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The evolution of price elasticity of electricity demand in South Africa: A Kalman filter application

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ABSTRACT

In South Africa, the electricity mismatch of supply and demand has been of major concern. Additional to past problems, the 2008 electricity crisis made the solution crucial after its damaging consequences to the economy. The disagreement on the need and consequences of the continuous electricity price hikes worsens the situation.

To contribute to the recent electricity debate, this paper proposes a time-varying price elasticity of demand for electricity; the sensitivity of electricity consumption to price fluctuations changes throughout the years. The main purpose of this study is the estimation of the price elasticity of electricity in South Africa during the period 1980–2005 by employing an advanced econometric technique, the Kalman filter.

Apart from the decreasing effect of electricity prices to consumption (−71.8% in the 1990s and −94.5% in the 2000s in average), our results conclude to an important finding: the higher the prices (for example in the 1980s) the higher the sensitivity of consumers to price fluctuations.

Thus, further increases of the electricity prices may lead to changes in the behaviour of electricity consumers, focusing their efforts on improving their efficiency levels by introducing demand-side management techniques or even turning to other sources of – cheaper – energy.

1. Introduction

In South Africa, the electricity mismatch of supply and demand has been of major concern to energy policy makers. Additional to past problems, the electricity crisis at the beginning of 2008 (Bayliss, 2008), together with the severe consequences for the economy in its entirety, has made the solution of the problems as urgent as ever. In the third quarter of 2009, the national electricity supplier, Eskom, applied to the National Energy Regulator (NERSA) for an increase in the electricity prices in order to fund their current and future investment plans. At the end of September 2009, NERSA's decision was made public: an approximate 25% increase of the electricity prices per year over the next three years.

Before NERSA's latest decision, the debate on whether South Africa needs a price hike and the consequences of such an increase did not reach a consensus. One argument is that these price hikes will affect the economy negatively in the long-run. A counter-argument from energy policy makers was that the funding needed for the further expansion and maintenance of the existing power plants in the country makes the price rise essential.

According to international and local research on this issue, price has proven to be a significant factor on the electricity consumption of a region or a sector. However, the significance of this factor can change through the years due to fluctuations in price, changes in the conditions of the electricity market as well as the economic environment of the country.

To contribute to the recent electricity debate, this paper proposes that the sensitivity of the consumption to increases of electricity prices changes through the years; that is the price elasticity of the demand for electricity is time-varying. Since 2008/09 the electricity sector in South Africa is in new uncharted territory; hence, focus on variation is more important than only examining the level of change. The main purpose of this study is the estimation of the time-varying price elasticity of electricity in South Africa during the period 1980–2005 by employing the Kalman filter.

This paper is structured as follows: Section 2 summarises international and local studies estimating the price elasticity of electricity demand. Section 3 presents the Kalman filter methodology, data used and the theoretical model while the empirical results are presented in the subsequent section. Finally, in Section 5 a discussion of the results and policy implications is presented before the conclusion.

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2. Studies on price elasticity of electricity

During the last decade, energy studies have received great attention mainly due to the shortage of energy as well as the severe projected consequences to the environment. It is vital to examine and control the energy – and more specifically the electricity – consumption, and identify its affecting factors. The most important factor has been proven to be the electricity price; hence, the complete understanding of electricity consumption's sensitivity to prices is essential for the future.

In Table 1, a summary of international studies and their methodologies and findings are presented. This group of studies is indicative of studies investigating the aggregate electricity demand in a number of developed and developing countries for different time periods.

From Table 1, it can be observed that no consensus has been reached on the most appropriate methodology to be used for electricity modelling. Also, it is noted that the price elasticity estimated or assumed varies depending on the country and more importantly the period investigated. The importance of the period of the study can also be confirmed by the inconclusive results of studies on the estimation of the price elasticity of South African aggregate electricity demand (Table 2).

The common denominator in the above studies is the assumption that the price elasticity remained constant through the periods examined; hence, the differences among the results of the various studies. This study will take this type of analysis a step further, assuming that the price elasticity evolves during the years due to a number of reasons and therefore it should not be treated by policy makers as stable.

