Revisiting the Causality between Electricity Consumption and Economic Growth in South Africa: Evidence from Bootstrap Rolling Window Approach

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ABSTRACT

This paper revisits the causality relationship between electricity consumption and economic growth in South Africa for the period 1972-2009 using annual data and takes into consideration time variation in causal relationships using bootstrap rolling Granger non-causality tests. Full-sample Granger causality tests find absence of any causality between electricity consumption and economic growth. However, Parameter stability tests indicate that there is instability in our VAR model and therefore findings from full-sample Granger causality test cannot be relied upon. This motivates the use of bootstrap rolling window estimation to investigate the electricity consumption-growth nexus which accounts for the time varying causal link between the two variables. The results indicate two sub periods, 2002-2003 and 2005-2006, whereby electricity consumption had a causal effect on GDP supporting the growth hypothesis. The policy implication is that energy conservation policies could be a hindrance on economic growth since electricity consumption seems to be the driving force behind GDP during these sub periods. Apart for these brief sub periods, the results indicate no causality between the two series. On the contrary, we find that GDP has no predictive power over electricity consumption for the entire sample considered.

Keywords: electricity consumption, GDP, economic growth, causality, bootstrap rolling window

1. INTRODUCTION

Great interest has emerged in the field of energy economics attempting to discover a relationship between electricity consumption and economic growth. The purpose of this study is to investigate this relationship between electricity consumption and economic growth in South Africa for the period 1972-2009 using bootstrap and rolling window estimation techniques applied to Granger causality tests. Numerous studies have investigated this causal nexus between electricity consumption and GDP and report very different and contradictory results. Payne (2010) carried out a study on the electricity consumption - economic growth literature and attributes the variation in results to variable selection, model specification, time periods of the studies and the economic approaches implemented. Moreover, most studies assume that the existence and direction of the causality remains constant over a time period. However, occurrence of certain economic events may affect the trend behaviour of energy consumption and real domestic product (Esso, 2010). Ignoring structural shifts or instability in an economy may result in misleading full sample Granger causality results and therefore testing for parameter stability is of interest to detect whether structural breaks are present in the time series and whether there is the possibility that the causal relationship change over time. To overcome the above issues, Balcilar et al. (2010) utilize bootstrap Granger non-causality tests with fixed size rolling subsamples which analyze the time-varying causal links between two series. This paper employs the same estimation technique.

The novelty in this paper is that we test for Granger causality in a bivariate Vector Auto Regression (VAR) model considering the variation over time using time varying rolling bootstrap causality techniques. Instead of just performing causality test on the full sample which assumes a single causality relationship, we also perform Granger causality tests on the rolling subsamples with a fixed window size. This method allows us to capture any structural shifts in the model as well as the evolution of causal relationships between sup-periods.

The direction of causal relationship between electricity consumption and economic growth can be unidirectional, bidirectional or non-existent. International and local studies have classified their results on the direction of the causality into confirming four hypotheses named ‘growth’, ‘conservation’, ‘neutrality’ and ‘feedback’ (Payne, 2010). Unidirectional causality is distinguished according to whether electricity consumption causes economic growth or economic growth causes electricity consumption. If the direction of causality runs from electricity consumption to economic growth (growth hypothesis), electricity conservation policies would negatively affect economic growth (Ciarreta and Zarraga, 2010; Shahbaz and Shabbir, 2011; Shahbaz and Lean, 2012). If economic growth causes electricity consumption, also called the conservation hypothesis, then conservation policies designed to reduce electricity consumption and waste will have little or no effect on economic growth (Ozturk and Acaravci, 2011).Bidirectional causality implies the feedback hypothesis and that both electricity consumption and economic growth are interdependent and therefore energy saving policies may have a negative effect on GDP. No causality or neutrality indicates the absence of any relationship between economic growth and electricity use and neither conservative nor expansive policies have any effect on economic growth (Chen et al, 2007). The direction of causality has important implications for energy policy and also gives insight on whether a country is energy dependent or not. Shui and Lam (2004) asserts that knowledge of the existence and direction of the causality between electricity consumption and economic growth shed light on future electricity policies, such as conservation programs, the planning of capacity expansion and the construction of nation-wide interconnection of power networks. Therefore it is important to determine whether causality exists between the two variables and in which direction.

South African literature that investigates the bivariate relationship between electricity consumption and economic growth is limited. We therefore report studies on energy and electricity consumption synonymously. Odhiambo (2009) analyses the electricity-growth relationship for the period 1971-2006 and employ the employment rate as an intermittent variable in the bivariate model. The results support the feedback hypothesis in both the short and long run and because South Africa’s electricity production has fallen short behind demand in the past decade, the author recommends policies geared towards the expansion of electricity infrastructure in order to bridge the gap between electricity demand and supply. Many local and international studies tend to focus more on multivariate time series. Wolde-Rufael (2006) explores the bivariate relationship for African countries using the Toda-Yamamoto approach to Granger causality and the result for South Africa indicates no causality between electricity consumption and economic growth for the period 1971- 2001. In this case energy saving policies do not have any effect on GDP. Other research studies which tend to focus more on total energy consumption include Al-mulali and Sab (2012), Menya and Wolde-Rufael (2010), Odhiambo (2010) and Wolde-Rufael (2009) find unidirectional causality flowing from energy consumption to economic growth. All these studies include a third or more variables in the bivariate setting when testing for a causal relationship. Eggoh et al (2011) categorized 21 African countries under investigation into net energy importers and net energy exporters and included prices, labour and capital as additional variables. They find bidirectional causality between energy consumption and economic growth for South Africa for the period 1970-2006 Inglesi-Lotz and Pouris (forthcoming) identified the main difference for the conflicting results to the time periods examined, the econometric approaches and the variables included in the estimation.

. All these studies look at full sample causality using different approaches and time spans. To our knowledge, no studies on South Africa have analysed the causality relationship in a time varying approach.

