The time-varying elasticity of South African electricity demand: 1980–2018

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Abstract

This study estimates the price and income elasticity coefficients of domestic South African electricity demand for the period 1980 to 2018, considering both the aggregate economy as well as the mining sector in isolation. South African electricity prices were falling in real terms between 1983–2005. It then increased sharply in response to substantial tariff increases between 2008–2011. A time-varying parameter model with the Kalman filter is applied to estimate the evolution of the elasticities over time. This allows the analysis to distinguish between the two regimes of decreasing and increasing real electricity prices, and evaluate the evolution of demand elasticities accordingly. The main result, consistent with existing South African literature, is that electricity consumption was unresponsive to price changes in the period of falling real electricity prices up to 2005. However, when real prices started increasing, the price elasticity coefficient increased markedly in absolute terms. This indicates that price sensitivity is notably higher when real prices are increasing. A secondary result is that electricity consumption in the mining sector, due to the inertial nature of mining operations, is much less responsive to price changes.

1 Introduction

After more than 20 years of falling real South African electricity prices, real prices have started increasing since 2006, with a very sharp rise since 2008. The real electricity price has fallen by 38% from around 50 c/kWh in the early 1980s to 31 c/kWh by 2005. However, it then climbed to 83 c/kWh by 2018, representing a real price increase of 168% in just 13 years (DME, 2019). Eskom,[1]

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[1] Eskom generates approximately "90% of the electricity used in South Africa, and about 40% of the electricity used in Africa" (DME, 2019:32).

the South African electricity utility, applied for significant tariff increases to compensate for the deep financial and operational difficulties it finds itself in. In 2007 and 2008, South Africa experienced significant shortages in electricity supply,[2] which culminated in the first rolling rotational blackouts. Rotational blackouts aim to ration electricity supply through the country in order to prevent the full demand load from catastrophically collapsing the entire grid.[3] By this time it had become clear that Eskom needed to expedite its generation capacity expansion programme. It needed significant increases in revenue to build a sizeable balance sheet, which could be used as leverage for borrowing the capital required to finance urgent and crucial capital expansion. To this end, Eskom applied for substantial tariff increases with the National Energy Regulator of South Africa (NERSA). After the first Multi-Year Price Determination (MYPD) programme was launched in 2005, these tariff applications were publicly known around a year before they were approved and implemented, following several rounds of negotiation between Eskom and NERSA. NERSA cannot ignore Eskom's pleas for substantial tariff increases: Eskom is the monopoly supplier of South African electricity, and a sustainable supply of electricity is critical for the economy. If Eskom collapses the South African economy will likely follow suit. Conversely, burdening Eskom's customers with excessive tariff increases runs the risk of customers substituting away from Eskom and into other sources of energy.

Eskom finds itself between a rock and a hard place. On the one hand, it seeks substantial electricity tariff increases to alleviate its precarious financial position. On the other hand, if tariff increases are too high it might push electricity consumers towards substitute energy sources. This could include 'green' initiatives such as wind or solar power, or the construction of self-generating capacity.[4] Price increases which are so high that it pushes a critical mass of consumers away from Eskom would perversely decrease Eskom's total revenue, thus hampering its ability to (a) service its existing debt and (b) invest in maintenance and additional generation capacity. Therefore, electricity price policy makers have to be mindful of both the grid price level and the price and tariff structure. If a correct price structure is not put in place, the utility could experience a self-induced death spiral. As Parsons et al. (2015:3) point out, "the fall in electricity consumption (or users switching to other sources of energy supply permanently because of cost or supply uncertainties), [could cause] Eskom's finances [to] further deteriorate, thus ostensibly requiring further tariff increases." High prices, coupled with unreliable electricity supply, "are powerful incentives for its customers to exit Eskom and not return" (Parsons et al., 2015:5).

For this reason, the price elasticity of electricity demand (E_p) is a crucial consideration when tariff increases are considered. If the demand response is

[2] This is attributed mainly to insufficient generation capacity due to Eskom's ageing and poorly maintained fleet of power stations, and failed construction of new power stations.

[3] Blackouts returned in 2014, 2015, 2018, 2019 and 2020

[4] The South African government has itself signalled its intent to make this easier by lowering some of the barriers associated with self-generation (RSA, 2020).

inelastic (0< $|E_p|$ <1), an increase in price would likely result in an increase in revenue from electricity sales. However, if the demand response is *elastic* ($|E_p|$ >1), an electricity price increase could result in a decrease in revenue, further straining the utility's financial position. Therefore, knowledge of the 'true' price elasticity of demand is of paramount importance when tariff applications and decisions are considered, in order to gauge and forecast the impact price changes would have on electricity demand. However, South African literature on the topic is somewhat dated. The most recent data considered in estimating the price elasticity of electricity demand is from 2007 (Amusa et al., 2009). Comparable studies' – e.g. Inglesi-Lotz (2011) and Kohler (2014) – samples end in 2005 and 2007 respectively. These studies have in common that they find either an insignificant or very small role for electricity prices to explain electricity demand. However, these studies were all done across a period of *falling* real electricity prices, which suggests that the demand response to price changes were likely muted.

The main contribution of this paper is therefore to extend the analysis of previous studies in the South African context into a period of sharply-increasing real electricity prices and to gauge the impact of the recent price increases on electricity demand. In addition, elasticities are bound to change over time, as economic conditions, preferences, technology and the regulatory environment change. To this end, the Kalman filter approach is employed here to estimate the evolution of demand elasticities over time. This is especially pertinent in the face of recent sharp increases in real electricity prices, which represents a structural shift away from the preceding regime of falling real prices. Because income or wealth is also viewed as a notable determinant of electricity demand (Wang and Mogi, 2017), the analysis also considers the income elasticity of electricity demand. Finally, it should be noted that, while a small portion of Eskom's generated electricity is exported and therefore subject to different pricing agreements, this paper only considers domestic electricity prices and demand.

Secondly, this paper considers the unique role of the mining sector in the South African energy space. In a resource-based economy, mining enterprises are typically some of the electricity utility's biggest customers. Since 2000, the mining sector has accounted for between 14–18% of total electricity consumption, although it earlier consumed as much as 30% of total electricity supplied in 1980 (Eskom, 2019). The benefits to the utility are security and predictability of demand, and long-term institutional contracts. Conversely, the absence of such a significant demander of electricity complicates the utility's ability to efficiently plan and supply its electricity. Furthermore, only a limited amount of literature on the price elasticity of electricity demand in the mining sector exists, both in South Africa and internationally. Historically, electricity demand in this sector has been considered to be inflexible due to its capital intensity and long-term nature of its operations. However, the advent of distributed generation (DG)[5]

[5] Distributed generation refers to small-scale on-site generation and storage of electricity. It also follows that as the technology around DGs develops their costs are likely to decrease.

has ushered in new flexibility in the mining sector's electricity demand profile. Therefore, because the mining sector is expected to become more sensitive to electricity price increases, this study is an early contribution towards a body of knowledge that will be acquired as the proliferation of self-generation technologies increases.

