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RE-VISTING THE ELECTRICITY-GROWTH NEXUS IN SOUTH AFRICA

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ABSTRACT: This research study contributes to the ever-expanding literature by examining multivariate cointegration and causality relationships between electricity consumption, economic growth and other growth determinants for quarterly South African data collected between 1994/Q1 – 2014/Q4. The motivation behind this current research case study becomes apparent when taking into consideration that no previous studies have gone further than bivariate and trivariate analysis in investigating the electricity-growth nexus in South Africa. In conducting our empirical investigation, our obtained empirical results are two-fold in nature. Firstly, we find significant multivariate long-run cointegration relationships between economic growth, electricity consumption and other growth determinants. Secondly, our empirical analysis offers support in favour of the neutrality hypothesis, that is, the notion of no causal effects existing between electricity consumption and economic growth in the long-run. However, we find that exports directly cause electricity consumption whereas economic growth, domestic investment and employment levels causally flow to exports.

Keywords: Electricity consumption, Economic growth, Investment, Inflation, Employment, Exports, Co-integration, Granger causality, South Africa.

JEL Classification Code: C22, C32, Q43.

1. *INTRODUCTION AND MOTIVATION OF THE STUDY*

Even though relatively novel in its placement within the academic paradigm, the empirical investigation into the effects of electricity consumption on economic growth has proven, beyond reasonable doubt, to be a highly relevant issue from a policy perspective. This observation becomes more apparent, within the South African context, when contemplating on the recent 2014-2015 energy crisis which led to a series of blackout events that threatened to destabilize the economy's national electricity grid layout. The aforementioned South African energy crisis has taken both academic connoisseurs and other observers by surprise seeing that South Africa has always held a reputation for maintaining an excess supply of energy as well as being particularly renowned for being well-endowed with energy resources which remain untapped. Therefore, in wake of the economy's current energy crisis, the interrelationship between electricity usage and economic growth in South Africa necessitates the need for more academic attention, especially when considering that the repercussions of the energy crisis continues to be felt within the economy even up-to-date. Such academic efforts could possibly prove to be of significant value in the construction or evaluation of practical policy remedies.

From a pragmatic point of view, a number of academic concerns can be raised when attempting to 'shed light' on the South African energy issue at hand. First and foremost, it may be questioned as to whether the current energy crisis is aggravated by a lack of energy infrastructure or whether it is caused by a hindrance in economic growth or even possibly by a combination of these factors. Empirically, these issues are typically addressed by examining whether there are any causal relationships between electricity consumption and economic growth. So far the literature identifies four possible causal relations that can exist between the two variables; those being (1) causality running from electricity consumption to economic growth (i.e. growth hypothesis); (2) causality from economic growth to electricity consumption (i.e. conservation hypothesis); (3) bi-directional causality between the two variables (i.e. feedback hypothesis); and (4) no causality between the time series (i.e. neutrality hypothesis). The first type of causality implies that the current energy crisis would exert an adverse effect on output productivity within the economy. Under the second type of causality, improvements in economic growth would cause an increase in electricity usage which could further aggravate the energy crisis, that is, if appropriate energy demand-supply management strategies are not put in place. The third type of causality implies that contemporaneous policies which simultaneously affect the two variables would suffice in minimizing the current negative consequences of the energy crisis on overall economic activity. Lastly, the fourth type of causality renders no effectual relationship between the pair of time series variables such that policies direct at economic growth, on one hand, and those directed at electricity consumption, on the other hand, should be treated as independent and separate stratagems.

In addition to the above-specified concerns, it may be further questioned as to whether there are other alternative economic channels linking electricity consumption to economic growth. Identifying such alternative channels of influence could provide policymakers with possible avenues through which they may be able to control electricity consumption through economic growth, or control economic growth through electricity consumption. This issue is of particular academic relevance given that the existing literature up-to-date concerning South African data tends to be prone to the omission of relevant variables in the empirical analysis. As thoroughly discussed in Lutkepol (1982), this may possibly lead to biasness in the obtained empirical results due to an oversimplifying of the actual electricity-growth relationship. And in addition to such empirical complexities, there exist no clear-cut theoretical guidelines which connect electricity consumption to economic growth or vice versa, and hence a great amount of caution must be used when attempting model the multivariate relationship between electricity consumption and economic growth. On a positive note, the literature does identify at least three other significant economic variables which could be included in the estimation regression, those being CPI inflation (Kahsai et. al., 2012), investment (Wolde-Rufael, 2010), exports (Narayan and Smyth, 2009) and labour force participation which is frequently proxied by employment rates (Apergis and Payne, 2011), all which we consider in our current study.

