The nexus of electricity consumption, economic growth and CO_2 emissions in the BRICS countries

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Abstract

This study reexamines the causal link between electricity consumption, economic growth and CO_2 emissions in the BRICS countries (i.e., Brazil, Russia, India, China, and South Africa) for the period 1990-2010, using panel causality analysis, which accounts for dependency and heterogeneity across countries. Regarding the electricity-GDP nexus, the empirical results support evidence on the feedback hypothesis for Russia and the conservation hypothesis for South Africa. However, a neutrality hypothesis holds for Brazil, India and China, indicating neither electricity consumption nor economic growth is sensitive to each other in these three countries. Regarding the GDP-CO_2 emissions nexus, a feedback hypothesis for Russia, a one-way Granger causality running from GDP to CO_2 emissions in South Africa and reverse relationship from CO_2 emissions to GDP in Brazil is found. There is no evidence of Granger causality between GDP and CO_2 emissions in India and China. Furthermore, electricity consumption is found to Granger cause CO_2 emissions in India, while there is no Granger causality between electricity consumption and CO_2 emissions in Brazil, Russia, China and South Africa. Therefore, the differing results for the BRICS countries imply that policies cannot be uniformly implemented as they will have different effects in each of the BRICS countries under study.

Keywords: Electricity Consumption; Economic Growth; CO_2 Emissions; BRICS Countries; Dependency and Heterogeneity; Panel Causality Test

1. Introduction

With increasing levels of industrialisation, a rapidly climbing global population, changes in lifestyle and rising levels of electricity consumption, the threat of global warming has grown over the last few decades. With the increased concern over the ability of energy supply to keep up with demand, combined with worries over global warming, the study of the relationship between electricity consumption, economic growth and greenhouse gas (GHG) emissions has gained increasing amounts of attention (Ang, 2007; Soytas et al. 2007; Apergis et al. 2010, Lean and Smyth 2010; Menyah and Wolde-Rufael 2010, Pao and Tsai 2010; Al-Mulali 2011; Li et al 2011, Pao et al. 2011; Pao and Tsai 2011; Akpan and Akpan 2012; El Hedi Arouri et al. 2012; Farhani and Ben Rejeb 2012; Ozturk and Uddin 2012; Chang and

Wolde-Rufael, 2013).

During the Fifth BRICS (Brazil, Russia, India, China and South Africa) Summit, held in Durban in March 2013, the delegations from the BRICS countries acknowledged that "climate change is one of the greatest challenges and threats towards achieving sustainable development" (Fifth BRICS Summit, 2013). Accordingly, the delegates from the BRICS countries have signed a "multilateral agreement on climate co-operation and the green economy", which will ensure the exchange of technical and financial support to combat the negative impact of climate change on developing countries (South African Government News Agency, 2013). Due to recent economic growth and the fact that the BRICS countries still use large quantities of fossil fuels for electricity generation, emissions are expected to increase contributing further to global warming.

The direction of causality between economic growth, electricity consumption and CO_2 emissions is important for the implementation of related policies. If, for example, electricity consumption causes economic growth, the country would have to implement expansive energy policies. If electricity also causes CO_2 emissions, then the country would rather have to invest in increasing electricity efficiency in order to decrease emissions without negatively impacting economic growth. If, on the other hand, economic growth causes electricity consumption, then conservative energy policies can be implemented without any adverse effect on economic growth. If there is no causality between these variables, then the country will have to implement separate policies to affect the levels of the individual variables as a change in the levels of one of the variables will have no impact on the other variable. Finally, if there is bidirectional causality between any of these variables, then they are mutually affected and policies need to take into consideration that any change in one will impact the other.

This paper re-investigates the relationship between electricity consumption, economic growth, and CO_2 emissions in the BRICS countries over the period of 1990-2010 by focusing on country-specific analysis. In detecting causal linkages the panel causality approach is applied. This approach is able to examine cross-state interrelations and country-specific heterogeneity, for example differences in energy resource endowments, energy policies, population size etc. The inclusion of CO_2 emissions as a third variable will help to prevent possible omitted variable bias that may occur in the bivariate case. It also makes sense to include this variable as all of the BRICS countries have an abundance of energy resources, mainly fossil fuels, which when used for electricity generation result in CO_2 emissions. In addition as mentioned earlier the BRICS countries have mutual agreements with regards to combating climate change and mitigate the effects of GHG emissions. Since the recent inclusion of South Africa into BRICS no study, to our knowledge, has been done using electricity consumption, economic growth and CO_2 emissions.