The literature on causality between economic growth and energy is extensive and has mixed results showing all four hypotheses. However, in cases of multivariate analysis, the presence of causality in a certain direction is often confirmed. On the other hand, the degree of evidence of causality in the bivariate setting seems to be minimal. It is plausible to assume that by adding a third variable in the model the causality between electricity consumption and economic growth could be indirectly affected by the additional variable or variables. The additional variable included in the model will have an effect on both electricity consumption and economic growth and hence may suggest unidirectional or even bidirectional causality even when no causality between the two series. Table 1 shows selected international studies that investigate the causal relationship between electricity consumption and economic growth.

The paper is structured as follows. Section 2 describes the econometric methodology and data used. Section 3 presents and discusses the empirical results. Finally, in section 4, the conclusion and policy recommendation are discussed.

Table 1 Summary of the empirical results from causality tests between electricity consumption and GDP for international countries

Authors	Countries	Time period	Methodology	Conclusion(s)	Other variables included
Abosedra et al. (2009)	Lebanon	01/1995-12/2005	Granger causality	EC→ EG	Change in temperature; relative humidity
Acaravci and Ozturk (2010)	15 Transition economies	1990-2006	Pedroni panel cointegration	No	no
Akinlo (2009)	Nigeria	1980-2006	Granger causality	EC→ EG	no
Bildirici and Kayikci (2012)	Commonwealth Independent States	1990-2009	Panel ARDL test	EC→ EG	no
Chandran et al (2010)	Malaysia	1971-2003	ARDL	EC→ EG	price
Chen et al (2007)	China	1971-2001	Pedroni panel cointegration	No	no
	Hong Kong			EC↔EG	
	Indonesia			EC→ EG	
	India			EG→EC	
	Korea			EG→EC	
	Malaysia			EG→EC	
	Phillipines			EG→EC	
	Singapore			EG→EC	
	Taiwan			No	
	Thailand			No	
Cheng-Lang et al (2010)	Taiwan	1982-2008	Linear and nonlinear causality	mixed results	separate industrial; residential consumption
Ciarreta and Zarraga (2010)	12 European countries	1970-2007	system GMM	EC→ EG	price
Ghosh (2002)	India	1950/51-1996/97	Granger causality	EG→ EC	no
Ahamad and Islam (2011)	Bangladesh	1971-2008	Granger causality	EC↔ EG	no
Gurgul and Lach (2012)	Poland	2000/01-2009/04	Linear and nonlinear causality	EC→EG	employment
Jamil and Ahmad (2010)	Pakistan	1960-2008	Granger causality	EG→ EC	no
Jumbe (2004)	Malawi	1970-1999	Granger causality	EG→ EC	no
Narayan and Smyth(2009)	Six middle Eastern countries	1974-2002	Panel Granger causality	EC↔EG	exports
Narayan and Singh (2007)	Fiji	1971-2002	Granger causality	EC→EG	labour

Lean and Smyth (2010)	Malaysia	1971-2006	Granger causality	EC↔EG	exports
Mozumder and Marathe (2007)	Bangladesh	1971-1999	Granger causality	EG→ EC	no
Narayan and Smyth (2005)	Australia	1966-1999	Granger causality	EG→ EC	employment
Narayan and Prasad (2008)	OECD countries	1970-2002	Granger causality and Bootstrapped	EC→ EG (8 out of 30); no causality for the rest	no
Ouedraogo (2010)	Burkina Faso	1968-2003	Granger causality	EC→ EG	capital formation
Shiu and Lam (2004)	China	1971-2000	Granger causality	EC→EG	no
Wolde-Rufael (2004)	Shanghai	1952-1999	Toda-Yamamoto causality	EC→EG	no
Altinay and Karagol (2005)	Turkey	1950-2000	Dolado-Lutkepohl causality	EC→EG	no
Shahbaz et al (2011)	Portugal	1971-2009	Granger causality	EG→EC	employment
Shahbaz and Lean (2012)	Pakistan	1972-2009	Granger causality	EC↔EG	capital, employment
Shengfeng et al (2012)	China	1953-2009	Granger causality	EC→EG	
Shiu and Lam (2004)	China	1971-2000	Granger causality	EC→EG	no
Shuyun and Donghua (2011)	China	1985-2007	Panel Granger causality	EC↔EG	capital, employment
Squalli (2007)	Algeria	1980-2003	Toda-Yamamoto causality	EG→EC	population
	Indonesia			EC→EG	
	Iran			EG→EC	
	Iraq			EG→EC	
	Kuwait			EG→EC	
	Libya			EG→EC	
	Nigeria			EC→EG	
	Qatar			EC↔EG	
	Saudi Arabia			EC↔EG	
	UAE			EC→EG	
	Venezuela			EC→EG	
Yoo (2005)	Korea	1970-2002	Granger causality	EC↔EG	no
Yoo and Kim (2006)	Indonesia	1971-2002	Granger causality	EG→EC	no
Yuan et al (2007)	China	1978-2004	Granger causality	EC→EG	no

Note: EC→EG means that causality runs from electricity consumption to economic growth.
EG→EC means that causality runs from economic growth to electricity consumption.
EC↔EG means that bidirectional causality exists between electricity consumption and economic growth.