Therefore, in our current research study, we contribute to the ever-expanding literature by examining the multivariate relationship between electricity consumption and economic growth in South Africa for quarterly data spanning between the periods 1970 and 2014. The motivation behind and the contribution of this current research case study becomes apparent when taking into account that no previous studies have gone beyond bivariate or trivariate frameworks in investigating cointegration and causality effects in the electricity-growth nexus exclusively for South African data. As means of achieving this objective, we employ the vector error correction (VEC) framework of Johansen and Julius (1990) as well the conventional causality tests in the Granger (1969) framework. Our paper therefore follows a host of other empirical works inclusive of Paul and Bhattacharya (2004), Mozumber and Marathe (2007) and Shahiduzzaman and Alam (2012), who have used similar frameworks and yet, to the best of our knowledge, our paper is the first which applies this framework exclusively to South African data. Thus against this backdrop, we structure the remainder of the research paper as follows. The following section presents an overview of electricity usage in the South African economy. The third section of paper provides a review of the associated literature. The fourth section introduces the data as well as the empirical framework of the study whereas we conclude the study in the fifth section of paper in the form of policy recommendations and possible avenues for future research.

2. *AN OVERVIEW OF ELECTRICITY USAGE IN SOUTH AFRICA*

South Africa is frequently hailed as being amongst the leading powerhouses in terms of electricity provision, not only within the Southern African region, but also on a global platform. Boasting one of the largest dry-cooled power stations in the world (i.e. Matimba power station) as well as operating the only official nuclear power station in Africa (i.e. Koeberg nuclear plant); South Africa is ranked amongst the top seven in generating capacity and is also highly recognized as being one of the four cheapest producers of electricity worldwide. According to the Department of Energy (DoE) and other local editorial statements, an estimated 92 percent of South Africa’s electricity is generated by coal-fired power stations; another 7 percent is generated by nuclear stations; whereas the remaining 1 percent or so is provided by hydroelectric and pumped storage schemes. It is also worth noting that South Africa’s electricity supplying activities are not domestically constrained, as the economy is also responsible for supplying approximately two-thirds of Africa’s electricity. Within the Southern African Development Community (SADC) region, South Africa supplies electricity to other neighbouring countries such as Lesotho, Swaziland, Botswana, Namibia, Mozambique and Zimbabwe which roughly accounts for about 2 percent of total net energy produced nationally. It has also been previously reported that South Africa occasionally imports electricity directly from Mozambique, Zimbabwe, Zambia and the Democratic of Congo (DRC).

Electricity generation in South Africa is dominated by the Electricity Supply Commission (ESKOM), the state-owned, partially-monopolistic company, which supplies approximately 95 percent of the country’s electricity. ESKOM operates within an integrated national high-voltage transmission system which is responsible for supplying nearly 60 percent of electricity produced directly to commercial farmers, mining companies, mineral beneficiaries and other large institutions; whereas the remaining 40 percent is indirectly allocated to residential consumers. In allocating electricity to residential sectors, ESKOM carries its activities through the Integrated National Electrification Programme (INEP) by selling bulk to amalgamate municipal distributors who repackage and then resell compatible units to consumers within their designated jurisdictions. In referring to domestic electricity consumption, it is estimated that over 75 percent of South Africa's population have access to electricity, which is a figure well above the SADC average of less than 25 percent. In fact, over the last decade or so, there have been a number of reports which have emerged, claiming that the economy as a whole has increased its electricity consumption at rate which marginally exceeds that of its production counterpart. This is evident from the 2008 as well as the recent 2014-2015 power crisis which saw ESKOM fail to supply enough electricity in response to escalating electricity demand which resulted in a nation-wide load shedding scheme. Odhiambo (2010) describes this load-shedding strategy as "...a last resort [used by ESKOM] to prevent a system wide blackout [in order to have enabled] ESKOM to bring the demand for electricity slightly closer to its supply, while at the same time maintaining a reasonable reserve margin...".