The paper is organised as follows: Section 2 provides an overview of the theoretical and empirical literature on local and international studies estimating electricity demand elasticities. The data and econometric approach are presented in Section 3, with the aggregate results discussed in Section 4. Section 5 investigates the mining sector's electricity demand profile and elasticities in depth. This in itself fills a notable gap, as the majority of existing literature consider *aggregate* – and not *sectoral* – elasticities. Section 6 concludes.

2 Literature review

Numerous international studies have considered the impact of price changes on electricity demand and consumption. The vast majority of these studies follow a fixed-parameter methodology, either variations on ordinary least-squares (OLS) techniques such as cointegration or the auto-regressive distributed lag (ARDL) approach, or panel estimations. Examples in this category include, chronologically, Von Hirschhausen and Andres (2000), Al-Faris (2002), Kamerschen and Porter (2004), De Vita et al. (2006), Ghaderi et al. (2006), Atakhanova and Howie (2007), Amarawickrama and Hunt (2008), Hosoe and Akiyama (2009), Athukorala and Wilson (2010), Bianco et al. (2010), Dilaver and Hunt (2011), He et al. (2011), Ziramba and Kavezeri (2012), Blázquez et al. (2013), Egorova and Volchkova (2013) and Campbell (2018).[6] Notable exceptions to the fixed-parameter paradigm are Arisoy and Ozturk (2014), Wang and Mogi (2017) and Tiwari and Menegaki (2019), in which time-varying methodologies are applied to analyse the evolution of price and income elasticities for electricity demand in, respectively, Turkey, Japan and India.

In the South African literature, Pouris (1987), Blignaut and De Wet (2001), Ziramba (2008), Amusa et al. (2009), Inglesi (2010), Inglesi and Pouris (2010), Inglesi-Lotz and Blignaut (2011) and Kohler (2014) have all estimated fixed-parameter models. To date only a single study by Inglesi-Lotz (2011) applied a time-varying Kalman filter approach, utilising data up to 2005. Selected results from the South African literature are summarised in Table 1. South African studies generally find a very small, and often statistically insignificant, price elasticity. Income elasticities are usually significant, which suggests that income – and not prices – is the main determinant of electricity demand.

The main shortcoming in the current South African literature, however, is the fact that the most recent data considered is dated 2007. By 2005 South African real electricity prices started rising. Between 2008–2011 the increases

In the long term the utility could therefore face some increased competition from DGs as their costs decrease and the grid price increases.

[6] A detailed summary of recent literature is provided by Tiwari and Menegaki (2019).

were quite sharp (a nominal increase in excess of 25% each year against average inflation of 6.9% over the same time). The historically low levels of real electricity prices (1980–2005, see Figure 1 below) has likely induced a lack of demand responsiveness to price changes, which is borne out by the small and often insignificant price elasticities estimated for South Africa over the same time (Table 1). The sample periods in the most recent South African studies stop right before real prices started to increase. The main contribution of this paper is therefore to extend the sample of the existing South African literature into a period of sharply-increasing real electricity prices and to gauge the impact of these recent price increases on electricity demand. In addition, while the majority of these studies considered *aggregate* electricity demand, only some have performed disaggregated analyses. Blignaut and De Wet (2001) considered the manufacturing sector, while Ziramba (2008) concentrated on residential demand. Inglesi-Lotz and Blignaut (2011) and Kohler (2014) are the only detailed studies considering various sectors. We therefore identify this lack of sectoral analysis, specifically on the South African mining sector, as an additional shortcoming in the current literature, and duly consider this further in Section 5.

3 Data and methodology

3.1 *Data*

Electricity demand is approximated by total electricity sales, measured in gigawatt-hours (GWh), as reported in Eskom's Annual and Statistical Reports (Eskom, 2005) and Integrated Reports (Eskom, 2019). The Department of Minerals and Energy reports both averaged and disaggregated nominal electricity prices in terms of cents per kilowatt-hour (c/kWh) in their Energy Price Reports (DME, 2019). From here we source the electricity prices for both the aggregate economy and the mining sector. Since electricity prices are not always uniform, and subject to mid-year adjustments or differential tariff structures, prices are reported as average prices for a given year. *Real electricity prices* are calculated by deflating the average annual nominal prices by the CPI index (StatsSA, 2018). *Income* is measured by annual real GDP figures, obtained from the South African Reserve Bank's Quarterly Bulletin (SARB, 2020). All variables are in natural logarithms. Descriptive statistics are summarised in Table A1.

Figure 1 presents the evolution of electricity prices since 1980. Real electricity prices had been decreasing from 1983 until 2005. While 2006 and 2007 saw moderate increases in price, nominal prices increased by more than 25% per year between 2008–2011. Figure 2 shows a positive correlation between electricity consumption and real GDP, confirming that as an economy's output or income grows it consumes more electricity. However, there appears to be a decoupling in this relationship around 2008 as output kept increasing while electricity consumption started decreasing.[7]

[7] In 2005 Eskom changed its financial year end from December to March. This resulted in a spike in the reported data on electricity consumption for 2005.

3.2 *Kalman filter*

The majority of existing studies estimating electricity elasticities follow a fixed-parameter methodology (see Section 2). However, OLS estimations are invalid in cases where parameters are expected to change over time. In this context it could be the result of structural changes in economic conditions, technological advancement, regulation and so forth. Under such conditions, fixed parameters would represent the *average* elasticity over the sample. This type of aggregation obviously runs the risk that dynamic and relevant information is lost. An additional drawback of OLS models is its inability to simultaneously treat stationary and non-stationary data. While the ARDL approach allows stationary and non-stationary variables to be simultaneously considered, it still remains unable to estimate time-variant parameters. In such environments the Kalman filter is a superior modelling approach. The Kalman filter allows the assumptions of stationarity to be relaxed (Morrison and Pike, 1977). Crucially, it allows for time-varying parameters to be estimated.[8] And, in the event that parameters do, in fact, remain stable over the sample, the Kalman filter produces similar estimates to OLS models (Morrison and Pike, 1977). For this reason, a move towards time-varying approaches is visible in the more recent international literature.

The Kalman filter (1960) is one specification of state-space models, which has its origin in the fields of physics and engineering. The general idea behind state-space models is that "an observed . . . time series y_t...depends upon a possibly unobserved state z_t which is driven by a stochastic process" (Lütkepohl, 2005:611). The relationship between y_t and z_t can be described by the *measurement* equation $y_t = \mathbf{H}_t z_t + \quad v_t$, with the state vector generated as $z_t = \mathbf{B}_{t-1} z_{t-1} \quad + \quad w_{t-1}$. The state vector is a first-order autoregressive process which describes the transition of the state of nature from time $t-1$ to time t, and is therefore called the *transition* equation (*Ibid.*). In this analysis, electricity demand (consumption) represents the observed variable y_t, while the state vector z_t consists of the (possibly unobserved) preferences and factors which govern electricity demand.