2. METHODOLOGY

2.1 Econometric Model

According to Engle and Granger (1987), a time series (*X*) is said to granger cause another time series (*Y*) if the prediction error of current *Y* declines by using past values *X* in addition to past values of *Y*. In this paper we employ granger causality tests and apply them to a bivariate VAR model to find the causal relationship between economic growth and electricity consumption. The test statistics used in our Granger causality tests are the Likelihood ratio and Wald statistics. A disadvantage of standard Granger causality tests in VAR's has to do with their non-asymptotic properties when the variables in the model are integrated or cointegrated or when the sample size is too small. We employ the Toda and Yamamoto (1995) modified Granger causality test which has the advantage that it can be applied to series integrated of any order whether cointegrated or non-cointegrated whilst producing valid asymptotic critical values. To address issues of sample size, we use bootstrapping granger causality tests which are robust against small sample size and pre-testing bias. The study employs the residual based bootstrap (RB) technique used by Balcilar et al. (2010). The RB method provides robust critical values when testing Granger causality as demonstrated by Shukur and Mantalos (1997a, 1997b); Mantalos and Shukur (1998); Shukur and Mantalos (2000) and Mantalos (2000). Hence, we carry out the bootstrap technique with Toda and Yamamoto modified version Granger causality test.

To test for the presence of unit root we use augmented Dickey Fuller (ADF) tests, Phillip Perron and Ng-Perron test which take in to account serial correlation in error terms and have the same asymptotic distribution. The following test specification is employed to test for unit root

$$\Delta y_t = \beta_0 + \delta y_{t-1} + \sum_{i=1}^{k} \alpha_i \Delta y_{t-i} + e_t \qquad (1)$$

Where Δ represents the first difference of the series y_t and e_t are independent identically distributed (IID) error terms. The lag length is selected using the Akaike Information Criterion (AIC). Furthermore, if the stationarity tests show that our variables possess unit roots, we also investigate for a cointegrating relationship between variables using the Johansen (1991) maximum likelihood test. According to Engle and Granger (1987), if a cointegrating relationship between variables exists then we expect causality in at least one direction.

The methodology in this paper follows Balcilar et al (2010) paper on the causal nexus between energy consumption and economic growth for G7 countries. In their paper, they attribute the highly differentiated and contradictory causal relationships to small sample size, structural changes or regime shifts and how different literature handles the trending properties of data. To overcome these issues, Balcilar et al (2010) uses the bootstrap tests and rolling window estimation techniques. Bootstrap granger causality tests are applied to both the full sample and rolling window subsamples where causality is tested over different time periods.

In time series analysis we often assume that the parameter estimates are stable over time. However, policy changes and the continuously evolving economy may render this stability assumption as inappropriate. We thus have to take into account the model stability or instability properties in order to obtain reliable results. To do this we implement tests for parameter constancy. There may be subsample periods in which causality is found between variables, whether unidirectional or bidirectional, and other subsample periods where no evidence of causality is found to exist. We perform parameter stability tests on the VAR to investigate whether any structural breaks may have occurred over the span of our time period or whether estimated coefficients are stable. The Sup-F, Exp-F, Mean-F and Nyblom-Hansen L_c tests are used to check parameter instability and structural change.

If evidence of non stable parameters is reported by any of the stability tests then it is possible to detect in which period or sub periods the instability occurred and whether there is any likely phenomenon that may have caused it. This is done using rolling regressions in conjunction with granger causality tests. The rolling estimation method produces numerous parameter estimates which are more or less alike for the system to exhibit stability. If a time series exhibits parameter estimates that differ substantially from others, i.e. large fluctuations, the model is likely to suffer from instability and results of the estimation will probably be unreliable. Therefore, we employ rolling window granger causality tests which detect structural change and may give different causality results over the rolling subsamples of data.

We consider the following bivariate VAR model:

$$y_t = \Phi_0 + \Phi_1 y_{t-1} + \cdots + \Phi_p y_{t-p} + \varepsilon_t \qquad \mathrm{t} = 1,2,...,\mathrm{T} \qquad (2)$$

Where $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t})'$ is a white noise process with zero mean and covariance matrix ∑. The lag order p is determined by the Akaike Information Criterion. We can partition y_t into two subvectors y_{1t} and y_{2t} representing electricity consumption and GDP respectively and write equation (1) in the following compact form

$$y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \begin{bmatrix} \phi_{10} \\ \phi_{20} \end{bmatrix} + \begin{bmatrix} \phi_{11}(L) & \phi_{12}(L) \\ \phi_{21}(L) & \phi_{22}(L) \end{bmatrix} \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix} \qquad (3)$$

Where $\phi_{ij}(L) = \sum_{k=1}^{p} \phi_{ij,k} L^k, i, j = 1,2$ and the lag operator is defined as $L^k x_t = x_{t-k}$.

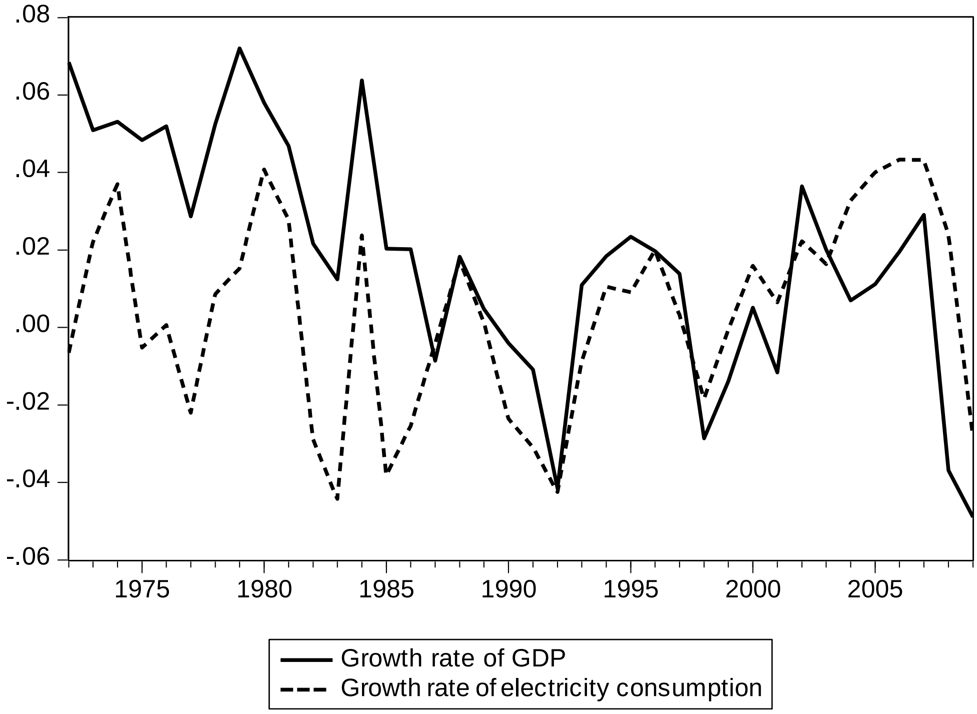
We can test the hypothesis that GDP does not granger cause electricity consumption by imposing the zero restriction $\phi_{12,i} = 0$. In a similar manner, we can test the null hypothesis that electricity consumption does not granger cause GDP with the restriction $\phi_{21,i} = 0$ for $i = 1, \cdots, p$.