Subsequently to the 2008 electricity crisis, a number of initiatives have been proposed as a means of improving the overall effectiveness as well as facilitating the efficiency of energy supply in South Africa. Up-to-date, a vast majority of South Africa's energy woes have been blamed on the country's historical energy structure which is characterized by an energy-intensive sector built almost exclusively upon coal-based power generating schemes. Besides placing unwarranted pressure on mining new coal deposits, heavy reliance upon the coal-based scheme has resulted in extremely high levels of carbon emissions; of which ESKOM is currently ranked as the second largest power utility emitter of CO_2 globally. Therefore, particular emphasis on the future development of power generating schemes is currently being directed towards increasing reliance upon alternative power sources which are capable of producing electricity with environmental benefits. The key challenge is for South African energy authorities to move to a cleaner, more efficient use of energy supply, while extending affordable access to modern energy services (Winkler, 2005). Currently, the South African government is embarking on both medium and long-term programmes, which are meant to enable the country to efficiently cope with the future demand for electricity (Odhiambo, 2009). On the forefront of these programmes, the Department of Energy has formulated an Integrated Resource Plan (IRP) which outlines a mix of energy sources aimed at obtaining the most energy efficiency trade-off between least investment cost, climate change, mitigation, diversity of supply localization and regional development (Roula, 2010). The particular IRP energy mix consists of a target 48 percent coal; 13.4 percent nuclear energy; 6.5 percent hydro; 14.5 percent other renewable energy; and 11 percent peaking open cycle gas turbine; which are general targets planned set to be achieved by 2030. Therefore, in order for energy authorities to successfully usher in these future prospects, it is quite essential for energy authorities to acquire a growing understanding of the evolving empirical interrelations between electricity consumption and economic growth.

3. *REVIEW OF THE ASSOCIATED LITERATURE*

The causal relationship between energy consumption and economic growth has been extensively studied following the seminal work of Granger (1969). One of the earliest studies conducted on the causal relationship between energy and growth was researched by Kraft and Kraft (1978) using data for the United States of America collected between the periods 1947 to 1974. The study revealed unidirectional causality from economic growth to energy consumption. Since then, the causal relationship between energy consumption (hence electricity consumption) and economic growth has been vigorously examined albeit for different economies using a variety of econometric techniques. The literature is filled in abundance with differing methodologies for evaluating the relationship between electricity consumption and economic growth. In testing for cointegration the popular methods among the authors are the Engle-Granger (EG) two-step cointegration testing procedure (Engle and Granger, 1987), the conventional cointegration tests developed by Johansen and Juselius (1990); the bounds test of Pesaran et al. (2001); and the newly developed error-correction model (ECM)-based *F*-test of Kanioura and Turner (2005). On the other end of the spectrum, the conventional granger causality tests and the modified Wald (MWALD) test of Toda and Yamamoto (1995) are popular candidates for determining the long run causality whereas the examination of the significance of the short-run coefficients of the error correction models suffices for testing for short-run causality. For convenience as well as reference sake, we summarize the findings of the cointegration analysis and causality tests between electricity consumption and economic growth for South African case studies in Table 1 below.

As is evident from Table 1, there exists only a handful of empirical studies exclusively conducted for the case of South Africa; and these are limited to Wolde-Rufael

(2006), Ziramba (2009), Odhiambo (2009, 2010), Esso (2010), Menyah and Wolde-Rufael (2010) and Bildirici et. al. (2012). And if the literature be further narrowed down to studies dedicated strictly to electricity consumption per se, instead of energy consumption as a whole, we note Odhiambo (2009) as the sole author who satisfies the criteria. On a positive note, each of the aforementioned studies has proven that energy/electricity consumption and economic growth are time series variables which are indeed cointegrated. However, the studies seem to contradict each other when it comes to causality test results. Take for instance, Esso (2010), Wolde-Rufael (2006) and Ziramba (2009), who having used Toda and Yamamoto (1995) modified Wald test, came to a common consensus of no evidence of causality existing between electricity consumption and economic growth. Hence the implications of their findings are that the consumption of electricity has a minor impact on economic growth of South Africa and vice versa. Furthermore, this also implies that energy (in this case, electricity) conservation policies can be applied without affecting the economic growth of the country as well as growth policies having no effect on electricity consumption. On the other hand, Menyah and Wolde-Rufael (2010) and Odhiambo (2010) suggested unidirectional causality in the direction electricity consumption to economic growth. The empirical results of these two studies give policymakers the idea that electricity consumption plays an important role in fostering South Africa's economic development. Moreover, Menyah and Wolde-Rufael (2010) bring in an interesting idea regarding South Africa's electricity being generated from coal resources. The aforementioned authors argue that since most of South Africa's electricity is generated from coal, their causality tests are indicative of Granger causality running from pollutant emissions to economic growth. Therefore, contrary to what policymakers and other researchers popularly claim, the author's insinuate that economic growth is not the solution towards reducing levels of pollution. And yet, Bildirici et. al. (2012) present evidence contrary to the aforementioned authors by finding that economic growth causes electricity consumption hence validating the notion that policies directed at economic growth are the solution to maintain efficient electricity consumption within the country. These conflicting evidences necessitate the need for further empirical investigation on the subject matter.