3. Method and materials

3.1. General issues

Econometric modelling has evolved substantially the last two decades with co-integration analysis being one of the main developments (Engle and Granger, 1987; Johansen, 1991; Hendry and Juselius, 2000, 2001). Energy related econometric analysis was not the exception of the trend.

Although popular, the co-integration approaches are highly dependent on the stationarity of the series and also on the assumption that the estimated parameters do not change substantially over time (the estimated coefficients are averages throughout the studied period). Given these requirements, researchers have started doubting the overdependence on the co-integration analysis in some cases. Harvey (1997) mentions that all dynamic econometrics should not be based on autoregressions. Also Hunt et al. (2003) add that methodologies that allow for their coefficients to vary stochastically over time can be proven helpful.

The Kalman filter methodology that this paper employs presents all the above-mentioned required characteristics and provides the ideal framework for estimating regressions with variables whose impact varies over time (Slade, 1989). Morisson and Pike (1977) also argue that in the case that the estimated coefficients do not vary over time, the Kalman filter and the least squares approach are expected to produce similar results. However in the presence of parameter instability, the Kalman filter can be proven superior to the least squares model (Morisson and Pike, 1977).

Therefore, before choosing the most appropriate technique for a specific case, the researcher needs to establish the possibility of existing parameter instability. To test for instability of parameters, a number of tests are proposed in the literature (Andrews, 1993; Chu, 1989; Hansen, 1992). Hansen (1992) proposes an extended version of past approaches to cover general models with stochastic and deterministic trends. The null hypothesis is parameter stability and he proposes use of the *Lc* statistic which arises from the theory of Lagrange Multiplier tests. Performing this test in this paper will confirm or reject the assumption of time-varying price and income elasticities, before estimating them. If the estimated coefficients are proven to vary over time, then the Kalman filter is the most appropriate method.

Table 1
Summary of selected international studies on price elasticity.[a]

Authors	Country	Period	Methodology	Price elasticity
Al-Faris (2002)	GCC countries	1970–1997	Johansen co-integration methodology	Short-run: −0.09 Long-run: −1.68 (average of GCC countries)
Amarawickrama and Hunt (2008)	Sri Lanka	1970–2003	Various models (such as Engle–Granger, Johansen, fully modified OLS)	Long-run: range from −0.63 to 0 Short-run: 0
Atakhanova and Howie (2007)	Kazakhstan	1990–2003	Panel data	Insignificant
De Vita et al. (2006)	Namibia	1980–2002	ARDL–ECM	Long-run: −0.34
Diabi (1998)	Saudi Arabia	1980–1992	Panel data (OLS, fixed effects (time and region), random effects)	Range from −0.139 to 0.01
von Hirschhausen and Andres (2000)	China	1996–2010	Cobb–Douglas for forecasting purposes	(By assumption) −0.02
Kamerschen and Porter (2004)	USA	1973–2008	Flow adjustment model and 3-stage least squares	Range from −0.51 to 0.02 Range from −0.15 to −0.13

[a] Studies organised in alphabetical order.

Table 2
Summary of local studies on price elasticity.[a]

Authors	Period	Methodology	Price elasticity
Pouris (1987)	1950–1983	Unconstrained distributed lag model	Long-run: −0.90 Short-run: n/a
Amusa et al. (2009)	1960–2007	Auto-regressive distributed lag (ARDL) approach	Insignificant
Inglesi (2010) and Inglesi and Pouris (2010)	1980–2005	Engle–Granger and ECM models	Long-run: −0.56 Short-run: Insignificant

[a] Studies organised in chronological order.

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In addition, the Kalman filter is characterised as predictive and adaptive because it looks forward with an estimate of the covariance and mean of the time series one step into the future. What makes it efficient is that as a recursive filter, it estimates the internal state of a linear dynamic system from a series of noisy measurements.