The justification for using bootstrap granger causality test with rolling estimation instead of the traditional granger causality test lies in the fact that traditional granger causality test assume parameters are constant over time which may result in incorrect inference. Rolling window granger causality tests based on the bootstrap method enable us to investigate structural breaks in the model. By using rolling estimation, the causal link between variables is detected as it evolves over time and we are able to capture any structural changes as well as causal relationship for rolling different subsamples.

2.2 Data

We employ annual aggregate data for real GDP and real electricity consumption for the sample period 1972-2009. The starting period under consideration was based on availability of electricity consumption data. The data was mainly extracted through Quantec data bases and sourced from the World Bank (World Economic Indicators/Global Development Finance). Electricity consumption is described as electric power consumption and measures the production by power plants. Electricity consumption is measured in kilowatts per hour (kWh); while GDP is measured at constant 2005 prices in millions of Rand. Both variables are transformed into their growth rates and used in their natural logarithm form. Fig. 1 shows the trending properties of the data for the period 1972 to 2009 and reveals a strong correlation between the two variables and also a considerable amount of volatility of the series.

Figure1: South African Growth Rates of GDP and EC



Source: World Bank (World Economic Indicators/Global Development Finance)

4. EMPIRICAL RESULTS

We test for unit root of the two series using the ADF, the Phillip (1987) and Phillips and Perron (1988) and the Ng-Perron tests for stationarity. We use three separate specifications: the one including only a constant; the second including a constant and a trend and the last one with none of the two. Critical values are computed by Mackinnon (1996). The tests show that both electricity consumption and GDP are non-stationary in their levels but after differencing once, they become stationary (integrated of order one - *I(1)*). Results of these tests are reported in the appendix.

The next step is to detect a long run relationship between the variables given that both series are integrated of the same order. We apply the Johansen (1991) maximum likelihood test for cointegration. Starting from p = 1 to p = 5 we sequentially increased the lag length by one and the Akaike information criterion selects one as the optimal lag length of our VAR. The results of the Johansen cointegration tests are summarised in Table 2. The null hypothesis of the test is no cointegation between electricity consumption and GDP against the alternative that cointegration exists. Both the trace test and maximum Eigen value test have statistics that are below the critical values at the 5 percent level of significance when testing for the null that r = 0 which implies that we cannot reject the null hypothesis of no cointegration at a 5 percent level of significance. Hence both tests confirm that no long run relationship exists between the series. We therefore employ a VAR when testing for causality relationship of the two series.

Table 2: Johansen cointegration test

Series	Null Hypothesis	Alternative Hypothesis	Trace Test	Maximum Eigen Value test
Electricity consumption and GDP	r = 0	r > 0	12.092	9.775
	r ≤ 1	r > 1	2.317	2.317

Notes: One-sided test of the null hypothesis that the variables are cointegrated. The critical values for the trace and maximum eigen value tests come from Osterwald-Lenum(1992) and the 5-percent critical values equal 15.49 and 14.26, respectively, for testing r = 0 and 3.84 and 3.84, respectively , for testing r ≤ 1.
** indicates significance at the 5 percent level

After establishing that our series are I(1) and no cointegration exists in the model, we perform a full sample Granger causality test. Since no cointegration exists, we test causality using our bivariate VAR instead of a Vector error correction model (VECM). Although no cointegration is detected between electricity consumption and GDP, short run causality may still exist between these series. Full sample Granger causality test is constructed based on the bootstrap Likelihood ratio and Wald test statistics for the sample period 1972-2009. Table 3 shows the full sample Granger causality test results. The results suggest that we cannot reject the null hypotheses that electricity consumption does not Granger cause GDP and also that GDP does not Granger cause electricity consumption at a 5 percent level of significance. This result from full sample bootstrap Granger causality tests support the neutrality hypothesis and show that neither electricity consumption nor GDP have any predictive power over each other in the short term for South Africa.

Table 3: Full-Sample Granger Causality Tests

	H_0: Electricity Consumption does not Granger cause GDP		**H_0: GDP does not Granger cause Electricity Consumption**	
	Statistics	***p*-value**	**Statistics**	***p*-value**
Bootstrap *LR* Test	0.040	0.866	3.338	0.128
Bootstrap Wald Test	0.040	0.866	3.531	0.128

Moreover, investigating temporal stability of the coefficients of our estimated VAR model is important in order to confirm validity of our full sample causality results. If the parameter estimates are in fact stable over the full sample period, we conclude that our full sample Granger causality results are valid. On the contrary, if parameter estimates are found to exhibit temporal instability and the consequence being unreliable full sample Granger causality results therefore necessitating the investigation of the periods in the sample for which instability occurs. Structural breaks may create shifts in parameters and the pattern of causal relationship may change over time due to these shifts (Balcilar et al, 2012). It is for this reason that different studies using varying sample periods may give conflicting causality results. Therefore it is imperative that we test for parameter stability and the possible causes of such change in parameters. The Sup-F, mean-F and Exp-F tests are used to test for the short run stability of parameters. The Sup-F, mean-F and Exp-F test the null hypothesis of parameter constancy against the alternative, parameter instability. The Sup-F test is used to test whether a swift regime shift had occurred whilst the Exp-F and Mean-F tests, determine whether the model was stable over time (Balcilar et al, 2010). We also conduct the Nyblom (1989) and Hansen (1992) L_c test for parameter constancy of all the parameters in the system jointly with our variables integrated of order one. This test can be also be used as a test for cointegration for individual equations.