Table 1: Summary of case studies for South Africa

Author	Period	Methodology		Results	
		Cointegration	Causality	Cointegration	Causality
Bildirici et. al. (2012)	1978-2010	Pesaran et al. (2001)	Granger (1988) – VEC	Cointegrated	*EG→EC*
Esso (2010)	1970 – 2007	Gregory-Hansen (1996)	Toda and Yamamoto (1995) – MWALD	Cointegrated	*EC≠EG*
Menyah and Wolde-Rufael (2010)	1965 – 2006	Pesaran et al. (2001)	Toda and Yamamoto (1995) - MWALD	Cointegrated	*EC→EG*
Odhiambo (2009)	1971 – 2006	Johansen-Juselius (1990)	Granger (1988) – VEC	Cointegrated	*EC↔EG*
Odhiambo (2010)	1979 – 2006	Pesaran et al. (2001)	Granger (1988) – VEC	Cointegrated	*EC→EG*
Wolde-Rufael (2006)	1971 – 2006	Pesaran et al. (2001)	Toda and Yamamoto (1995) – MWALD	Cointegrated	*EC≠EG*
Ziramba (2009)	1980 – 2005	Pesaran et al. (2001)	Toda and Yamamoto (1995) – MWALD	Cointegrated	*EC≠EG**

Note: notation: →, ←, ↔ and ≠ represent causality runs to economic growth, causality runs to electricity consumption, bidirectional causality and no causality, respectively.

Abbreviations: EC = electricity consumption and EG = economic growth

Abbreviations for models: MWALD = modified Wald; VAR = vector autoregressive model and VEC = vector error correction model.

* Denotes author used Industrial Production in place of Economic Growth

4. *DATA AND METHODOLOGY*

Our dataset used in the empirical study consists of gross domestic product (GDP_t); electricity consumption (EC_t), CPI inflation (π_t); gross fixed capital formation (INV_t), total employment in the private sector, (EMP_t) and total exports (EXP_t). The entire data sample is collected from the South African Reserve Bank (SARB) as well as from the Statistics South Africa (STATSSA) online databases and is collected on a quarterly basis from a period ranging between 1994/Q1 – 2014/Q4; which gives us a total of 80 observations available for analytical use. In a majority, if not all case studies, testing for cointegration between electricity consumption and economic growth is achieved by making use of the two-step co-integration approach as innovatively introduced by Engle and Granger (1989). The first step under this approach consists of determining the presence of stochastic trends among the time series through the use of unit root testing procedures. In view of the observed series being mutually integrated of order I(1), the second phase of the empirical process consists of determining the extent to which the series are cointegrated. This task is achieved via formal cointegration tests and error correction analysis. As a means of investigating the integrating properties of the observed time series variables, our paper uses the convention augmented Dickey-Fuller (ADF) unit root testing procedure. Pragmatically, the ADF test is based on the following univariate time series regression:

$$\Delta y_t = \alpha_t + \delta T + \beta y_{t-1} + \sum_{i=1}^{k} \sigma_i \Delta y_{t-1} + e_t \quad (1)$$

Where y_t represents the time series, Δ is a first difference operator, α_t is a drift term, T is a time trend and ϵ_t is the regression error term. The Dickey-Fuller (DF) statistic is used to facilitate testing the null hypothesis of a unit root (i.e. $H_0 : \beta = 0$) against the alternative of a stationary process (i.e. $H_0 : \beta < 0$). The test statistic can only reject the null hypothesis of a unit root in the vent that it is found to be lower in absolute value compared with critical values computed in MacKinnon (1996). Following our tests of stationarity on the time series variables, we proceed to conduct our cointegration analysis. To test for cointegration between the time series we rely on Johansen (1991) likelihood ratio tests for evaluating the number of cointegration vectors (r) within the system of time series. The first of these tests is the lambda-maximum test which is based on the log-likelihood ratio $In[L_{max}(r) / L_{max}(r+1)]$ and is conducted sequentially for r = 0,1,...,k-1. The test statistic involved is a maximum generalized eigenvalue which tests the null hypothesis that the cointegration rank is equal to r against the alternative that the cointegration rank is equal to r+1. The second cointegration test is the trace test which is based on the log-likelihood ratio In[L_{max}(r) / L_{max}(k)], and is conducted sequentially for r = k-1,...,1,0. The involved test statistic is the trace of a diagonal matrix of generalized eigenvalues and is designed to test the null hypothesis that the cointegration rank is equal to r against an alternative of the cointegration rank being equal to k. In the event that the aforementioned cointegration tests can detect at least one cointegration vector within the system of time series variables, then the following system of vector error correction models (VECM) can be estimated:

$$\begin{pmatrix} \Delta GDP_t \\ \Delta EC_t \\ \Delta \pi_t \\ \Delta INV_t \\ \Delta EMP_t \\ \Delta EXP_t \end{pmatrix} = \begin{pmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \\ \varphi_5 \\ \varphi_6 \end{pmatrix} + \sum_{i=1}^{k}(1-L) \begin{pmatrix} \beta_{11} & \beta_{12} & \beta_{13} & \beta_{14} & \beta_{15} & \beta_{16} \\ \beta_{21} & \beta_{22} & \beta_{23} & \beta_{24} & \beta_{25} & \beta_{26} \\ \beta_{31} & \beta_{32} & \beta_{33} & \beta_{34} & \beta_{35} & \beta_{36} \\ \beta_{41} & \beta_{42} & \beta_{43} & \beta_{44} & \beta_{45} & \beta_{46} \\ \beta_{51} & \beta_{52} & \beta_{53} & \beta_{54} & \beta_{55} & \beta_{56} \\ \beta_{61} & \beta_{62} & \beta_{63} & \beta_{64} & \beta_{65} & \beta_{66} \end{pmatrix} \begin{pmatrix} \Delta GDP_{t-i} \\ \Delta EC_{t-i} \\ \Delta \pi_{t-i} \\ \Delta INV_{t-i} \\ \Delta EMP_{t-i} \\ \Delta EXP_{t-i} \end{pmatrix}$$

$$+ \begin{pmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \\ \lambda_5 \\ \lambda_6 \end{pmatrix} (\xi_{t-1}) + \begin{pmatrix} \mu_{t1} \\ \mu_{t2} \\ \mu_{t3} \\ \mu_{t4} \\ \mu_{t5} \\ \mu_{t6} \end{pmatrix} \quad (2)$$

Where (1- L) is a lag operator; ξ_{t-1} represents the lagged error correction term derived from the long-run cointegration relationship which determines the speed of adjustment within the VECM system in the event of disequilibrium from its steady state. Within the context of long-run cointegration analysis, another crucial task when evaluating the electricity consumption-growth relationship concerns the evaluation of causal effects amoung the involved time series variables. The idea of causality stems from the notion that if a series x_t contains information in past terms which helps in the prediction of another time series y_t, and if this information is not contained in any other times series used in the predictor, then y_t is said to granger cause x_t (Granger, 1969). Typically, granger causality is facilitated within a vector autoregressive (VAR) framework where the null hypothesis is formulated as zero restrictions on the coefficients of the lags of a subset of variables. However, these tests may have been criticized on the basis of having nonstandard asymptotic properties in the event that the time series variables considered in the VAR are cointegrated. In response to this shortcoming, Dolado and Lutkepohl (1996) devise the following VAR (p+1) for empirical testing of causal effects within a pair of time series variables x_t and y_t.

$$\begin{pmatrix} x_t \\ y_t \end{pmatrix} = \sum_{i=1}^{p+2} \begin{pmatrix} \alpha_{1,i} & \alpha_{2,i} \\ \beta_{1,i} & a\beta_{2,i} \end{pmatrix} \begin{pmatrix} x_{t-i} \\ y_{t-i} \end{pmatrix} + CD_t + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} \quad (3)$$

The null hypothesis that x_t des not granger cause y_t is evaluated as H_0: $\beta_{1,i} = 0$ for i=1,2,…,p+1. Conversely, the null hypothesis that x_{1t} des not granger cause y_{2t} is evaluated as H_0: $\alpha_{1,i} = 0$. A Wald test statistic is used in conjunction with an F-distribution for testing these restrictions.

5. *EMPIRICAL RESULTS*

We begin our empirical analysis by examining the unit root properties of the time series variables using the ADF unit root tests using three variations namely; (1) with a drift, (2) with a trend and (3) with none. The results of unit root tests, as reported in Table 1, present corroborating evidence on the integration properties of the time series. As can be observed, the ADF unit root test statistics provide strong evidence of all the time series failing to reject the null hypothesis of unit roots at all significance whereas in their first differences the variables manage to reject the null hypothesis in favour of stationarity at all significance levels. We therefore perceive this evidence as being encouraging since it is in conformity with the Engle-granger theorem which states that when a system of time series variables are integrated of order I(1), then there must exist at least a linear I(0) vector which renders the variables as being cointegrated.