The Kalman filter can be considered to be one of the simplest dynamic Bayesian networks (Masreliez and Martin, 1977). The Kalman filter calculates estimates of the true values of measurements recursively over time using incoming measurements and a mathematical process model. Next, the Kalman filter application is presented thoroughly.

3.2. Kalman filter application

The Kalman filter technique is based on the estimation of state-space models that were originally employed for engineering and chemistry applications (Kalman 1960, 1963; Wiener, 1949). Researchers started applying the technique in economics only in the 1980s (Currie and Hall, 1994; Cuthbertson, 1988; Harvey, 1987; Lawson, 1980).

According to Cuthbertson et al. (1992), there are two main types of models in compliance to representation via Kalman filter: (a) unobservable components models and (b) time-varying parameter models. In this study, the state-space model is applied with stochastically time-varying parameters to a linear regression in which coefficients representing price elasticity and income elasticity are allowed to change over time.

Firstly, the formal representation of a dynamic system written in state-space form suitable for the Kalman filter should be described. The following system of equations presents the state-space model of the dynamics of a $nX1$ vector, y_t.

Observation (or measurement) equation: $$y_t = Ax_t + H\xi_t + w_t \quad (1)$$

State (or transition) equation: $$\xi_{t+1} = F\xi_t + v_{t+1} \quad (2)$$

where A, H and F are matrices of parameters of dimension $(n\times k)$, $(n\times r)$ and $(r\times r)$, respectively, and x_t is a $(k\times 1)$ vector of exogenous or predetermined variables, ξ_t is a $(r\times 1)$ vector of possibly unobserved state variables, known as the state vector.

The following two equations represent the characteristics of the disturbance vectors w_t and v_t, which are assumed to be independent white noise.

$$E(v_t v_\tau') = \begin{cases} Q, & \text{for } t=\tau \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

$$E(w_t w_\tau') = \begin{cases} R, & \text{for } t=\tau \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

where Q and R are $(r\times r)$ and $(n\times n)$ matrices, respectively.

As shown in the following two equations, the disturbances v_t and w_t are uncorrelated at all lags.

$$E(v_t w_\tau') = 0 \quad \text{for all } t \text{ and } \tau \quad (5)$$

In the observation equation the factor x_t is considered to be predetermined or exogenous which does not provide information about ξ_{t+s} or w_{t+s} for s=0,1,2,... beyond what is given by the sequence $y_{t-1}, y_{t-2},\dots,y_1$. Thus, x_t could include lagged values of y or variables which are uncorrelated with ξ_τ and w_τ for all τ.

The overall system of equations is used to explain a finite series of observations $\{y_1, y_2,\dots,y_T\}$ for which assumptions about the initial value of the state vector ξ_t are needed. With the assumption that the parameter matrices (F, Q, A, H or R) are functions of time, then the state-space representation Eqs. (1) and (2)) become:

$$Y_t = \alpha(x_t) + [H(x_t)]'\xi_t + w_t \quad (6)$$

$$\xi_{t+1} = F(x_t)\xi_t + v_{t+1} \quad (7)$$

where $F(x_t)$ is a $(r\times r)$ matrix whose elements are functions of x_t, $\alpha(x_t)$ is a $(n\times 1)$ vector-valued function and $H(x_t)$ is a $(r\times n)$ matrix-valued function.

Eqs. (6) and (7) allow for stochastically varying parameters, but are more restrictive in the sense that a Gaussian distribution is assumed.

3.3. Theoretical model

In the past, local and international models primarily assumed that the price elasticity of electricity remained constant over time. However, electricity models have to allow price sensitivity to change over time in order to capture the changes in economic conditions as well as developments in the electricity market.

Eq. (8) includes standard variables, used in international and local literature (Inglesi, 2010; Nakajima and Hamori, 2010; Dilaver and Hunt, 2010) such as prices of electricity and output of the economy, to explain the electricity consumption.

$$Ln\_elec\_cons_t = \alpha \ln\_elec\_price_t + \beta \ln\_output_t + \varepsilon \quad (8)$$

where *elec_cons* is the electricity consumption; *elec_price* is the price of electricity and *output* is the gross domestic product of the economy in time t. All variables are in their natural logs, as indicated.

