated products (ICSG, 2017). This is different from the traditional IoU of copper, which measures the final consumption per capita income. The ICSG (2017) expresses the refined copper IoU as follows:

$$\text{IoU} = \text{Refined copper consumption (metric tonnes)}/\text{GDP (USD bln)}. \qquad [2]$$

The intensity of consumption of refined copper can also be viewed as an indication of connectedness of various sectors of the economy along the copper value chain. The strong intra-country connectedness brings about longer chains of downstream activities or forward linkages and ultimately higher industrial value added. Ideally, copper-producing countries should have stronger and entrenched domestic industrial consumers along the copper value chain, possible even significant domestic end-user market complemented by exports of final products.

In South Africa, mineral downstream processing has four official stages; namely, primary, secondary, tertiary and final (Robinson and von Below, 1990). The unit value of the mineral in a product increases from primary to the tertiary stage, where the latter is largely focused on the production of high-end products for final consumption. All of these four stages are generally not undertaken in many resource-rich countries in Africa, due to domestic constrains, and they thereby opt to export prematurely. The production of refined copper is equivalent to secondary stage of beneficiation.

The DRC and Zambia are two of the prominent producers of refined copper in Africa. In Zambia, refined copper contributed 57% to the export account valued at USD 9.25 billion in 2015 and very little was consumed locally (Observatory of Economic Complexity (OEC), 2018a). Similarly, refined copper contributed 47% to the DRC's export account, valued at USD 5.69 billion in 2015, and again very little was consumed locally (OEC, 2018b). South Africa is a relatively distant third-largest producer of refined copper in Africa, but it is the continent's biggest consumer thereof. Africa, in general, is the lowest regional consumer of refined copper globally (see Figure 3).

Figure 5 shows the IoU of refined copper of China, Chile, South Africa, Zambia and that of combined African countries (Total Africa). The IoU of refined copper was determined on the basis of the 2010 USD constant prices covering a period from 1998 to 2016. It can be noticed that the IoU in all countries except for China appears to trend downwards as GDP per capita increases. This can partially be explained by the strong consumption of refined copper by China in relation to other countries in Figure 5 between 1998 and 2016, as shown in Figure 6.

During the said period, China's average 13% growth rate of refined copper consumption was greater than its average 9% GDP growth rate when measured in 2010 USD constant prices. Other countries' GDP growth rates were higher than their respective refined copper consumption. In fact, average consumption rates of South Africa, Zambia and Chile over the same period were -2%, -0.1% and 0% against GDP growth rates of 3%, 0% and 4%, respectively. Zambia experienced a surge in consumption of refined copper between 2006 and 2009, followed by a sharp decline of 47% in 2010. This resulted in a spike in its IoU. Data for Total Africa from 1998 to 2003 and from 2014 to 2016 were not obtained, but for a period between 2004 and 2013 total Africa's IoU was also trending downwards. Consumption data for DRC were not obtainable.

PREDICTIVE MODEL FOR SOUTH AFRICA

According to the theory, IoU of a country over time follows an inverted parabola, defined by a quadratic function of the following form (Warrell and Olsson, 2009):

$$IoU = -aY^2 + bY + c, \quad [3]$$

where Y is GDP per capita, with a, b, and c being parameters of the model and a is not equal to zero. With this equation, it is conceivable that, at some point in the past, IoU was zero and, at some point in the future, it will be zero. That being the case, it can then be expected that the discriminant in Equation 3 will take the following form:

$$b^2 - 4ac > 0. \quad [4]$$

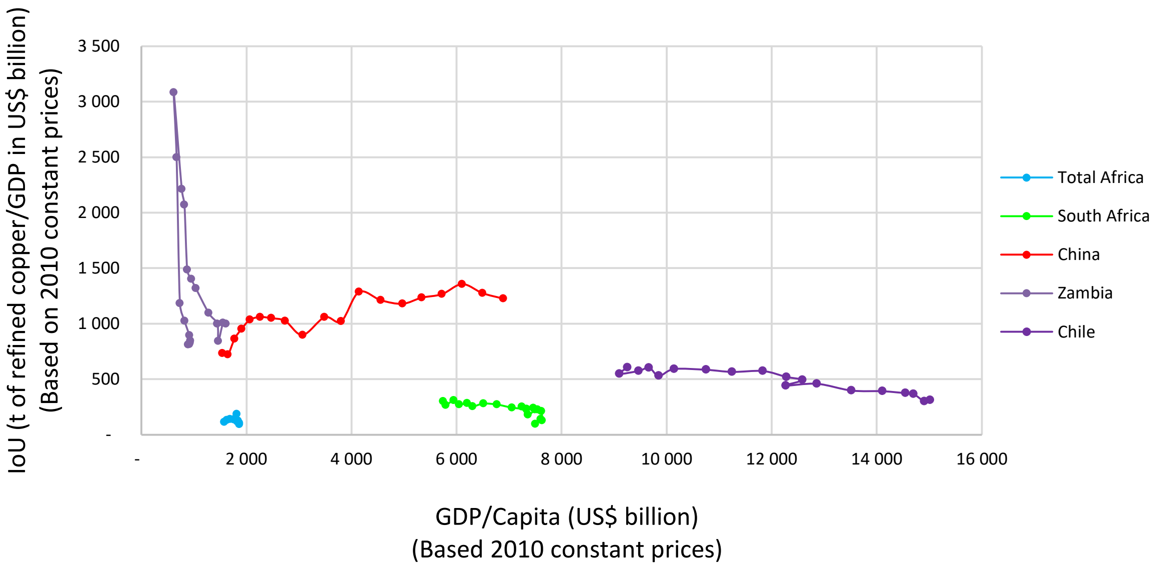
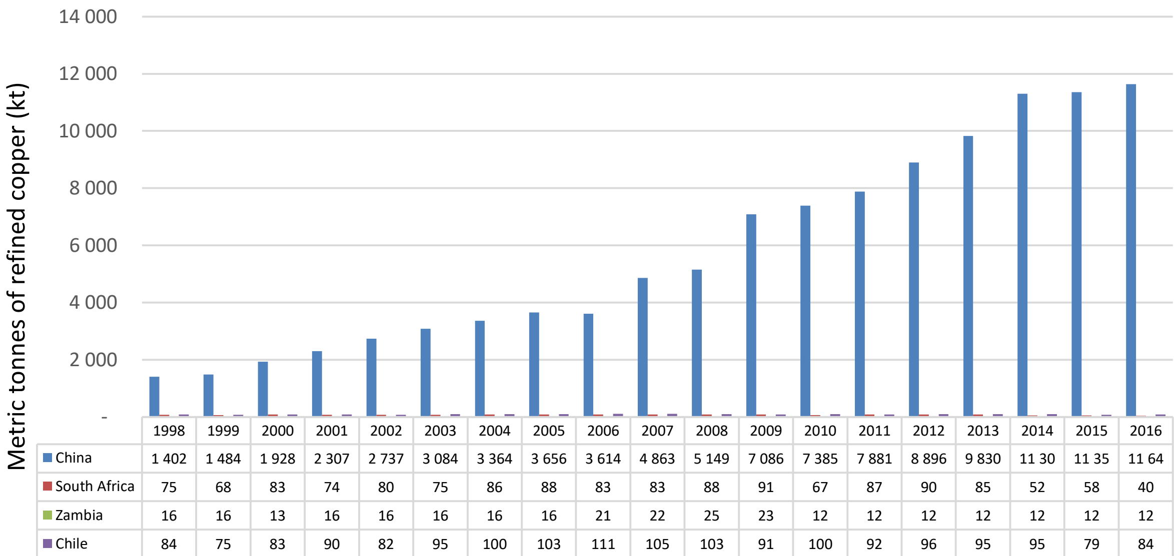


Figure 5: Refined copper IoU of selected countries and that of all African countries. Data sources: Cully (2014); Chamber of Mines of South Africa (2017); The World Bank (2018); and USGS (2018).



	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
China	1 402	1 484	1 928	2 307	2 737	3 084	3 364	3 656	3 614	4 863	5 149	7 086	7 385	7 881	8 896	9 830	11 30	11 35	11 64
South Africa	75	68	83	74	80	75	86	88	83	83	88	91	67	87	90	85	52	58	40
Zambia	16	16	13	16	16	16	16	16	21	22	25	23	12	12	12	12	12	12	12
Chile	84	75	83	90	82	95	100	103	111	105	103	91	100	92	96	95	95	79	84

Figure 6. Refined copper consumption of China, Chile, South Africa, Zambia and that of combined African countries (Total Africa) between 1998 and 2016.