Table 1: ADF unit root test results

	none	drift	trend
GDP_t	-1.71	-2.67	-2.69
	(-4.49)***	(-4.45)***	(-4.41)***
EC_t	-0.84	-2.09	-1.89
	(-4.08)***	(-4.01)***	(-3.93)**
π_t	-1.42	-2.32	-2.33
	(-6.15)***	(-4.36)***	(-4.33)***
INV_t	-1.13	-2.33	-2.30
	(-4.05)***	(-4.02)***	(-4.02)***
EMP_t	-1.73*	-1.85	-2.31
	(-2. 71)**	(-2.13)	(-4.42)***
EXP_t	-1.68*	-2.46	-2.84
	(-4.31)***	(-4.28)***	(-4.30)***

Note: '***', '**' and '*' denote the 1%, 5% and 10% significance levels respectively. The unit root test results for the first differences on the time series are reported in parentheses.

Having performed the unit root tests on the time series variables, the next step in our empirical analysis is to test for the number of cointegration relations within the system of time series variables. Considering that we are dealing with a multivariate system of time series variables, there may not exist a unique, singular cointegration vector and there may be other possible linear combinations of the variables within the vector which determine the evolution of the cointegration vector. Given this foreknowledge, we employ the eigen and the trace tests, as proposed by Johansen (1991), which allows for the testing of multiple cointegration vectors within the system of time series variables and we report the results of these cointegration tests below in Table 2.

Table 2: Johansen's eigen and trace test results for cointegration

H_0	H_1	eigen statistic	99% c.v.	95% c.v.	trace statistic	99% c.v.	95% c.v.
$r \leq 5$	$r = 5$ ($r \geq 6$)	*7.24*	11.65	8.18	*7.24*	11.65	8.18
$r \leq 4$	$r = 4$ ($r \geq 5$)	*10.71*	19.19	14.90	*17.95***	23.52	17.95
$r \leq 3$	$r = 3$ ($r \geq 4$)	*20.15*	25.75	21.07	*39.11****	37.22	31.52
$r \leq 2$	$r = 2$ ($r \geq 3$)	*24.83*	32.14	27.14	*63.94****	55.43	48.28
$r \leq 1$	$r = 1$ ($r \geq 2$)	*33.82****	38.78	33.32	*97.76****	78.87	70.60
$r \leq 0$	$r = 0$ ($r \geq 1$)	*46.71****	44.59	39.43	*144.47****	104.20	90.39

Note: "***" and "**" denote the 1% and 5% percent significance levels respectively. The alternative hypothesis (H_1) of the trace tests are specified in parentheses.

In referring to the cointegration test results reported in Table 2, we note that the two cointegration test statistics produce differing results concerning the number of cointegration relations existing amoung the time series variables. In particular, we note that the eigen test rejects the null hypothesis up to two cointegration vectors at a 99 percent significance level; whereas the trace test statistic rejects the null hypothesis up to four cointegration levels at a 95 percent significance level. However, given that the purpose of this exercise was to merely evaluate as whether there exist any cointegration relations amoung the time series variables, we interpret these results as being rather positive, in the sense of proving evidence that there are no spurious correlations associated with any subsequent estimation of any long-run regression equations based on the observed time series. In light of these obtained results, we are able to proceed to estimate the corresponding VECM's for the system of time series variables with the estimation results of these error correction models being reported in Table 3 below.

Table 3: VECM estimates

dependent variables	GDP_t	EC_t	π_t	INV_t	EMP_t	EXP_t
Intercept	-0.02	-0.14	-0.85	-0.06	-0.01	0.31
	(0.94)	(0.61)	(0.65)	(0.83)	(0.96)	(0.84)
ξ_{t-1}	-0.72	-1.07	-0.89	-0.75	-0.86	-1.27
	(.000)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
ΔGDP_{t-1}	-0.06	0.27	-0.72	-0.24	-0.12	0.10
	(0.60)	(0.00)***	(0.43)	(0.02)*	(0.14)	(0.03)*
ΔEC_{t-1}	-0.10	-0.03	0.25	-0.01	-0.08	-0.65
	(0.39)	(0.73)	(0.24)	(0.86)	(0.76)	(0.18)
$\Delta\pi_{t-1}$	0.07	0.02	-0.09	0.14	0.03	0.22
	(0.54)	(0.87)	(0.83)	(0.13)	(0.75)	(0.66)
ΔINV_{t-1}	-0.37	-0.36	-0.42	-0.49	-0.43	-0.49
	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
ΔEMP_{t-1}	0.07	-0.03	-0.38	0.06	0.05	0.06
	(0.52)	(0.74)	(0.76)	(0.49)	(046)	(0.91)
ΔEXP_{t-1}	-0.15	0.08	-0.74	0.09	0.01	-0.43
	(0.19)	(0.36)	(0.37)	(0.30)	(0.98)	(0.37)

Note: "***" and "**" denote the 1% and 5% percent significance levels respectively. P-values are reported in ().