The estimation of this equation would result in a constant coefficient α representing the price elasticity of electricity and a constant coefficient β representing the income elasticity of electricity. However, in this study by applying a Kalman filter estimation, the coefficients α and β are time varying; hence, the equation to be estimated looks as follows:

$$Ln\_elec\_cons_t = \alpha_t \ln\_elec\_price_t + \beta_t \ln\_output_t + \varepsilon_t \quad (9)$$

In order to estimate this, the model contains four equations based on the notation of *Eviews* software to allow for time varying coefficients:

$$Ln\_elec\_cons_t = sv1 \ln\_elec\_price_t + sv2 \ln\_output_t + sv3 \quad (10)$$

$$sv1 = sv1(-1) \quad (11)$$

$$sv2 = sv2(-1) \quad (12)$$

$$sv3 = c(2)sv3(-1) + [\text{var} = \exp(c1)] \quad (13)$$

Eqs. (11) and (12) show that the time varying coefficients evolve through time according to a random walk process. All variables are integrated of order 1.

3.4. Data

To apply the Kalman filter techniques for the analysis, local and international sources of data were used. Aggregate electricity consumption is derived from two different sources: *South African Energy Statistics* of the National Energy Council (NEC, 1990) and the *Energy Balances* of the Department of Minerals and Energy (DME, Various issues). The series on real average electricity prices is obtained by the *Energy Price Report, 2005* (Department of Minerals and Energy, DME, 2005); while the data series on Gross Domestic Product was obtained from the *World Economic Outlook* (WEO) of the International Monetary Fund (IMF) (IMF, 2009).

The aggregate electricity consumption is measured in GWh; the electricity prices in Rand cents/KWh (constant prices 2000) and finally, the GDP in R billion (constant prices 2000). Table 3 summarises the descriptive statistics of the series (in their linearised version and the difference of the linear). These elementary descriptive statistics (in their majority, averages through the period) are reported only as an indication of the nature of the raw data to be used in the analysis.

Table 3
Data descriptive statistics.

	Electricity consumption		Electricity price[a]		Output[a]	
Unit of measurement	GWh		Rand cents (KWh)		R billion (constant 2000)	
	Ln	Diff (ln)	Ln	Diff (ln)	Ln	Diff (ln)
Mean	11.913	0.033	2.756	−0.022	6.725	0.022
Median	11.852	0.032	2.734	−0.015	6.674	0.027
Maximum	12.332	0.173	3.004	0.020	7.016	0.050
Minimum	11.631	−0.056	2.562	−0.074	6.564	−0.022
Std. dev.	0.188	0.047	0.173	0.027	0.137	0.021
Skewness	0.669	1.066	0.223	−0.363	0.664	−0.589
Kurtosis	2.715	5.118	1.450	1.991	2.277	2.248
Jarque–Bera	1.714	8.280	2.386	1.418	2.097	1.792
Probability	0.425	0.016	0.303	0.492	0.350	0.408
Sum	262.095	0.734	60.637	−0.479	147.947	0.490
Sum sq. dev.	0.745	0.046	0.627	0.016	0.394	0.009

[a] Exchange rate: R6.94=US$1.

Fig. 1 presents the electricity consumption and electricity prices for the period 1980–2005 in South Africa. The overall negative relationship between them is observable from this figure, since the electricity consumption shows a clear upward trend through the years while the real electricity prices have decreased for the period.

However, the relationship between electricity consumption and the total output of the economy is shown to be positive, since both of them show an upward trend for the time period in question (Fig. 2).

4. Empirical results

As discussed in the methodology section, before applying the Kalman filter, the Hansen test will assist by confirming whether the estimated parameters change over time. The null hypothesis of the test is that the parameters are stable; contrary to the alternative that indicates parameter instability. The results are displayed in Table 4. The test-statistic is 0.679 with p-value of 0.0149. Since the p-value is smaller than the 5% level of significance, the Hansen test does reject the null hypothesis that the parameters are stable. Given this result we proceed with the Kalman filter application.