Given the observations of y_t, the Kalman filter "provides estimates of the state vectors and measures of the precision of these estimates" (Lütkepohl, 2005:612). The generalised state-space model for the Kalman filter approach can be presented as follows (Lütkepohl, 2005:625):

Measurement (observation) equation:

$$\mathrm{y}_t = \mathbf{H}_t \mathrm{z}_t + \mathbf{G} \mathrm{x}_t + v_t$$

Transition (system) equation:

$$z_t = \mathbf{B} z_{t-1} + \mathbf{F} x_{t-1} + w_{t-1}$$

for $t = 1, 2, \ldots$, and where

[8] The Kalman filter is also an ideal framework to estimate systems with latent (unobserved) variables such as technology (Slade, 1989).

y_t is a $(K \times 1)$ vector of observable output variables,
z_t is a $(N \times 1)$ state vector,
x_t is an $(M \times 1)$ vector of observable inputs or instruments,
$\mathbf{H}_t$ is a $(K \times N)$ measurement matrix,
$\mathbf{G}$ is a $(K \times M)$ input matrix of the measurement equation,
$\mathbf{B}$ is an $(N \times N)$ transition matrix,
$\mathbf{F}$ is an $(N \times M)$ input matrix of the transition equation,
v_t is a $(K \times 1)$ vector of measurement errors, and
w_t is an $(N \times 1)$ vector of transition equation errors.

The matrices $\mathbf{G}$, $\mathbf{B}$ and $\mathbf{F}$ are assumed to be time-invariant and known at time t, while v_t and w_t are independent Gaussian white noise processes with time-invariant covariances. $\mathbf{H}_t$ is assumed to be known and non-stochastic at time t. The Kalman filter then applies maximum-likelihood estimation to "recursively estimate the states z_t, given observations $y_1, ..., y_T$ of the output variables" (Lütkepohl, 2005:625). The Kalman filter model is therefore 'learning' in real time as each additional data point is observed. This agility allows the model to observe disturbances in the evolution of the parameter coefficients as time progresses, which allows the estimated coefficients to be time-variant.

Following Inglesi-Lotz (2011) we want to estimate the equation

$$C_t = \beta_1 P_t + \beta_2 Y_t + \varepsilon_t \qquad (1)$$

where C_t is electricity consumption (demand), P_t is the price of electricity and $Y_t$is income. All the variables are in their natural logs; a log-log specification of this kind allows the coefficients β_1 and β_2 to be interpreted as elasticities. ε_t is the stochastic error term. If this equation was estimated using OLS, the parameters β_1 and β_2 would remain fixed, thus reflecting the average elasticities over the whole sample period. However, given that our sample includes both a period of relatively stable, and then sharply increasing, real electricity prices, the average elasticities would likely misrepresent the true nature of the relationships. To this end, the Kalman filter, which allows the coefficients β_1 and β_2 to vary over time, is deemed superior. The equation to estimated therefore takes the form

$$C_t = \beta_{1,t} P_t + \beta_{2,t} Y_t + \varepsilon_t \qquad (2)$$

with the coefficients $\beta 1,_t$ and $\beta 2,_t$ now time-varying. The Kalman filter representation is given by
$C_t = SV1P_t + SV2Y_t + SV3$
$SV1 = SV1(-1)$
$SV2 = SV2(-1)$
$SV3 = C(2)SV3(-1) + [var = exp(C(1))]$

where $C(1)$ and $C(2)$ represent the constant parameters of the estimation and $SV1$ and $SV2$ represent the final estimates of, respectively, the price and income elasticities (the state variables). $SV3$ relates to the value of the remaining factors not included in the model that have an impact on electricity consumption in the sector. Its final term represents the variance of the innovation, which is restricted to be a positive function of C(1).

3.3 *Hansen test for parameter stability*

Hanson (1992) proposes a general approach to identify parameter (in)stability in time series regression models. The null hypothesis of the Hansen test is that parameters are stable, implying constant price and income elasticities in this context. The null hypothesis is evaluated against the Lc statistic. Table 2 confirms that the parameters are indeed unstable: The null hypothesis can be rejected at a 10% level of significance. This result suggests that parameters are indeed time-varying, and substantiates our choice of the Kalman filter.

4 Empirical results and discussion

Table 3 reports the Kalman filter estimation results. The evolution of the elasticity coefficients is depicted in Figure 3.[9] Price elasticity decreased (in absolute terms) sharply during the late-1980s, and remained very small until about 2005. This result is consistent with the South African literature (Table 1). Price elasticity is very small, while income appears to have been the main driver of electricity demand from the early-1990s onwards. If the model is estimated only up to 2005 (not shown), price elasticity is statistically insignificant, while the final income elasticity state is 0.577 and statistically significant. Despite slightly different data sets used, these findings are directly comparable to Inglesi-Lotz (2011)'s main result.

However, once the estimation is extended after 2005, the elasticities change significantly. The sharp price increases cause the price elasticity to explode dramatically, while the income elasticity decreases markedly. In its final state, price elasticity is given as $E_p = -0.288$ at a 5 per cent confidence level. This implies that a one per cent increase in the real electricity price would result in a 0.288 per cent decrease in electricity consumption. However, because the demand response is still *in*elastic ($0 < |E_p| < 1$), a price increase is unlikely to adversely affect total revenue from electricity sales.

Income elasticity was initially negative, suggesting that income was not an important determinant of electricity consumption. After about 1990 it started following a pattern identical to the estimation in Inglesi-Lotz (2011). While electricity consumption remained income-inelastic (i.e. $0 < |E_I| < 1$) throughout the sample period, income appears to play a diminishing role in determining electricity demand. In its final state, income elasticity is positive, albeit statistically insignificant.

A negative correlation[10] can also be observed between price elasticity and

[9] The first five observations are truncated due to the estimation's initial volatility inherent to the Kalman filter.

[10] The correlation coefficient of -0.45 suggests a moderate negative correlation.

price increases (Figure 4). As prices increase, elasticities increase in absolute terms. This suggests that when prices are stable, the influence of price on demand is limited, which is consistent with the South African literature. However, when prices are increasing, its influence on demand is more pronounced. Figure 4 also suggests that price elasticity was somewhat volatile between 2004–2011, corresponding to the period of sharp price increases. While the sharp price increases only came into effect from 2008 (see Figure 1), the preceding volatility in price elasticity suggests pre-emptive changes in consumption patterns borne out of uncertainty. This could potentially be explained by the uncertainty around Eskom's tariff applications in 2005/6, which was publicly known before it was even considered and finally implemented. It could also reflect customers' reaction to an increasingly constrained electricity supply in 2007.

The implications of these results compared to the current South African literature are the following:

1. During the time that electricity prices were falling in real terms, consumption was unresponsive to price changes. This explains the minute or statistically insignificant elasticities detected by previous South African studies.