Concerning our system of VECM's we are able to identify a significant negative lagged error correction term for each of the estimated error correction models. By default, this implies that for each of the time series variables, there is a significant conversion back to equilibrium in the event of an eternal shock to the system. However, concerning the short-run dynamics the reported results become less optimistic, in the sense that that there are very few significant short-run relationships between the time series variables, with domestic investment proving to exert the most prominent short-run effect on the observed time series variables. All-in-all, the results imply that the multivariate relationship between electricity, economic growth and other growth determinants is relatively stable in the long-run even though they may be deviation in the short-run. Thus having evaluated our error correction mechanisms between the time series (having put our error correction mechanisms into perspective), we move on to our final step in our empirical analysis, which entails performing the causality tests of Dolado and Lutkepohl (1996). The outcomes of these causality tests are reported in Table 4.

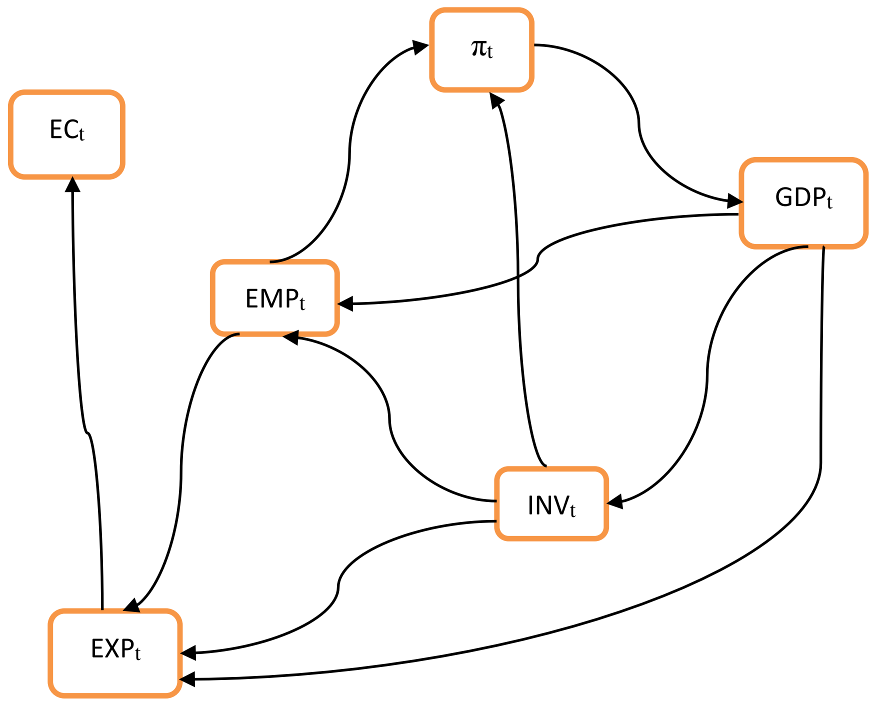
Table 4: Causality Test Results

Independent variable dependent variable	GDP_t	EC_t	$\Delta\pi_t$	INV_t	EMP_t	EXP_t
GDP_t	-	0.22 (0.80)	0.40 (0.67)	**4.88** **(0.00)***	**5.21** **(0.01)***	**9.04** **(0.00)***
EC_t	0.73 (0.48)	-	0.25 (0.78)	0.65 (0.52)	0.25 (0.78)	0.14 (0.87)
$\Delta\pi_t$	**2.52** **(0.08)***	0.12 (0.89)	-	2.06 (0.13)	0.87 (0.42)	0.17 (0.84)
INV_t	1.77 (0.17)	0.35 (0.71)	**5.67** **(0.00)***	-	**2.47** **(0.08)***	**2.96** **(0.05)***
EMP_t	0.85 (0.43)	1.33 (0.27)	**2.75** **(0.06)***	0.60 (0.55)	-	**3.16** **(0.04)***
EXP_t	1.49 (0.23)	**2.73** **(0.06)***	0.22 (0.80)	1.38 (0.26)	1.63 (0.19)	-

Note: "***" and "**" denote the 1% and 5% percent significance levels respectively. P-values are reported in (). For ease of interpretation of the empirical results all significant tests statistics which reject the null hypothesis are highlighted in bold.