The plan of this paper is organised as follows. Section 2 follows as a literature review relating to energy consumption, economic growth and pollutant emissions. Section 3 presents the data used in this study and Section 4 briefly describes the bootstrap panel Granger causality test proposed by Kónya (2006). Section 5 presents the empirical results. Finally, Section 6 provides a discussion of the results of this paper's empirical findings and concludes the paper.

3. Literature Review

The literature has shown extensive interest in the relationship between electricity, CO_2 and economic growth. The literature can be divided into three strands of study: firstly, the relationship between energy consumption and economic growth; secondly, the study of the economic growth - pollutant emissions nexus; and finally, the marriage of the first two strands into the study of the causal relationship between economic growth, pollutant emissions and economic growth.

The pioneering work with regards to the possible causal link between energy consumption and economic growth was introduced by Kraft and Kraft (1978). This paper studied the causal relationship between energy and Gross National Product (GNP) in the United States during the period 1947 – 1974. The main finding of the paper was that of unidirectional causality running from GNP to energy, without feedback. The conclusion reached was that government could pursue energy conservation policies without there being any negative effects on economic growth. Since then there has been an extensive amount of literature based on the causality between energy/electricity consumption and economic growth.

The direction of causality is important as the energy policy implications are vastly different for each possible direction. The presence of bidirectional causality between energy consumption and economic growth, also called the feedback hypothesis, implies that energy consumption and economic growth are jointly affected by shocks and any conservative energy policies may have an adverse effect on economic growth (Paul and Battacharya, 2004; Apergis and Payne, 2009b; Narayan and Smyth, 2009; Odhiambo, 2009; Bildirici, 2012; Shabaz *et al.*, 2012). Unidirectional causality from energy consumption to economic growth, also known as the growth hypothesis, implies that the country is energy dependent and thus energy consumption has both a direct and indirect effect on economic growth. The growth hypothesis implies that any conservative energy policies will have an adverse effect on economic growth (Cheng, 1997; Apergis and Payne, 2010; Adebola, 2011; Masuduzzaman, 2012). However, if the unidirectional causality runs from economic growth to energy consumption, otherwise known as the conservation hypothesis, the economy is less-energy dependent and conservation of energy policies can be implemented with little or no adverse effects on economic growth (Zhang and Cheng, 2009; Shaari *et al.*, 2012). Finally, in the absence of causality between economic growth and energy consumption, the neutrality hypothesis, there is no long-run relationship between the two variables and any energy consumption policies, whether they be expansive or conservative, will have no effect on economic growth (Wolde-Rufael, 2006; Acaravci and Ozturk, 2010).

The second strand of studies focuses on the relationship between economic growth and environmental degradation, with focus on pollutant emissions. The Environmental Kuznets Curve (EKC) is derived from the work done by Kuznets (1995) who postulated the inverted-U shape relationship between income inequality and economic development. The basic idea behind the EKC is that as a country's economy starts the process of industrialisation, resource extraction increases as income increases, thus raising the levels of pollution. As income increases further, people start becoming aware of the environmental quality and are now willing and able to pay for the use of cleaner energy sources e.g. hydro, solar and nuclear power, thus pollutant emissions decline after a certain point. Therefore, an inverted – U shape is realised. The original work proposing the inverted-U shape of the EKC hypothesis was done by Grossman and Krueger (1991) and since then there has been a vast amount of research done on the validity of the EKC hypothesis. The policy implication for the EKC is that ensuring economic growth will in the long-run improve the environment. Thus according to Beckerman (1992) the best way to decrease the levels of environmental pressure is for the country to become wealthy. Richmond and Kaufman (2006), Galeotti *et al.* (2009), Fodha *et al.* (2010) and Akpan and Chuku (2011) have all attempted to test the possible existence of the EKC. The results of these studies have been mixed, even among the literature supporting the existence of the EKC, there is no agreement on the level of income where environmental degradation starts decreasing. Extensive reviews of the literature on the existence and robustness of the EKC are done by Dinda (2004) and Stern (2004).