According to Andrews (1993) we trim the ends of the latter short run stability tests and perform the tests on the trimmed sample. Fifteen percent of the ends are trimmed and sample is reduced to [0.15. 0.85] which is the sample that is tested for parameter instability. These stability tests have the advantage that they do not require prior knowledge of the timing of the structural break. The results of the stability tests are shown in Table 4.

The parameter stability results overall indicate that there exists structural breaks in our sample implying instability in our model. The Nyblom-Hansen L_c testing joint stability of the *Var*(1) system does not reject the null hypothesis of parameter constancy for the system. Therefore there is no evidence of structural breaks and the model exhibits joint stability. The Mean-F, Exp-F and Sup-F tests all detect some instability in the model. The Mean-F and Sup-F test statistics show that there is parameter instability in the electricity consumption equation as the null hypothesis is rejected at a 1 percent level of significance. However, the null hypothesis of parameter constancy is not rejected by the Exp-F test in the electricity consumption equation. All other three sequential tests, the Mean-F, Exp-F and the Sup-F tests are consistent with instability of parameters in the GDP equation since the null hypothesis is rejected at a 1 percent level of significance. Moreover, all three short run stability tests statistics reject the null hypothesis of constant parameters at a 5 percent level of significance for the system as a whole. From our stability test results, we can conclude that our model has non constant parameters over the sample period implying that the full sample results cannot be relied on and are ultimately invalid.

Table 4: Parameter Stability Tests in *VAR* (1) Model

	Electricity Consumption Equation		**GDP Equation**		***VAR*(1) System**	
	Statistics	**Bootstrap *p*-value[b]**	**Statistics**	**Bootstrap *p*-value**	**Statistics**	**Bootstrap *p*-value**
Mean-F	8.79**	0.01	10.04***	<0.01	12.02**	0.02
Exp-F	32.07	0.67	25.93***	<0.01	9.04**	0.01
Sup-F	70.81***	<0.01	58.52***	<0.01	23.33**	0.01
L_c for system[a]					1.14	0.29

Notes: *, ** and *** indicates significance at 10, 5 and 1 percent, respectively
[a]Hansen-Nyblom tests for parameter stability for the system jointly
[b]p-values are obtained with 2000 replicates

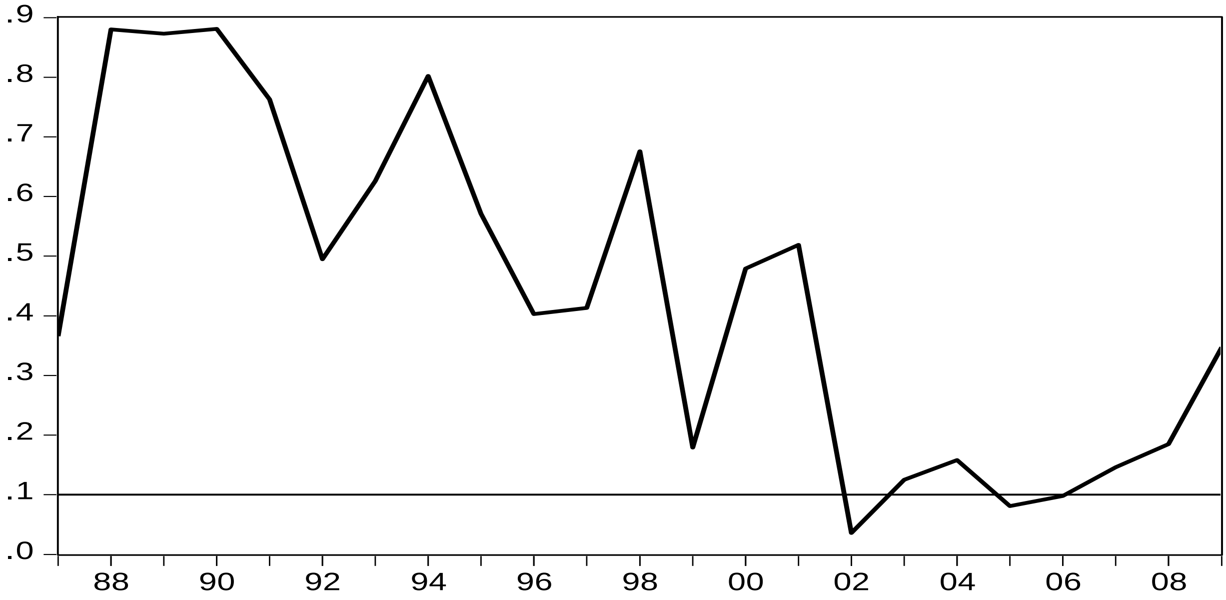
The stability tests established that structural shifts are present in the model and this gives us enough motivation to employ rolling window method in the estimation of our VAR (1) model allowing us to capture any structural changes in the model. In rolling regressions, we begin with a fixed sample size and roll the subsample, updating our rolling regressions by deleting the first observation at the start of the sample and adding one more observation at the end of our sample. The advantage of the rolling window regression technique pointed out by Balcilar et al. (2010) is that we are able to determine how the system evolved over time as well as detect subsample instability in the system. The number of observations in the benchmark subsample is known as the window size and can be chosen based on the expected accuracy and precision of parameter estimates. We select a 15 year window period. According to Balcilar et al (2013) the choice of the window size is an important aspect to consider as it determines the number of rolling estimates. They state that the larger the window size, the greater the precision of estimates although in the presence of heterogeneity there may be less representativeness of parameters. On the other hand, a smaller fixed window size may increase representativeness and heterogeneity but may lead to large standard errors which result in biased parameter estimates. When choosing our window size, *l*, we have to take into account these two aspects and try and establish a balance between the accuracy and representativeness. Following Balcilar et al (2010), we opt for a smaller window size of 15 to guard against heterogeneity. For a small window size, the bootstrap method applied to all 23 causality tests will produce more precise estimates.