To construct an IoU model based on Equation 3, time-series data for South Africa, China, Zambia and Chile were used. The results from the model are shown in Table I and the relationship between the IoU of refined copper and GDP per capita of the selected countries is shown in Figure 7. It can be noticed that R^2 values for all countries are close to 1, implying that parameters of the model closely represent the actual time-series data. It can also be noticed that the value of the discriminant is greater than zero and a has a negative value for all countries except for China, implying that the model in the case of the latter will not be an inverted parabola, therefore not conforming to the expected outcome between the 1998 and 2016 time period. This means that China did not reach or go past its peak IoU in the said period.

Table I: Parameters of model to predict future consumption of refined copper for selected countries.

Parameters	South Africa	China	Zambia	Chile
$\boldsymbol{a}$	−0.00005	0.000002	−0.00009	−0.000008
$\boldsymbol{b}$	0.624	0.984	1.211	0.160
$\boldsymbol{c}$	−1644.30	−25.11	−168.81	−175.36
$\boldsymbol{b^2 - 4ac}$	0.06	0.97	1.41	0.02
R^2	0.8325	0.9998	0.9977	0.9371

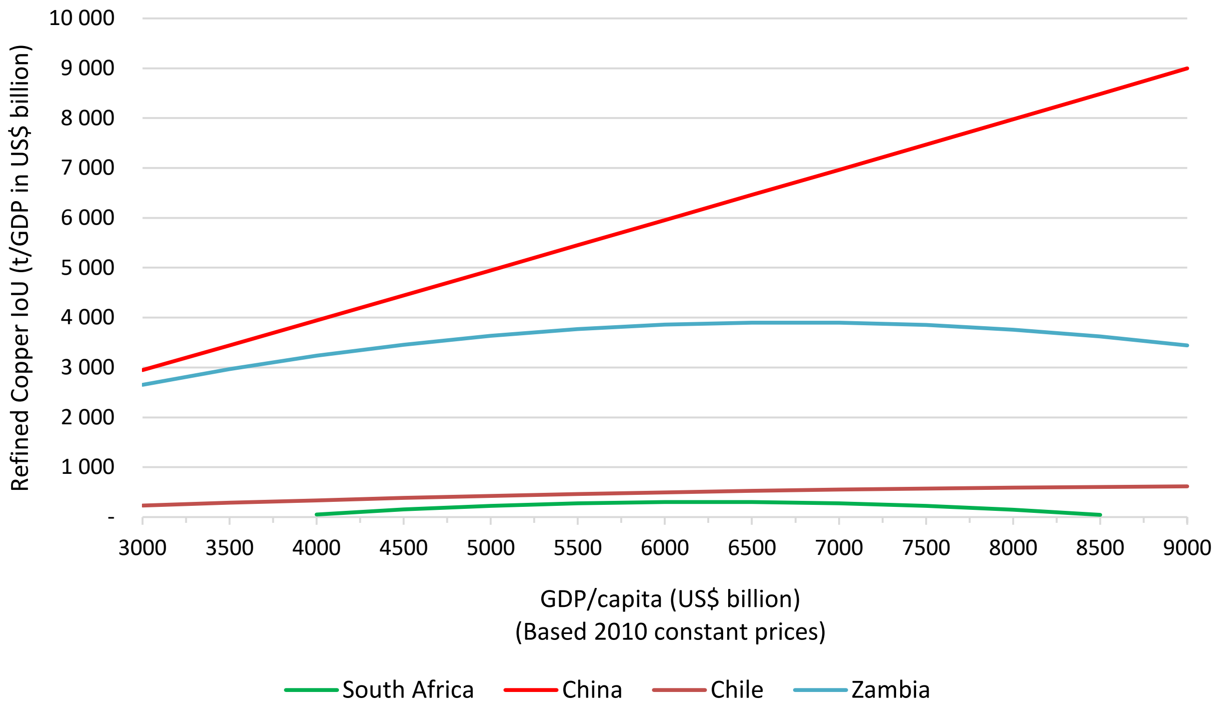


Figure 7: Results of predictive model for four countries. (Data sources: Cully, 2014; Chamber of Mines of South Africa, 2017; The World Bank, 2018; USGS, 2018; Cochilco, 2007; Colchilco, 2016.)

In the case of South Africa, the model predicted that when Y is between 4000 and 8500, the IoU of refined copper will be greater than zero, while before 4000 and beyond 8500 there will be none. With South Africa's industrial activity stretching as far back as in the 1920s and copper mining going back further than that, it is unlikely that the scenario painted by the model is a true reflection of market activity. A view taken was that with the entrenched industrial activity of South Africa in the past, the zero consumption of refined copper when Y was between zero and 4000 has to be rejected (this range coincided with a period of import substitution). Therefore, it was necessary to adjust the model.