2. Under a regime of increasing real prices, however, consumption is significantly more sensitive to changes in prices. This is consistent with Inglesi-Lotz (2011:3695)'s result that the "price elasticity of electricity is higher for higher levels of real prices" and Wang and Mogi (2017:240)'s conclusion that "consumers become less [more] sensitive to price when the real price of electricity declines [increases]".

3. While real prices were falling, income was a significant determinant of consumption. However, once real prices started increasing, income elasticities started falling to the point where it is no longer statistically significant. Under the latter regime, prices – and not income – is the notable driver of electricity demand. This is also consistent with the 2008 decoupling between real GDP (income) and electricity sales observed in Figure 2.

The final price and income elasticities of -0.288 and 0.387 are close to Tiwari and Menegaki (2019)'s Kalman filter estimates of -0.21 and 0.41 for India. In addition, the same inverse relationship between price and income elasticities observed here is evident in India where "price elasticity increases in time while the income elasticity becomes lower in time" (Tiwari and Menegaki, 2019:386).

The time-varying nature of price and income elasticities substantiates the fact that the Kalman filter approach is superior to fixed-parameter estimations. However, the Kalman filter provides an added advantage of depicting how the elasticity estimate has evolved over time such that the timing and impact of key events can be detected. It is clear that the sharp price increases from 2006–2011 has had a significant impact on aggregate electricity demand. This translated into greater price sensitivity, with the price elasticity coefficient increasing (in absolute terms) over this time. Price elasticity stabilised from 2011 onwards, but at a higher – and now statistically significant – level than pre-2005. These results indicate that the higher electricity prices, the higher consumers' sensitivity to changes in prices.

5 Extension: The South African mining sector

South Africa is a resource rich economy, and mining has been a mainstay of economic growth and employment creation for over a century. There is also an important symbiosis between the mining sector and Eskom. The discovery of a gold reef in Johannesburg in 1886 sparked a rush that had an immense impact on the city as well as on the electricity sector as a whole. The soaring demand for electricity caused by a booming mining sector hastened the need for network integration, regulations and a greater electricity supply at an affordable price. Prior to this, electricity was generated by private or municipality-owned generators, which operated in a disintegrated network (Amusa et al., 2009:4168). Given these new requirements, Parliament approved the 1922 Electricity Act in terms of which Eskom was established and given the task of supplying a large amount of electricity at relatively low prices to the mining sector in particular and the broader economy in general (Marquard, 2006:126). It follows that from the outset the mining sector has always provided a significant customer base for Eskom. The sector also creates a significant level of stable and predictable electricity consumption. Unlike other sectors which have peak and off-peak demand during the day, the mining sector's demand profile is fairly static throughout the day. This creates an essential level of around the clock minimum demand which is crucial for operating the electricity network efficiently. Eskom also depends on the mining sector for the supply of coal which is used as fuel for its power stations. South Africa has vast coal reserves, which serve as a source of cheap primary energy; subsequently coal-fired power stations produce most of the country's electricity.[11] Over the past 30 years, the mining sector has accounted for between 14–22% of total electricity consumption (Eskom, 2019, 2005). However, mining's share of total electricity consumption has been falling, presumably due to increased demand from households added to the grid over the same time. Moreover, the contribution of mining to the economy has also declined, as Figure 5 attests. The share of mining in total GDP has fallen from just under 18% in 1980 to around 7% in 2019 (SARB, 2020). Employment in the mining sector has also fallen sharply, despite mining production remaining relatively constant. This suggests that capital intensity has increased.

5.1 *Electricity intensity*

During the 1950s the objectives of national energy security and self-sufficiency were paramount (Van Horen, 1996). This aggressive electricity infrastructure expansion programme was based on the assumption that economic growth would

[11] In 2019, coal-fired power stations generated about 83 per cent of all electricity produced in South Africa (DME, 2019:17).

continue at a rapid pace, thus providing demand for more electricity power in the future. However, by the late 1970s and early 1980s the South African economy had slowed down materially. This slowdown was occasioned by political unrest and international financial sanctions that were imposed on the country. By the late 1980s Eskom was left with excess capacity and sluggish electricity demand. It was against the background of surplus capacity that the 1991 'national price compact' was formulated (Steyn, 2004). According to this agreement, annual electricity price increases were deliberately set below the inflation rate in order to encourage electricity consumption and stimulate economic growth. This meant that every year, electricity became relatively cheaper as compared to other goods and services. This strategy encouraged growth in the electricity-intensive industries, such as mining, as the low electricity price was effectively a subsidy to these industries.[12]

It could be argued that an unintended consequence of the 1991 electricity price pact or any other similar pricing strategy would be the over-allocation of electricity as a factor of production. The sustained lower-than-inflation price increases resulted in electricity being cheaper as compared to other factors of production. This could result in an over-allocation of electricity in the production process (i.e. an electricity-intense production structure), while resulting in little incentive to save energy (Inglesi and Pouris, 2010:113). According to Inglesi-Lotz and Blignaut (2011:4495) electricity intensity more than doubled from 0.329 in 1990 to 0.713 GWh/$ million in 2007, as compared to the relatively constant 0.35 GWh/$ million in OECD countries. The high level of energy intensity can also be attributed to the resource-based nature of the South African economy and the local abundance of coal. The historical domestic under-pricing of coal and electricity has led to a heavily capital and electricity intensive developmental path, largely driven by mining activities (Kohler, 2014:525).

5.2 *Increasing real prices and electricity substitution*

By 2006, the price compact was no more. Real electricity prices began to increase in 2006 and were rapidly escalating by 2008. DME (2019) data suggest that between 2006 and 2013 nominal electricity prices for the mining sector increased by over 20% per year on average, with massive increases of 30.8% and 40.9% in 2009 and 2010 alone. While aggregate economy and mining sector electricity prices trend together over time, from 1980 to 2010 electricity prices for the mining sector was on average about 5% lower than for the aggregate economy. However, since 2013 the mining sector faced marginally higher electricity prices than the aggregate economy (DME, 2019).

These higher prices create the risk that the mining sector could look to alternative sources of energy, and so reduce their dependence on Eskom. Given the significant consumption share of the mining sector, a reduction, for whichever reason, in the mining sector's consumption of electricity, could result in a significant drop in Eskom's revenue. In addition, the mining sector – by virtue of

[12] According to Steyn (2004:15), this led to more than 10 years of "'special deals' for large industrial consumers".

the scale and capital intensity of the industry – is perhaps best placed to create their own electricity generating facilities. In the long-run new technologies and new production processes are introduced. This creates scope for the consumers to migrate from their current capital equipment into more energy efficient equipment as part of their business recapitalisation processes. With the benefit of time, consumers could also re-engineer their production processes such that they become more energy-efficient and more cost-effective. They could even consider other options, which were not available to them in the short-term. For example, they could install their own electricity generators for their own consumption and/or adjust their work schedules such that most of their production activities – and subsequently consumption – are shifted from peak to off-peak periods. Recent legislation (RSA, 2020) suggests that the South African government is trying to make it easier for consumers to adopt these technologies, by exempting licensing requirements for generators with a capacity of less than 1MW. This removes some of the barriers to self-generation and signals the government's intent to actively support such practices. As a result, price elasticity coefficients are expected to be higher in the long run than in the short-term (Niemeyer, 2001:2).