Instead of estimating one causality test, we have *t-l* sequence of causality tests to estimate. This implies that we have to estimate a sequence of 23 subsamples and perform bootstrap causality tests on each subsample. We estimate our VAR for the 15 year fixed window period rolling through the sample and test the null hypothesis that electricity consumption does not Granger cause GDP and that GDP does not Granger cause electricity consumption. We calculate and plot the p-values produced by our residual based bootstrap causality tests and analyse the graphs for any drastic fluctuations in the parameter values which may imply parameter instability.

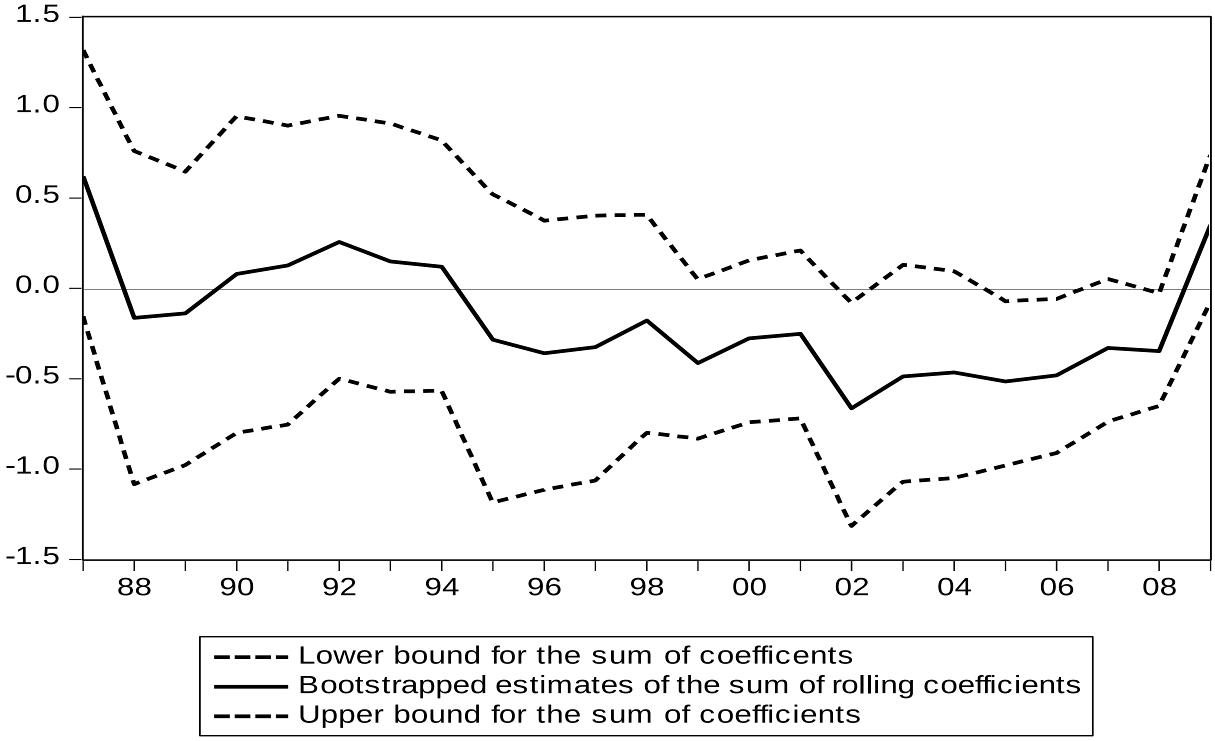
To ascertain structural shifts over our subsample, bootstrap p-values of the LR statistic are calculated rolling through the sample period from 1972-2009 and make use of the RB technique. Using the estimation of our VAR in equation (2) we roll through our sample, $t = \tau - 14, \tau - 13, . . . , \tau, \tau - 15, \ldots , T$ with a fixed window period of 15. The p-values obtained test the null hypothesis that GDP does not Granger cause electricity and vice versa. Following Balcilar et al (2010), we compute the magnitude of the impact of GDP on electricity consumption and the magnitude of electricity consumption on GDP. The mean of all bootstrap estimates measuring the effect of GDP on electricity consumption and the effect of electricity on GDP are calculated and are given by $N_b^{-1} \sum_{k=1}^{p} \hat{\phi}^*_{21,k^*}$ and $N_b^{-1} \sum_{k=1}^{p} \hat{\phi}^*_{12,k^*}$, respectively where N_b is the number of bootstrap repetitions. $\hat{\phi}^*_{21,k^*}$ and $\hat{\phi}^*_{12,k^*}$ are the bootstrap least squares estimates for the VAR in equation (3). The 90 percent confidence intervals are calculated, where the lower and upper bound equal the 2.5th and 95th quantiles of each $\hat{\phi}^*_{21,k^*}$ and $\hat{\phi}^*_{12,k^*}$, respectively.

Figure 2 and 3 plot the rolling window estimates for South Africa and shows their variation over time. Panel (a) and (b) of Figure 2 show the bootstrap p-values of the rolling test statistics testing the null hypothesis, electricity consumption (EC) has no effect on the growth and the magnitude of the impact of EC on GDP, respectively.