Although, our study focuses on the evolution of price elasticity of electricity demand, the model allows us to observe the evolution of income elasticity for the same period. Table 5 reports the Kalman filter estimation results.

$c(1)$ and $c(2)$ represent the constant parameters of the estimation; $sv1$ and $sv2$ represent the final estimates for price and income

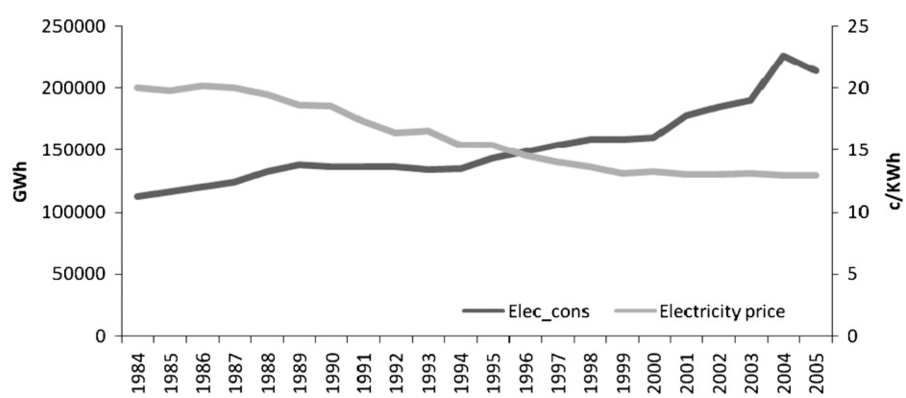

Fig. 1. Electricity consumption and price.
Source: DME (2005), DME (Various issues), NEC (1990).

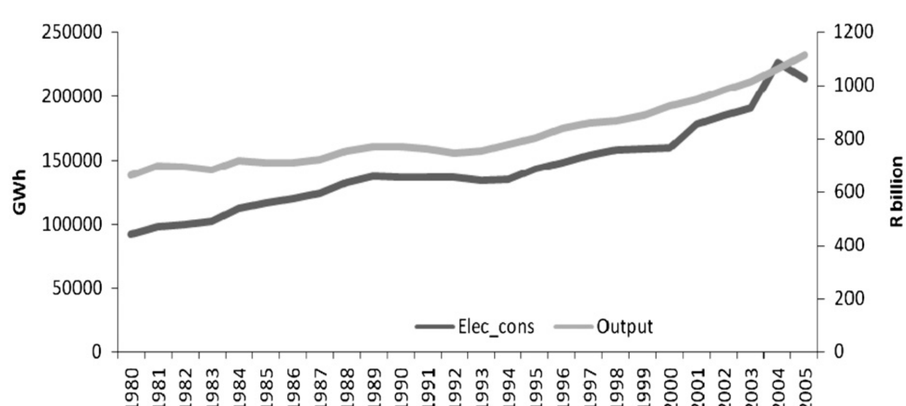

Fig. 2. Electricity consumption and GDP 1980–2005.
Source: DME (Various issues) IMF (2009) NEC (1990).

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Table 4
Hansen test results for parameter stability.

Series	*Ln_elec_cons* ln_*elec_price* ln_*output*
Null hypothesis	Parameters are stable
***Lc* statistic**	0.679
***p*-Value**	0.015**
Conclusion	Ho can be rejected → parameters are not stable

Note: *Statistically significant at 10% level of significance; **statistically significant at 5% level of significance; ***statistically significant at 1% level of significance.

Table 5
Kalman filter estimation results.

Space model		
Sample	1983–2005	
Included observations	23	
Number of iterations to convergence	7	
Variables	**Estimated coefficients**	***p*-Values**
c(1)	−6.213	0.000
c(2)	1.002	0.000
	Final state	***p*-Values**
*sv*1 (price coefficient)	−0.075	0.077
*sv*2 (Income coefficient)	0.794	0.073
*sv*3 (intercept)	6.908	0.037
Residuals		
Std. dev.	0.109	
Normality	1.075	
Skewness	−0.404	
Kurtosis	2.278	
Long-run variance	0.028	
Q-stat (6)	43.012	
Goodness of fit		
Log likelihood	14.275	
Akaike info criterion	−1.067	
Schwarz criterion	−0.969	
Hannan–Quinn criterion	−1.043	

elasticity, respectively[1]; and *sv*3 the value of the rest of the factors affecting the dependent variable (electricity consumption).