5.3 *Mining sector data*

Following Arisoy and Ozturk (2014) mining income is proxied by mining production, which is obtained from SARB (2020). Electricity consumption and price data for the mining sector are sourced from Eskom (2019) and Eskom (2005). All series are in natural logarithms and spans 1980 to 2018. Again, our choice of the Kalman filter is substantiated by the Hansen test, which confirms that the parameters are indeed unstable (Table 4).

5.4 *Empirical results*

Table 5 reports the Kalman filter estimation results. The evolution of the elasticity coefficients is depicted in Figure 6. Both price and income elasticities are statistically insignificant in its final state. Price elasticity remained in a narrow band around zero throughout the sample period. This, coupled with the very high p-value corresponding to the price coefficient, confirms that electricity prices do not play a significant role in determining electricity consumption in the mining sector. In the context of the mining sector this is not really surprising, given the capital-intensive nature of mining activity. Once the production plant has been constructed and mining operations commence, it is very difficult for mines to alter their electricity consumption in response to a variable cost like electricity costs: They do not have the agility to change their production process in the short term. While the price elasticity briefly responded to the sharp price increases, this reaction was short-lived and small.

Therefore, price sensitivity in the mining sector is a long-term consideration. The mining houses may consider the electricity price trajectory when setting up new plants or extending their current operations, but they are unlikely to scale down on consumption solely on the back of higher prices in the short to medium term. In addition, even if a decision to shut down operations were to be made, it would take at least several months to implement. A decision to shut down operations is usually an elaborate process. There are several time-consuming regulatory and legal processes that have to be followed, suggesting that a reaction to a higher electricity price cannot be swift and immediate.

The income elasticity estimated here is statistically insignificant and lower than the results in comparable studies. For example, Kohler (2014) estimates an income elasticity for the mining sector of 0.628. However, this result is obtained using an ARDL (fixed-parameter) estimation and over the sample 1993–2006, when the mining industry and South African electricity pricing and regulation were markedly different. This result could also point to the fact that the mining sector, by virtue of its capital-intensive production and inherent immobility, are also less responsive to changes in income compared to the relatively more agile aggregate economy. Because mining income was proxied by mining production, the income elasticity could also be interpreted as the elasticity of production. The positive elasticity coefficient indicates that an increase in mining production will naturally result in an increase in electricity consumption. The gradual decline in the elasticity coefficient could point to some electricity efficiency gains in the sector: The mining sector is using fewer units of electricity to produce a single additional unit of production. Alternatively, large mines could be moving towards self-generation, thus purchasing less electricity and substituting the shortfall with their own generation. The notable fall in both elasticities towards the end of the sample could suggest that the mining sector is gradually moving away from reliance on Eskom-supplied electricity. This might suggest that the mining sector is moving towards self-generation or alternative sources of energy, although at this early stage the evidence is not conclusive.

6 Conclusion and policy implications

This paper evaluated the evolution of price and income elasticities of electricity demand for the South African economy. It considered both the aggregate economy and the mining sector. To allow for time-varying parameters, a state-space model was constructed, with the parameters estimated using the Kalman filter. The advantages of this approach are that the assumptions of stationarity can be relaxed, while it allows for time-varying parameters to be estimated. This enabled the analysis to differentiate between elasticity coefficients in times of falling, and times of increasing, real prices.

This paper fills two important gaps in the South African literature. First, the most recent comparable studies were performed on data from more than 10 years ago. Since then, domestic electricity prices have moved from a period of falling (1983–2005) into a period of sharply increasing (2008–2011) real prices. This study updates the estimation with data up to 2018, enabling a critical evaluation of the effect of increasing real prices on price sensitivity.

The main result, consistent with the South African and international literature, is that electricity consumption was unresponsive to price changes in the period of falling real electricity prices. However, when prices started increasing, the price elasticity increased markedly (in absolute terms). This indicates that price sensitivity is notably higher when real prices are increasing. Energy price regulators should note this result. Previous research suggested that South African electricity demand is unresponsive to price increases; this, in turn, may have created the expectation that large electricity price increases would not meaningfully reduce electricity demand. The evidence from this paper warns that ever-increasing electricity prices could further increase price-sensitivity and lead to an accelerating fall in electricity demand. E_p has seemingly stabilised at -29% since 2011 despite peaking at -63% in 2006/7 (Figure 3). This suggests that, for the economy as a whole, price elasticity of electricity demand is still inelastic. In theory, it could therefore be argued that there is still some scope for further price increases without materially constraining demand. Such a position is more easily sustained in an environment where the economy is growing, and the income effect negates the negative impact that a price increase has on electricity demand. Nevertheless, it is important to note that the aggregate price elasticity coefficient has become more pronounced since the implementation of higher electricity price increases, while the income effect is now statistically insignificant. This confirms that, on aggregate, consumers have become more sensitive to price changes.

Second, while the mining sector plays an important role in the South African economy, there is a relative shortage of literature on electricity demand elasticities in the mining sector. This paper therefore considered the symbiotic relationship between Eskom and the South African mining sector, as well as its electricity demand profile. It found that electricity demand in the mining sector is extremely price inelastic and somewhat income inelastic. This could be ascribed to the capital intensive and immobile nature of mining operations. Given the inertia inherent in mining production, mines do not have the agility to alter their electricity consumption in response to a variable cost like electricity costs in the short term. However, mines are well-equipped to generate their own electricity. Already there is evidence that electricity is being used more efficiently in the mining sector, following largely inefficient use in times of cheap and abundant energy, as less electricity is being used for the same level of mining production. This suggests – apart from technological innovations in mining production – that certain mining operations are moving towards alternative sources of energy, including self-generation.

It is crucial to consider the impact of distributed generation (DGs) on the price elasticity coefficient for large power users like the mines. These customers have both the means and the incentive to consider electricity self-generation options in the future. As the technology for self-generation becomes cheaper and more proliferated, large customers will find it increasingly attractive to have their own electricity generation plants. If a significant number of large power users opt to have DGs to either replace or complement electricity supplied from the national grid, this could have a material impact on the price elasticity coefficient. The proliferation of DGs provides customers with options to substitute or at least supplement their grid supplied electricity, with large mines well-equipped to take advantage of this. If these technologies are adopted in mass, it could have negative revenue implications for the utility. As a result, electricity price policy makers have to be mindful of both the grid price level and the price structure. If a correct pricing structure is not applied, the utility could experience a self-induced death spiral. It also follows that as the technology around DGs becomes more matured their costs are likely to decrease. In the long term the utility could face some increased competition from DGs as their costs decrease and the grid price increases.