The last strand of literature has resulted from the marriage of the first two strands of literature resulting in studies on the economic growth-energy consumption-pollutant emissions nexus. Ang (2007) and Soytas *et al.* (2007) initiated this combined line of research. For the BRIC case, Pao and Tsai (2010, 2011) did two studies, one using carbon dioxide emissions, energy consumption and economic growth (2010) and the other including Foreign Direct Investment (FDI) (2011) as a fourth variable. In both of these studies they found support for the existence of the EKC hypothesis, however the turning points differ slightly occurring at 5.393 (in natural logarithms) and 5.638 (in natural logarithms) of income for Pao and Tsai (2010) and Pao and Tsai (2011) respectively. Pao and Tsai (2010) found a strong unidirectional causality from carbon dioxide emissions and energy consumption to real output in the short-run. A strong bidirectional causality between energy consumption and carbon dioxide emissions as well as between energy consumption and real output exists. Thus, concluding that growth in the BRIC countries is energy dependent. On the other hand, Pao and Tsai (2011) found evidence of bidirectional causality between emissions and FDI, emissions and output, energy consumption and FDI and energy consumption and output. In the long-run unidirectional causality was found to run from energy consumption to emissions and from output to FDI. Bidirectional causality was found between emissions and FDI. Therefore, BRIC countries need to increase investment in energy infrastructure and encourage industries to adopt new technologies in order to decrease emissions without negatively impacting these countries' levels of competitiveness.

With regards to the relatively recent inclusion of South Africa into the BRIC group, Chang and Wolde-Rufael (2013) have used panel causality analysis to re-investigate the relationship between energy consumption and economic growth over the period 1970-2010. For both Brazil and China no evidence of causality running in any direction between energy consumption and economic growth is found. In South Africa, unidirectional causality is found to run from energy consumption to economic growth. Thus support is found for the growth hypothesis. Conversely, unidirectional causality is found to run from economic growth to energy consumption in India. Finally, evidence of bidirectional causality between energy consumption and economic growth is found for Russia. Therefore, energy consumption and economic growth are jointly determined in Russia. Suggestions are made for the BRICS countries to find alternative sources of energy (e.g. solar and wind) and for finding ways of increasing the energy sectors' levels of efficiency.

The results regarding the direction of causality in all three of these strands of literature have been inconclusive. This variation may be attributed to the differing time periods under examination, variable selection and econometric techniques used. Even within a time series or panel data framework, the testing procedures vary. Some use traditional Granger causality (1986) tests, others use modified versions of the Granger causality test like the Toda and Yamamoto (1995) test. The tests for cointegration also vary, with some using Autoregressive Distributive lag (ARDL) bounds (Pesaran *et al*., 2001) testing procedure and other studies using Pedroni's (1999) cointegration test or the Gregory Hansen (1996a,b) testing approach. Another reason for the studies variation in results can be attributed to the availability, or lack of availability, of data for a specific variable or country (Inglesi-Lotz and Pouris, 2013). Finally, the lack of consensus reached by these studies may also be due to the fact that different studies focus on different countries. These different countries have different characteristics for example quantities and quality of fossil fuels and other possible energy sources, political institutions, cultures, existing energy polices and so on which may have played a role in these studies' mixed results (Chen et al. 2007, in Ozturk, 2010).

To our knowledge, there have been no studies on the causal relationship between energy consumption, pollutant emissions and economic growth in BRICS countries. This paper tries to fill this gap in the literature.

4. Data

The annual data used in this study cover the period from 1990 to 2010 for the BRICS countries (i.e., Brazil, Russia, India, China, and South Africa). The variables in this study include total electricity consumption (TEC), real GDP (RGDP) and CO_2 emissions (CO_2). Electricity consumption is expressed in terms of millions of GWHs and the data is derived from the BP Statistical Review of World Energy, 2012. Real GDP measured in constant 2005 U.S. dollars and comes from the World Development Indicators (WDI, 2011). Table 1, Table 2 and Table 3 show the summary statistics of real GDP, electricity consumption, and CO_2 emissions, respectively.

Table 1 Summary Statistics of GDP

country	Mean	Max.	Min.	Std. Dev.	Skew.	Kurt.	J.-B.
Brazil	768418.6	1049862	580258.1	139879.8	0.46	2.20	0.49
Russia	688159.2	948976.3	483439.4	154511.4	0.24	1.63	0.64
India	666675.1	1260013	347798.1	275382.1	0.71	2.37	0.72
China	1706233	3865593	523383.5	1005487	0.54	2.43	0.40
South Africa	212257.3	293620.9	159017.2	45300.54	0.52	1.93	0.05

Note: 1. The sample period is from 1990 to 2010.