Fig. 3 illustrates the evolution, thereof, of price and income elasticities. In the 1980s, the income elasticity experienced a downward trend; during the period 1986–1990, it was close to zero (not seriously affecting the electricity consumption), but from the beginning of 1990s, the income elasticity has been close to 1, showing the high impact that a small change in income/output has to the electricity demand.

Focusing on the main goal of this paper, the demand for electricity was close to unit elastic during the 1980s and beginning of 1990s. However, from 1991/92, it has decreased in absolute values from −1.077 in 1986 to −0.045 in 2005. The economy, therefore, has experienced inelastic demand, since the beginning of the 1990s, or in other words, the price has not played a significant role in the increase of electricity consumption during this period.

5. Discussion

After confirming with Hansen's test that the elasticities (parameters) did indeed change over time for the studied period,

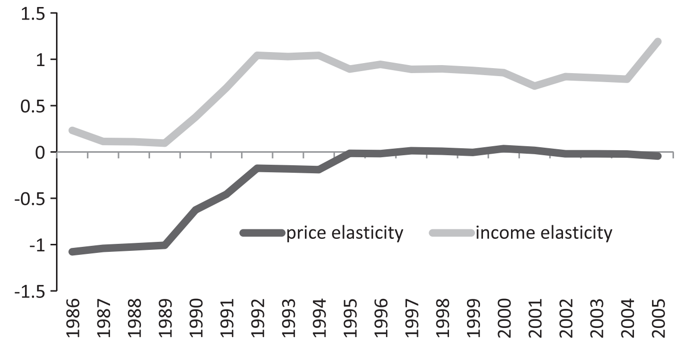

Fig. 3. Price and income elasticities 1986–2005.

the finding of the Kalman filter showed the evolution of the price and income elasticities through the last two decades. It is found that the price elasticity was significantly negative during the 1980s and early 1990s. However, since then, it has become less significant over time with values close to −0.04 (−0.045 in 2005). During the same period, the effect of income to electricity consumption has become more significant from close to zero in the middle of 1980s to almost unit elastic in the 2000s.

There are several points worth noting in this result. The evolution of the estimated price elasticity and the real prices is presented for the period 1986–2005 in Fig. 4. The importance of this picture lies with the fact that the price elasticity started becoming lower, in absolute terms, and therefore price was less significant to electricity consumption while the real prices of electricity started declining. That shows that the higher the real prices are, the higher the price elasticity; hence, the low level of the prices can explain the lack of price impact during the 1990s and 2000s.

Moreover, the price elasticity started becoming less significant while the income showed a higher impact in the electricity consumption (Fig. 3). The economic growth of the country has proven to be one of the main drivers of electricity consumption (Inglesi and Blignaut, 2010). In comparison, electricity prices have almost no effect to consumption trends due to two main reasons: they were relatively low in comparison to international standards and secondly, they were not market-driven but rather a monopolist decision.

Although it is too early to identify the effects of the recent price increases, one can be speculative about it. Initially the first price increases might not affect the electricity consumption significantly and directly since, the price elasticity is close to zero. However, if the real prices return to the high levels (close or higher to the levels of the 1980s) this may lead to changes in the behaviour of electricity consumers and their sensitivity to prices. Hence, price elasticity will become higher than zero again and prices will play an important role in electricity consumption.