Notwithstanding these concerns, the movement towards cost-reflective electricity pricing cannot be avoided. This should be done in tandem with ensuring that Eskom as a dominant player in the energy sector becomes more efficient. Policy makers should make a clear commitment to long-term cost-reflective pricing. This price path should converge towards the long-run marginal cost of supplying electricity. If the electricity sector is to attract the levels of investment it requires in order to alleviate supply constraints, there must be an assurance that electricity prices will reflect the long-term marginal cost of production. Electricity price increases must be smooth and fairly predictable, so that the long-term planning and capital investment that is required to sustain the electricity sector can be achieved in a less volatile environment. This kind of price stability could contribute to regulatory stability in the electricity sector. Such a policy position would ensure that investment in the sector could yield a fair return. This would attract new entrants to the electricity industry value chain, thereby diluting Eskom's monopoly position in the sector. It could also result in an improved security of aggregate electricity supply.

References

[1] Al-Faris, A. R. F. (2002). The demand for electricity in the GCC countries. Energy Policy 30(2), 117–124.

[2] Amarawickrama, H. A. and L. C. Hunt (2008). Electricity demand for Sri Lanka: A time series analysis. Energy 33(5), 724–739.

[3] Amusa, H., K. Amusa, and R. Mabugu (2009). Aggregate demand for electricity in South Africa: An analysis using the bounds testing approach to cointegration. Energy Policy 37(10), 4167–4175.

[4] Arisoy, I. and I. Ozturk (2014). Estimating industrial and residential electricity demand in Turkey: A time varying parameter approach. Energy 66(2014), 959–964.

[5] Atakhanova, Z. and P. Howie (2007). Electricity demand in Kazakhstan. Energy Policy 35(7), 3729–3743.

[6] Athukorala, P. W. and C. Wilson (2010). Estimating short and long-term residential demand for electricity: New evidence from Sri Lanka. Energy Economics 32, S34–S40.

[7] Bianco, V., O. Manca, S. Nardini, and A. A. Minea (2010). Analysis and forecasting of nonresidential electricity consumption in Romania. Applied Energy 87(11), 3584–3590.

[8] Blázquez, L., N. Boogen, and M. Filippini (2013). Residential electricity demand in Spain: New empirical evidence using aggregate data. Energy Economics 36, 648–657.

[9] Blignaut, J. N. and T. De Wet (2001). Some recommendations towards reducing electricity consumption in the South African manufacturing sector. South African Journal of Economic and Management Sciences 4(2), 359–379.

[10] Campbell, A. (2018). Price and income elasticities of electricity demand: Evidence from Jamaica. Energy Economics 69, 19–32.

[11] De Vita, G., K. Endresen, and L. C. Hunt (2006). An empirical analysis of energy demand in Namibia. Energy Policy 34(18), 3447–3463.

[12] Department of Mineral Resources and Energy (DME) (2019). Energy Price Reports (various editions). Available at http://www.energy.gov.za/files/media/media)_explained.html [30 June 2020].

[13] Dilaver, Z. and L. C. Hunt (2011). Industrial electricity demand for Turkey: A structural time series analysis. Energy Economics 33(3), 426–436.

[14] Egorova, S. and N. Volchkova (2013). Sectoral and regional analysis of industrial electricity demand in Russia. Available at SSRN 2241294.

[15] Eskom (2005). Annual and Statistical Reports (various editions). Available at http://www.eskom.co.za/sites/heritage/Pages/Annual-Reports.aspx [30 June 2020].

[16] Eskom (2019). Integrated Results (various editions). Available at http://www.eskom.co.za/OurCompany/Investors/IntegratedReports/Pages/Annual_Statements.aspx [30 June 2020].

[17] Ghaderi, F., M. Azadeh, and S. Mohammadzadeh (2006). Electricity demand function for the industries of Iran. Information Technology Journal 5(3), 401–404.

[18] Hanson, B. E. (1992). Tests for parameter instability in regressions with I(1) processes. Journal of Business & Economic Statistics 10(3), 45–59.

[19] He, Y., L. Yang, H. He, T. Luo, and Y. Wang (2011). Electricity demand price elasticity in China based on computable general equilibrium model analysis. Energy 36(2), 1115–1123.

[20] Hosoe, N. and S.-I. Akiyama (2009). Regional electric power demand elasticities of Japan's industrial and commercial sectors. Energy Policy 37(11), 4313–4319.

[21] Inglesi, R. (2010). Aggregate electricity demand in South Africa: Conditional forecasts to 2030. Applied Energy 87(1), 197–204.

[22] Inglesi, R. and A. Pouris (2010). Forecasting electricity demand in South Africa: A critique of Eskom's projections. South African Journal of Science 106(1-2), 50–53.

[23] Inglesi-Lotz, R. (2011). The evolution of price elasticity of electricity demand in South Africa: A Kalman filter application. Energy Policy 39(6), 3690–3696.

[24] Inglesi-Lotz, R. and J. N. Blignaut (2011). Estimating the price elasticity of demand for electricity by sector in South Africa. South African Journal of Economic and Management Sciences 14(4), 449–465.

[25] Kalman, R. E. (1960). A new approach to linear filtering and prediction problems. Journal of Basic Engineering 82(1), 35–45.

[26] Kamerschen, D. R. and D. V. Porter (2004). The demand for residential, industrial and total electricity, 1973–1998. Energy Economics 26(1), 87–100.

[27] Kohler, M. (2014). Differential electricity pricing and energy efficiency in South Africa. Energy 64, 524–532.

[28] Lütkepohl, H. (2005). New introduction to multiple time series analysis. Springer Science & Business Media.

[29] Marquard, A. (2006). The origins and development of South African energy policy. Ph. D. thesis, University of Cape Town. Available at http://www.erc.uct.ac.za/sites/default/files/image_tool/images/119/Papers-06/06Marquard-PhD_Thesis.pdf [30 June 2020].

[30] Morrison, G. W. and D. H. Pike (1977). Kalman filtering applied to statistical forecasting. Management Science 23(7), 768–774.

[31] Niemeyer, V. (2001). Customer response to electricity prices: Information to support wholesale price forecasting and market analysis. Electric Power Research Institute (EPRI).

[32] Parsons, R., W. Krugell, and G. Keeton (2015). Eskom's further application for a tariff increase. Joint submission to National Energy Regulator of South Africa (NERSA). Available at https://www.ee.co.za/wp-content/uploads/2015/06/NWU-submission-to-NERSA.pdf [25 August 2020].

[33] Pouris, A. (1987). The price elasticity of electricity demand in South Africa. Applied Economics 19(9), 1269–1277.

[34] Republic of South Africa (RSA) (2020). Government Gazette, No.43151, Vol.657, 26 March 2020. Available at http://www.energy.gov.za/files/policies/Licensing-Exemption-and-Registration-Notice.pdf [25 August 2020].

[35] Slade, M. E. (1989). Modelling stochastic and cyclical components of technical change: An application of the Kalman filter. Journal of Econometrics 41(3), 363–383.

[36] South African Reserve Bank (SARB) (2020). Quarterly Bulletin (various editions). Available at https://www.resbank.co.za/Publications/QuarterlyBulletins/Pages/QuarterlyBulletins-Home.aspx [30 June 2020].