Based on our causality test results reported in Table 4, we find evidence of no causal relations which exists between electricity consumption and economic growth for the data. Incidentally, Esso (2010), Wolde Rufael (2009) and Ziramba (2009) also obtain similar results of no causality existing between electricity consumption and economic growth in South Africa. Furthermore, our obtained result of no causal flow from electricity consumption to employment is in alignment with that obtained in Odhiambo (2009). However, in differing from Odhiambo (2009) we find that economic growth granger causes employment and yet the levels of employment do not granger cause economic growth. We are also able to find that inflation causes economic growth, a result which is contrary to that found in Odhiambo (2010) who finds no causality between inflation and economic growth in South Africa. Other interesting results include causality running from economic growth to employment. This particular result is theoretically in line with Okun's law. Also our result of causality running from employment to inflation is theoretically in line with rudiment versions of the Philips curve. Moreover, we are able to identify causality running from economic growth to exports in South Africa, a result which is in line with that obtained in Ajmi (2015). This result in contrast with the export-led growth hypothesis and hence supports the notion that exports are the handmaiden of economic growth (i.e. growth-led export hypothesis). Finally, we find causality running from both investment and employment to exports whereas exports cause electricity consumption and domestic investment causes inflation. Figure 1 below summarizes the causal flows amoung the different time series variables.

Figure 1: Causal relations between the time series



Note: ⟶ represents a uni-directional flow causality between the time series variables

6. CONCLUSIONS

In our paper, we investigated cointegration and causality effects between electricity consumption, economic growth and other growth determinants for the exclusive case of South Africa using quarterly data collected between 1994/Q1 – 2014/Q4. Our method of empirical investigation can be categorized into four distinct empirical phases namely; (1) ADF unit root tests (2) cointegration tests of Johansen (1991); (3) VECM estimation; and (4) the VAR-based causality tests of Dolado and Lutkepohl (1996). The main findings obtained from our empirical study can be summarized as follows. Firstly, we establish that there exists a significant multivariate long-run cointegration relationship between electricity consumption, economic growth and other growth determinants in South Africa. This result implies that any bivariate cointegration relationship that is estimated for South Africa is most likely misspecified due to the well-known problem of omission of relevant variables. Secondly, from our causality analysis we find that there exist no direct causal effects from electricity consumption to economic growth or from economic growth to electricity consumption. As previously noted, this result is reminiscent of that obtained in the previous studies of Esso (2010), Wolde Rufael (2009) and Ziramba (2009), and implies that movements in either electricity consumption or economic growth does bear an influence upon the counter-variable. Thirdly, we find that inflation is the only catalyst of economic growth whereas exports are the only catalyst of electricity consumption. In referring to the later point, we further note that whilst exports are the direct catalyst of electricity consumption, it is the time series variables of economic growth, the levels of employment as well as the levels of domestic investment which ultimately affect exports. Ultimately, this places economic growth, employment and domestic investment as indirect catalysts of electricity consumption within the economy through the channel of exports.

In further deriving from our empirical summaries, the following policy implications are deducted. Firstly, policymakers are not advised to be concerned with either attempting to directly influence electricity consumption through an alteration in economic growth levels and neither should they rely on increasing electricity consumption in order to improve levels of economic growth. In other words, electricity generation conservation polies such as efficiency improvement strategies and demand management policies, on one hand, and other policies aimed at improving economic growth, on the other hand, should be treated as independent and separate stratagems. Secondly, we note that economic growth is caused by the domestic inflation rate, a result which places emphasis on the importance of monetary authorities' efforts at stabilizing the domestic inflation rate through the current inflation targeting regime. In also considering that economic growth, in conjunction with employment rates and domestic investment causally flows to exports, which in turn causally flows electricity consumption, we can advise that policymakers should consider economic growth, domestic investment and employment levels as indirect channels which can be used to influence electricity consumption. In summing it up altogether, we note that price stability policies, through their influence of economic growth which in turn influences exports; which then influences electricity consumption may be the key towards indirectly influencing electricity consumption through an indirect channel of economic growth. Other policies which support employment and domestic investment can also be devised as a means of indirectly affecting electricity consumption through exports. Lastly, our finding of exports directly causing electricity consumption should not be surprising seeing that South Africa is one of the seven largest coal producing economies and one of the top five coal-exporting economies. Therefore, policymakers should consider placing trade policies on the exports of coal as a means of preserving raw energy resources for electricity production and consumption. Such conservative policies on the exporting of coal may serve as a plateau to curbing the economy's current electricity crisis.

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