Figure 2



(a) Bootstrap p-values testing the null hypothesis that EC does not Granger cause GDP

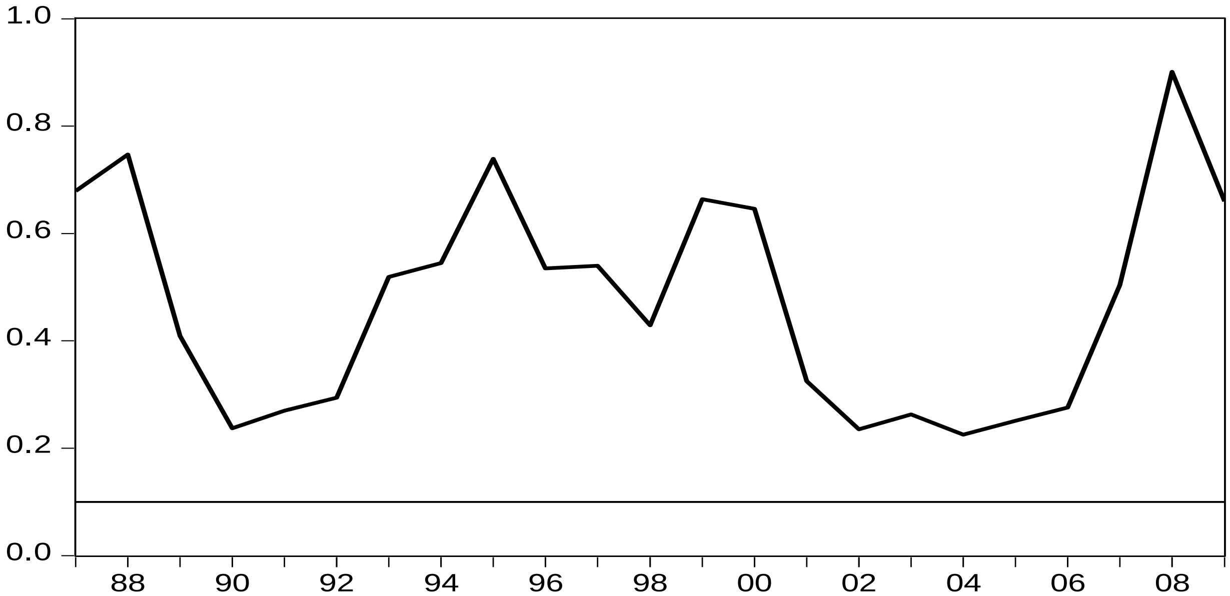


(b) Bootstrap estimate for the sum of the rolling coefficients for the impact of EC on GDP

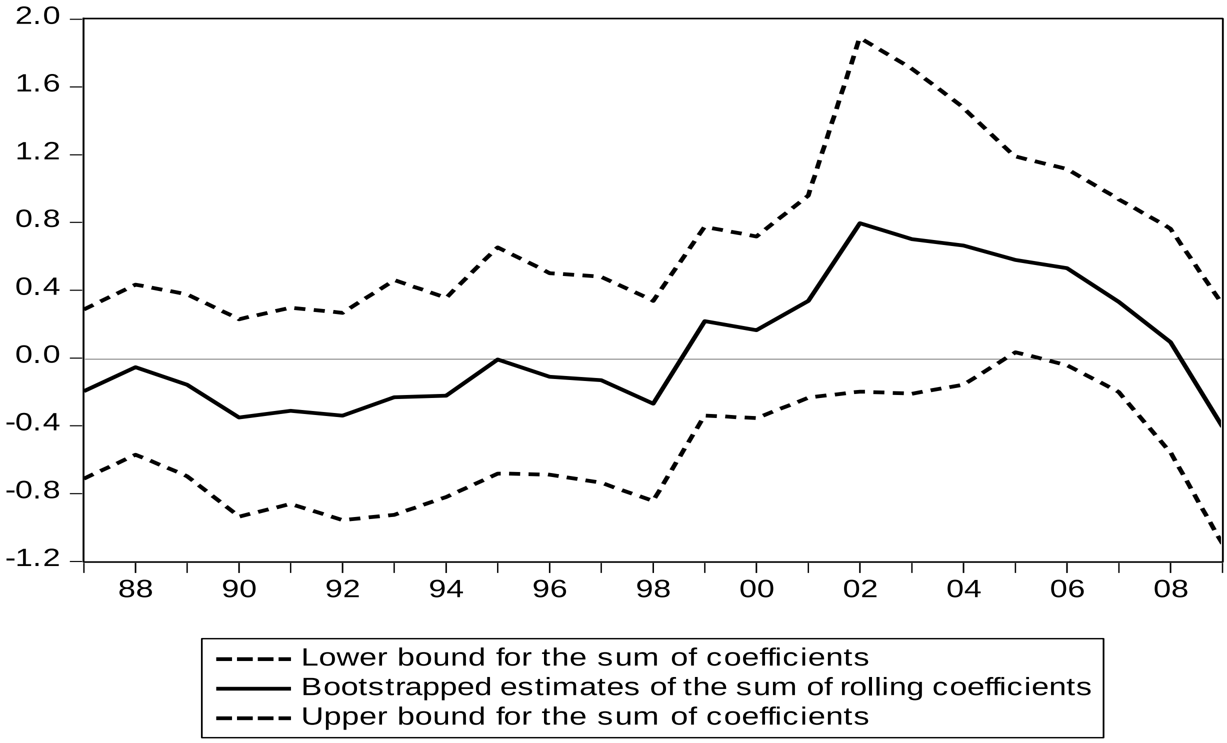
We do not reject the null hypothesis that EC does not Granger cause GDP for most of the sample, however, there are brief sub periods where we reject the null hypothesis. We reject the null hypothesis that EC does not Granger cause EC at a 10 percent level of significance in panel (a) of Figure 2 during the sub periods 2002-2003 and 2005-2006 and conclude that EC has an impact on GDP during these periods. Panel (b) of Figure 2 shows the bootstrap estimate of the sum of rolling window coefficients testing the null EC does not granger cause GDP and indicates that from 2002-2003 EC had negative predictive power over GDP of about -0.6 and is statistically significant. In 2005-2006, EC had negative predictive power on GDP of around -0.5 and is also significant.