[37] Statistics South Africa (StatsSA) (2020). Consumer Price Index (CPI). Available at http://www.statssa.gov.za/publications/P0141/ CPI-History.pdf [30 June 2020].

[38] Steyn, G. (2004). Administered Prices – Electricity. Report prepared for The National Treasury. Available at http://www.treasury.gov.za/publications/other/epir/Electricity.pdf [30 June 2020].

[39] Tiwari, A. K. and A. N. Menegaki (2019). A time varying approach on the price elasticity of electricity in India during 1975–2013. Energy 183(2019), 385–397.

[40] Van Horen, C. (1996). Counting the social costs: Electricity and externalities in South Africa. Ph. D. thesis, University of Cape Town. Available at https://open.uct.ac.za/bitstream/handle/11427/21698/thesis_com_1996_van_horen_clive.pdf?sequence=1 [30 June 2020].

[41] Von Hirschhausen, C. and M. Andres (2000). Long-term electricity demand in China – From quantitative to qualitative growth? Energy Policy 28(4), 231–241.

[42] Wang, N. and G. Mogi (2017). Industrial and residential electricity demand dynamics in Japan: How did price and income elasticities evolve from 1989 to 2014? Energy Policy 106, 233–243.

[43] Ziramba, E. (2008). The demand for residential electricity in South Africa. Energy Policy 36(9), 3460–3466.

[44] Ziramba, E. and K. Kavezeri (2012). Long-run price and income elasticities of Namibian aggregate electricity demand: Results from the bounds testing approach. Journal of Emerging Trends in Economics and Management Sciences 3(3), 203–209.

Table 1: South African literature review summary (selected)

Author(s)	**Sample**	**Methodology**	E_p	E_I
Pouris (1987)	1950–1983	Unconstrained distributed lag	-0.9	n/a
Ziramba (2008)	1978–2005	ARDL (residential)	Insign.	0.31
Amusa et al. (2009)	1960–2007	ARDL	Insign.	1.67
Inglesi (2010)	1980–2005	ECM, Engle-Granger	-0.56	0.42
Inglesi-Lotz (2011)	1980–2005	Kalman filter	-0.075	0.79
Inglesi-Lotz and Blignaut (2011)	1993–2006	Panel (aggregate, sectoral)	Insign.	0.60
Kohler (2014)	1993–2006	ARDL (industrial & subsectors)	-0.939	0.63

E_p = price elasticity, E_I = income elasticity.
Unless indicated otherwise, *aggregate* electricity demand was analysed.

Table 2: Hansen parameter instability test

L_c **statistic**	***p*-value**
0.410423	0.0780

Table 3: Aggregate estimation results: Kalman filter

State-space model		
Sample	1980 – 2018	
Included observations	39	
Variables	**Estimated coefficients**	***p*-values**
C(1)	-5.867	0.000
C(2)	1.002	0.000
	Final state	***p*-values**
SV1 (price coefficient)	-0.288	0.029
SV2 (income coefficient)	0.387	0.298
SV(3) (intercept)	7.760	0.174

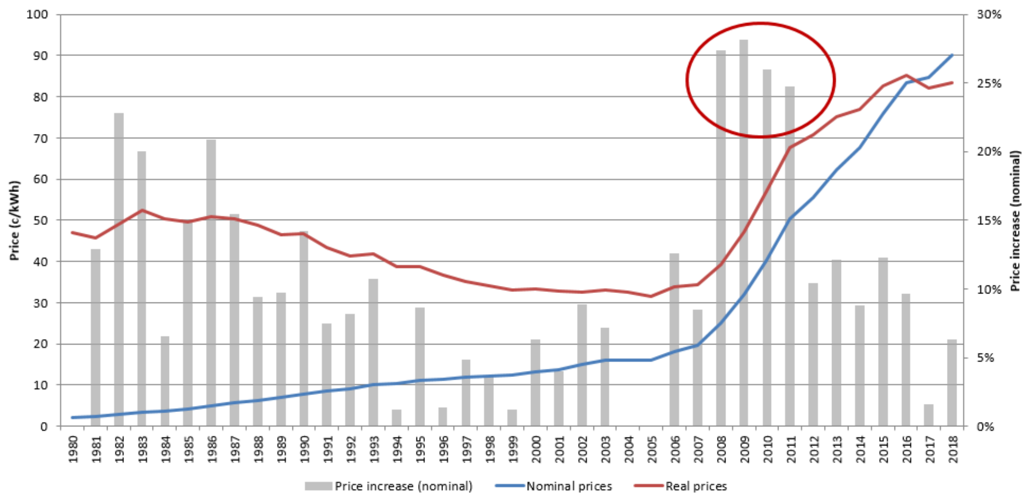
Table 4: Hansen parameter instability test: Mining sector

L_c **statistic**	***p*-value**
0.382	0.0945

Table 5: Estimation results (mining): Kalman filter

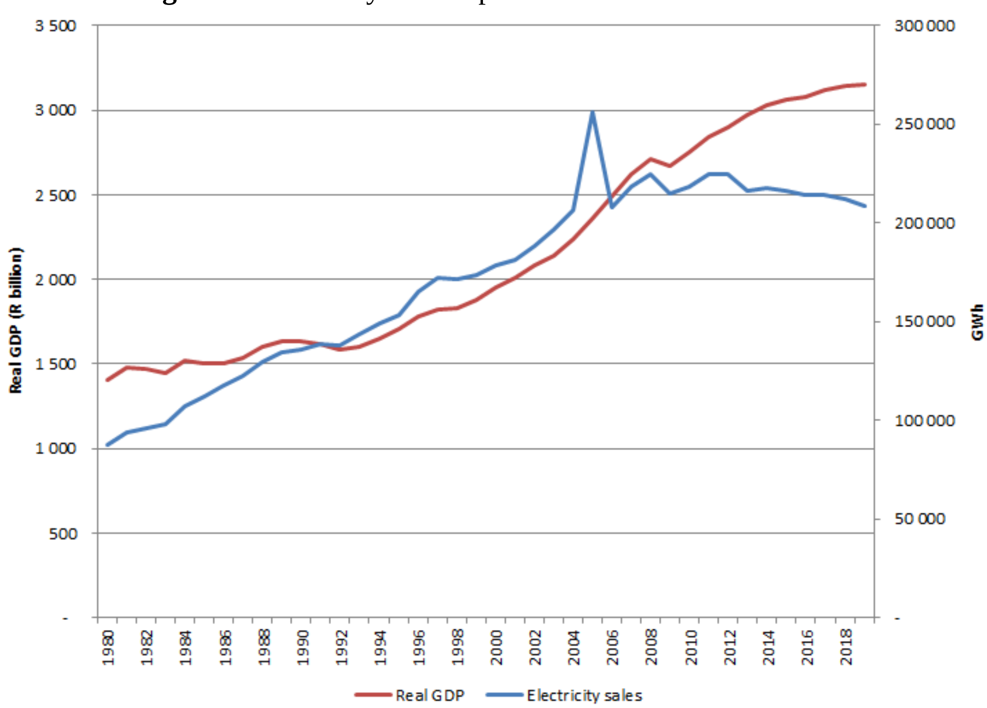
State-space model		
Sample	1980 – 2018	
Included observations	39	
Variables	**Estimated coefficients**	***p*-values**
C(1)	-5.190	0.000
C(2)	1.001	0.000
	Final state	***p*-values**
SV1 (price coefficient)	-0.019	0.905
SV2 (income coefficient)	0.422	0.337
SV(3) (intercept)	8.477	0.000

Figure 1: Evolution of electricity prices: 1980–2018



Source: Own calculations from DME, 2019

Figure 2: Electricity consumption and real GDP: 1980–2018



Source: Own calculations from Eskom (2005), Eskom (2019) and SARB, 2020.