These results can also explain the differences in the estimation results between Amusa et al. (2009) and Inglesi (2010). The first study concluded on the insignificance of the electricity price as a factor affecting electricity consumption. That can be connected to the 'almost' zero elasticity values for a period. Therefore, with focus on short-term dynamics (as in Autoregressive Distributive Lag (ARDL) approach employed), price can be estimated as insignificant. It was also confirmed by Inglesi (2010) and Inglesi and Pouris (2010) that in the short-run, price did not play a significant role to the evolution of electricity consumption. In contrast, in the long-run, taking into account that real prices of electricity were higher than in the last part of the period examined, they played a significant role in the overall period.

[1] The average values for the studied time period are −0.237, 0.799, 7.232 for *sv*1, *sv*2 and *sv*3, respectively.

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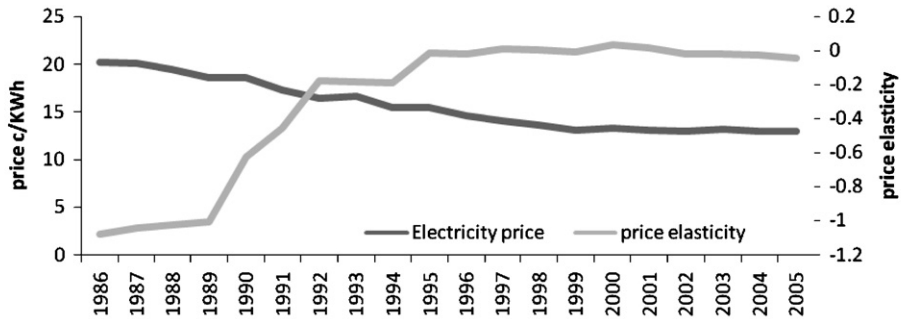

Fig. 4. Electricity prices and price elasticity 1986–2005.
Source: DME (2005) and author's estimation.

6. Conclusion

The analysis of the price elasticity of electricity is not a recent topic in the continuous debate on energy economics of the last decade. Especially, in South Africa the effect of electricity prices to the electricity consumption is of high importance for the energy policy makers after the recurring price hikes applied by Eskom and approved by NERSA. Our paper's contribution to the existing international and local literature is the argument that the price elasticity is a time varying indicator. It changes over time due to a number of reasons such as the economic activity and its importance, the regulation of prices and the level of prices.

We used the Kalman filter to model our assumption of time varying coefficients of price and income with regards to electricity consumption. This technique was preferred for a number of reasons. Firstly, it allows for the components to vary stochastically over time. It is a predictive and adaptive as well as it can be used with non-stationary data. For these reasons, it provides the ideal framework for estimating equation with variables that their impact varies over time.

International and local studies estimated the price elasticity of aggregate (but also residential) electricity within the range of -2–0 and income elasticity between 0 and 2 (Taylor, 1975; Nakajima and Hamori, 2010; Inglesi, 2010). So, it is of high importance to mention that our results for the price and income elasticities are within the previously estimated ranges.

The results show a decreasing effect of electricity prices to electricity consumption during the period examined. This decreasing trend is in contrast with the increasing income elasticity for the same period. An interesting additional finding is that the higher the prices (for example in the 1980s), the higher the price sensitivity of the consumers to changes in prices, that is the price elasticity of electricity is higher for higher levels of real prices.

These results are of great significance for the energy policy makers of the country. NERSA's recent decisions, after Eskom's applications, will lead to higher prices and finally, to pricing structures similar to the 1980s.

Initially the first price increases might not affect the electricity consumption significantly and directly since, the price elasticity is close to zero. However, if the real prices return to the high levels (close or higher to the levels of the 1980s), the energy policy makers need to reconsider the impact of prices in the long-run. Further increases of the electricity prices may lead to changes in the behaviour of electricity consumers and their sensitivity to prices. By focusing their efforts on improving their efficiency levels, the electricity consumers may introduce demand-side management techniques or even turn to other sources of – cheaper – energy, in order to "avoid" the high cost of electricity usage.

Future research would be focused on the investigation of whether the proposed relationship between real prices of electricity and price elasticity holds for other developed and developing countries. It would be of interest also to examine the evolution of income elasticity for other countries. Attention should be paid to cases of countries for which past studies concluded that there is no impact of electricity prices to electricity consumption for certain periods.

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