In the adjusted model, the value of c was set to zero with the hypothesis that when Y is zero (a condition where there is no industrial activity), then IoU will be zero. Given that the peak IoU in the time-series data was 300 tonnes of refined copper/GDP (USD billion) when GDP per capita (Y) was between 5000 and 6000, this was taken as the vertex in the adjusted model. With these conditions, new parameters of the South African model were generated and are shown in Table II.

According to the revised model (see Figure 8), the South African IoU of refined copper peaks at 300 tonnes of refined copper/GDP (USD billion) when the Y value is between 5000 and 6000 and will be nil at a Y value of 11 000. This is somewhat supported by the annualised 12% decline in the actual consumption of refined copper in South Africa from 90 kt in 2012 to 40 kt in 2016. If it is hypothesised that the GDP per capita over time in South Africa will rise, it is then conceivable that GDP per capita will reach the Y value of 11 000 in the future, at which South Africa's industrial consumption of refined copper will be zero. This being the case, it is likely that the revised model is correct and reflective of the trend in the usage of refined copper by industries (first-tier users) in South Africa. It should, however, be noted that IoU, as discussed in this paper, flows from mine production and has not taken into account the recycled scrap copper.

Table II: Parameters of the model to predict future consumption of refined copper for South Africa.

Parameters	South Africa
$\boldsymbol{a}$	−0.00001
$\boldsymbol{b}$	0.11
$\boldsymbol{c}$	0
$\boldsymbol{b^2 - 4ac}$	0.01
R^2	0.7769

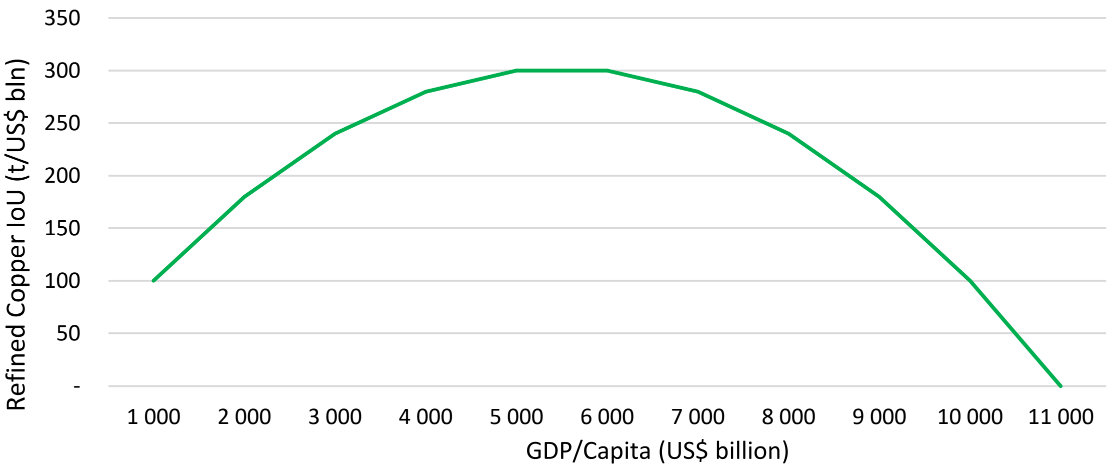


Figure 8: Results of the revised predictive model for South Africa.

CONCLUSION

In this paper, it has been demonstrated that Africa is a significant producer of refined copper while at the same time it is an insignificant consumer thereof. Refined copper is consumed largely by firms producing intermediary products, mainly in the industrial sector of the economy. This then implies that the industrial sectors of African economies are not intensive users of refined copper relative to other regions such as Asia. China was shown to have a positive annual growth trend of IoU of refined copper, underpinned by strong consumption of refined copper; while South Africa, Zambia, Chile and Africa in general have a downward trend of IoU. The DRC and Zambia are the largest producers of primary copper on the African continent, with Zambia currently being the biggest producer of refined copper, but South Africa is the largest consumer of refined copper on the African continent.

The paper presented a model that predicted future South African IoU of refined copper. The original model, while conforming to the IoU theory, was rejected on the basis that it was perceived not to reflect the historical long-term consumption of refined copper in South Africa. It was therefore necessary to adjust the original model. The adjusted model predicted that South Africa will have zero IoU of refined copper at 11 000 GDP per capita (USD billion). The prediction of the revised model is somewhat supported by the average 12% decline in the consumption of refined copper between 2012 and 2016.

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