Figure 3: Evolution of elasticities over time: 1986–2018

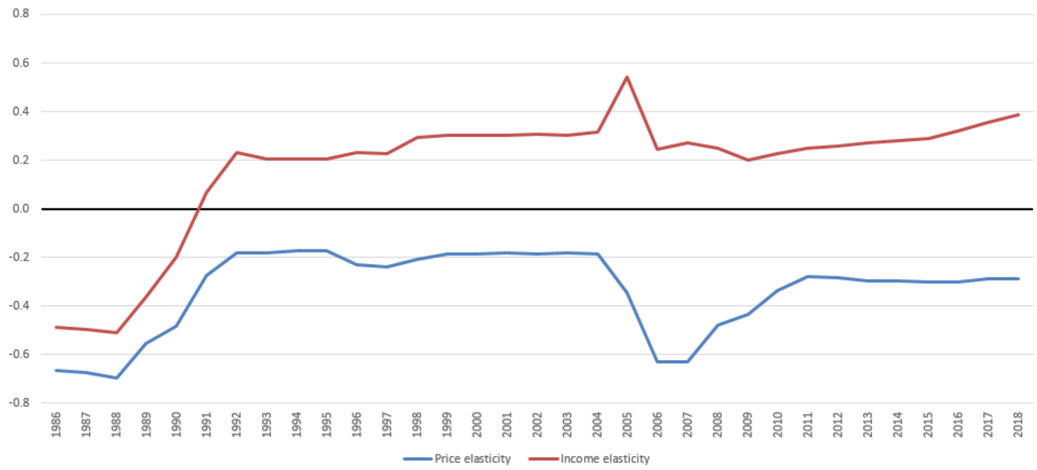
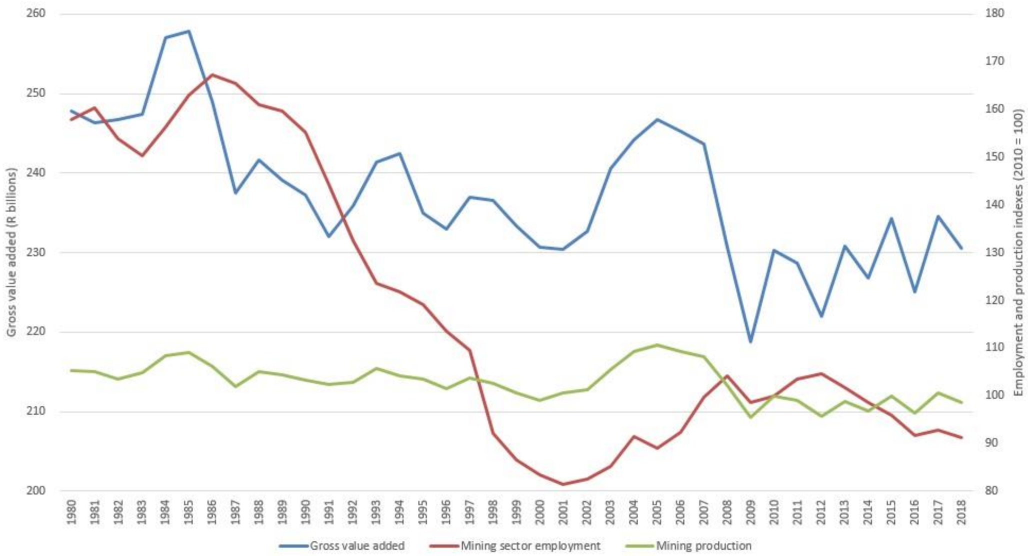


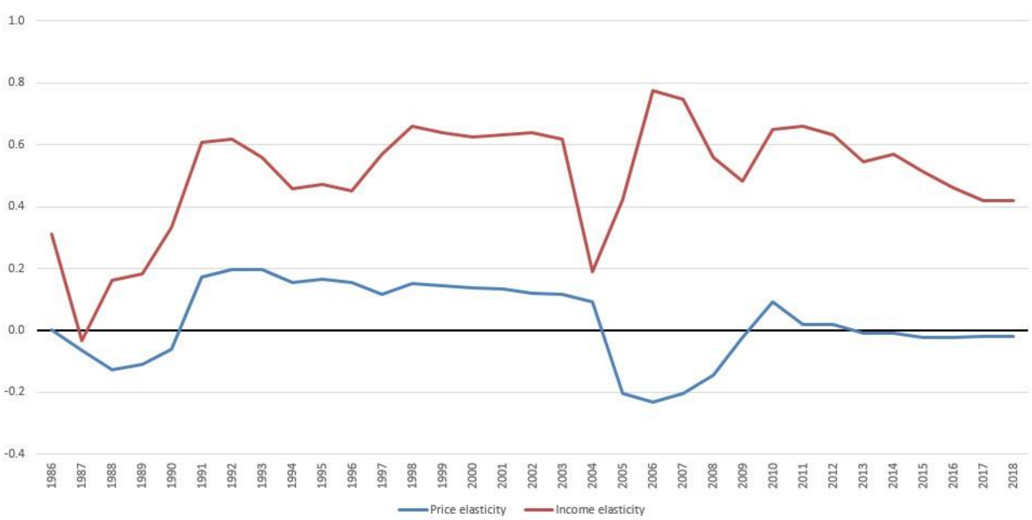
Figure 4: Price increases and elasticities: 1985–2018

Figure 5: Mining contribution to the economy



Source: SARB, 2020.

Figure 6: Evolution of elasticities over time: Mining sector (1986–2018)



Appendix A. Data

Table A1: Descriptive statistics

	Electricity consumption	**Electricity price**	**Income**
Mean	12.010	2.652	14.525
Median	12.063	2.521	14.445
Maximum	12.455	4.500	14.961
Minimum	11.380	0.703	14.155
Std. dev.	0.297	1.058	0.276
Skewness	-0.566	0.162	0.312
Kurtosis	2.135	2.239	1.550
Jarque-Bera	3.298	1.112	4.050
Probability	0.192	0.574	0.132
Sum	468.377	130.441	566.491
Sum Sq.Dev.	3.359	42.499	2.894