Panel (a) and (b) of Figure 3 show the bootstrap p-values of the rolling test statistics testing the null hypothesis that GDP does not Granger cause EC and the magnitude of the impact GDP on EC, respectively. In Figure 3(a), we cannot reject the null hypothesis that GDP does not Granger cause EC for the whole sample spanning from 1987-2009. This implies that during the whole sample period under consideration, GDP appears to have no predictive power over EC. Figure 3(b) shows that the sign of the impact of GDP on EC is positive from 1999 but is only just significant in 2005. Our results are inconsistent with the full sample Granger causality results reported in Table 3.

Figure 3



(a) Bootstrap p-values testing the null hypothesis that GDP does not Granger cause EC



(b) Bootstrap estimate of the sum of the rolling coefficients for the impact of GDP on EC

The results from the full sample bootstrap Granger causality tests, which show absence of a relationship between electricity consumption and GDP, are complementary with similar studies conducted by Ziramba (2009) and Wolde-Rufael (2006). Both these studies employed the Toda and Yamamota causality technique. However, in our study, bootstrap rolling window tests show some sub periods whereby neutrality does not hold. For the period ranging from 1987 to 2001, causality test support the neutrality hypothesis consistent with the full sample Granger results and only in 2002 and onward does variation from full sample test results occur for some sub samples.

The 2002-2003 sub - period relates to a short post recession period that hit the United States of America causing collapse of the stock market and contractions in GDP thereby inducing a global downturn in economic activity. This was further exacerbated by the *September 11* terrorist attacks which also had a declining effect on global stock markets. These attacks sparked a lot of uncertainty and a fall in confidence levels in the world markets thereby reducing the stimulus to spend by firms and consumers. Moreover, these events also had effects on the price of oil causing a decline in the oil price.

Moreover, in 2001 the Free Basic Electricity (FBE) was established in South Africa assisting a big number of households with their basic needs of energy. In 2002-2003 in the

Government Gazette, the policy was also complemented with ways to promote the National Electrification programme. The allocation of free basic electricity was set at 50kWh for the average poor household. This led to increased electricity consumption levels.

The period 2005-2006 coincides with periods in which Eskom embarked on massive capital expenditure in attempt to add to and maintain existing power stations and prevent electricity shortages by keeping up with rising electricity demand. Additionally, during this period South Africa and the world experienced high growth rates averaging approximately 5 percent (Statistics South Africa, 2012) but later falling as a result of the 2008 global credit crisis. Moreover, in 2004 South Africa began preparations for the 2010 world cup and the massive infrastructure investment projects that took place were expected to accelerate growth in the country.

To sum, over time there may exist structural breaks in estimation which may alter the parameters in the regression. In light of the events discussed, it follows that structural changes that occur in the global economy can impact whether electricity consumption has a causal relationship with GDP or vice versa. The rolling window estimation technique captures substantial changes in parameters therefore allowing us to detect such structural changes and find possible reasons for the variation in the parameters. Our Granger results show that over time there have been structural shifts that produced different causality results.

5. Conclusion

The paper investigated the causal relationship between electricity consumption and GDP growth for the South African economy focusing on the period between 1972 and 2009. Employing a bivariate VAR, stationarity and cointegration were tested and indicated that electricity consumption and GDP are integrated of order one and that no long run relationship was found between the two series. Full sample Granger causality test found absence of a relationship between electricity consumption and economic growth. Stability of parameter estimates was tested and instability was detected in the parameters which allowed us to investigate any structural shifts in our model. Moreover, the innovation in our study is that we considered time varying parameters, thereby necessitating bootstrap rolling window regression method applied to the Toda and Yamamoto modified test for causality which have the advantage that they do not take into consideration whether variables are integrated or cointegrated when testing.

The parameter stability tests indicate that there are structural shifts in our model and thus we cannot entirely rely on full sample Granger results as they do not account for stability of the parameter estimates. The bootstrap rolling window regression show that during sub periods 2002-2003 and 2005-2006, electricity consumption had predictive power over GDP. This outcome is in line with the growth hypothesis meaning that electricity saving polices during these periods would have reduced economic growth. On the other hand, we found no evidence in favour of economic growth causing electricity consumption (conservation hypothesis) and in this case, energy saving policies aimed at reducing the level of carbon emission will not have affect economic growth. According to these results we can deduce that Granger causality between electricity consumption is weak because for most of the period 1986-2001, Granger causality tests on rolling subsamples indicate that there is no causality between electricity consumption and economic growth meaning that energy conservation nor expansion policies will have an effect. Different directions of causality unfolding over time need different policy responses and therefore an individual policy may not be suitable at each and every time period. It is also important to note that policy responses to economic events have a delayed effect and hence a policy may not be suitable in future periods.

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Appendix

Appendix A: Unit Root Test Results

Variables	constant	constant and trend	none
Panel A: ADF tests			
LEC	-6.08***	-1.687	0.782
LGDP	-1.727	-1.624	0.547
First Differences			
ΔLEC	-2.586	-3.784**	-2.591**
ΔGDP	-3.588**	-3.549**	-3.582***
Panel B: Phillip-Perron tests			
LEC	-5.412***	-2.166	2.202
LGDP	-0.814	-0.562	0.777
First Differences			
ΔLEC	-2.466	-3.805**	-2.437**
ΔGDP	-3.572**	-3.419*	-3.565***
Panel C: Ng Perron tests			
LEC	-0.848	-4.644	
LGDP	-9.868**	-8.402	
First Differences			
ΔLEC	-7.679*	-15.25*	
ΔGDP	-14.292***	-15.127*	

Notes: *, ** and *** indicate significance at the 10, 5 and 1 percent, respectively.