Table 2 Summary Statistics of Electricity Consumption

	Mean	**Max.**	**Min.**	**Std. Dev.**	**Skew.**	**Kurt.**	**J.-B.**
Brazil	311239.7	437862	210820	68479.86	0.21	1.97	0.72
Russia	667101.4	826631	578523	71300.32	0.82	2.74	4.35
India	402819.5	710674	211733	143186.8	0.72	2.54	0.02
China	1475672	3492888	505563	925449.2	0.89	2.44	0.56
South Africa	176518.4	221746	127135	30166.34	-0.32	1.82	0.47

Note: The sample period is from 1990 to 2010. Std.Dev=standard deviation; Skew= skewness; Kurt=kurtosis, J.-B= Jarque-Bera test.

Table 3 Summary Statistics of CO_2 Emissions

	Mean	**Max.**	**Min.**	**Std. Dev.**	**Skew.**	**Kurt.**	**J.-B.**
Brazil	343.86	474.10	239.97	63.10	0.07	2.40	0.18
Russia	1727.31	2349.66	1526.32	257.87	1.49	3.75	1.50
India	996.33	1682.70	581.36	315.35	0.68	2.58	0.37
China	4394.52	8209.81	2387.00	1846.24	0.79	2.20	1.08
South Africa	376.23	462.43	296.95	50.03	0.09	1.93	0.55

Note: The sample period is from 1990 to 2010. Std.Dev=standard deviation; Skew= skewness; Kurt=kurtosis, J.-B= Jarque-Bera test.

Based on Tables 1, 2, and 3, we find that China and South Africa have the highest and lowest of mean real GDP of US$1706233 and US$212257.3, respectively, and the highest and lowest total electricity consumption of 1475672 and 176518.4 millions of GWHs, respectively. With respect to CO_2 emissions, China and Brazil have the highest and lowest levels of 4394.52 and 343.86 million metric tons, respectively. All of the data series are approximately normal. Additionally, China shows the greatest variation (defined by the standard deviation) in real GDP (1005487), total electricity consumption (925449.2) and CO_2 emissions (1846.24), while South Africa shows the least variation in each variable.

5. Methodology

5.1. Preliminary Analysis

One important issue in a panel causality analysis is to take into account possible cross-section dependence across regions. This is because high degree of economic and financial integrations makes a region to be sensitive to the economic shocks in other region with a country. Cross-sectional dependency may play an important role in detecting causal linkages for the BRICS countries.

The second issue to decide before carrying out causality test is to find out whether the slope coefficients are treated as homogenous and heterogeneous to impose causality restrictions on the estimated parameters. As pointed out by Granger (2003), the causality from one variable to another variable by imposing the joint restriction for the panel is the strong null hypothesis. Furthermore, as Breitung (2005) contends the homogeneity assumption for the parameters is not able to capture heterogeneity due to region specific characteristics. In the electricity consumption and economic growth nexus – as in many economic relationships – while there may be a significant relationship in some regions, vice versa may also be true in some other regions.

Given the above consideration before we conduct tests for causality, we start with testing for cross-sectional dependency, followed by slope homogeneity across regions. Then, we decide to which panel causality method should be employed to appropriately determine the direction of causality between electricity consumption, economic growth, and CO_2 emissions in BRICS countries. In what follows, the essentials of econometric methods used in this study are outlined.

5.1. Testing cross-section dependence

To test for cross-sectional dependency, the Lagrange multiplier (LM hereafter) test of Breusch and Pagan (1980) has been extensively used in empirical studies. The procedure to compute the LM test requires the estimation of the following panel data model:

$$y_{it} = \alpha_i + \beta_i' x_{it} + u_{it} \text{ for } i = 1,2,...,N;\ t = 1,2,...,T \quad (1)$$

where i is the cross section dimension, t is the time dimension, x_{it} is $k \times 1$ vector of explanatory variables, α_i and β_i are respectively the individual intercepts and slope coefficients that are allowed to vary across states. In the LM test, the null hypothesis of no-cross section dependence- $H_0 : Cov(u_{it}, u_{jt}) = 0$ for all t *and* $i \neq j$- is tested against the alternative hypothesis of cross-section dependence $H_1 : Cov(u_{it}, u_{jt}) \neq 0$, for at least one pair of $i \neq j$. In order to test the null hypothesis, Breusch and Pagan (1980) developed the LM test as:

$$LM = T \sum_{i=1=j}^{N-1} \sum_{i+1}^{N} \hat{\rho}_{ij}^2 \quad (2)$$

where $\hat{\rho}_{ij}$ is the sample estimate of the pair-wise correlation of the residuals from Ordinary Least Squares (OLS) estimation of equation (1) for each *i*. Under the null hypothesis, the *LM* statistic has asymptotic chi-square with $N(N-1)/2$ degrees of freedom. It is important to note that the LM test is valid for N relatively small and T sufficiently large.

However, the *CD* test is subject to decreasing power in certain situations that the population average pair-wise correlations are zero, although the underlying individual population pair-wise correlations are non-zero (Pesaran et al., 2008, p.106). Furthermore, in stationary dynamic panel data models the CD test fails to reject the null hypothesis when the factor loadings have zero mean in the cross-sectional dimension. In order to deal with these problems, Pesaran et al. (2008) proposes a bias-adjusted test which is a modified version of the LM test by using the exact mean and variance of the LM statistic. The bias-adjusted LM test is:

$$LM_{adj} = \sqrt{\left(\frac{2T}{N(N-1)}\right)} \sum_{i=1=j}^{N-1} \sum_{i+1}^{N} \hat{\rho}_{ij} \frac{(T-k)\hat{\rho}_{ij}^2 - \mu_{Tij}}{\sqrt{v_{Tij}^2}} \quad (3)$$

where μ_{Tij} and v_{Tij}^2 are respectively the exact mean and variance of $(T-k)\hat{\rho}_{ij}^2$, that are provided in Pesaran et al. (2008, p.108). Under the null hypothesis with first T→∞ and then

N→∞, LM_{adj} test is asymptotically distributed as standard normal.

5. 2. Testing slope homogeneity

Second issue in a panel data analysis is to decide whether or not the slope coefficients are homogenous. The causality from one variable to another variable by imposing the joint restriction for whole panel is the strong null hypothesis (Granger, 2003). Moreover, the homogeneity assumption for the parameters is not able to capture heterogeneity due to region specific characteristics (Breitung, 2005).

The most familiar way to test the null hypothesis of slope homogeneity- $H_0 : \beta_i = \beta$ for all *i*- against the hypothesis of heterogeneity- $H_1 : \beta_i \neq \beta_j$ for a non-zero fraction of pair-wise slopes for $i \neq j$- is to apply the standard *F* test. The *F* test is valid for cases where the cross section dimension (N) is relatively small and the time dimension (T) of panel is large; the explanatory variables are strictly exogenous; and the error variances are homoscedastic. By relaxing homoscedasticity assumption in the *F* test, Swamy (1970) developed the slope homogeneity test on the dispersion of individual slope estimates from a suitable pooled estimator. However, both the *F* and Swamy's test require panel data models where *N* is small relative to *T* [24]. Pesaran and Yamagata (2008) proposed a standardized version of Swamy's test (the so-called $\tilde{\Delta}$ test) for testing slope homogeneity in large panels. The $\tilde{\Delta}$ test is valid as $(N,T) \to \infty$ without any restrictions on the relative expansion rates of N and T when the error terms are normally distributed. In the $\tilde{\Delta}$ test approach, first step is to compute the following modified version of the Swamy's test:

$$\tilde{S} = \sum_{i=1}^{N} \left(\widehat{\beta}_i - \tilde{\beta}_{WFE}\right)' \frac{x_i' M_\tau x_i}{\tilde{\sigma}_i^2} \left(\widehat{\beta}_i - \tilde{\beta}_{WFE}\right) \tag{4}$$

where $\widehat{\beta}_i$ is the pooled OLS estimator, $\tilde{\beta}_{WFE}$ is the weighted fixed effect pooled estimator, M_τ is an identity matrix, the $\tilde{\sigma}_i^2$ is the estimator of σ_i^2.[1] Then the standardized dispersion statistic is developed as:

[1] In order to save space, we refer to Pesaran and Yamagata (2008) for the details of estimators and for Swamy's test.

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}\right) \tag{5}$$

Under the null hypothesis with the condition of $(N,T) \to \infty$ so long as $\sqrt{N}/T \to \infty$ and the error terms are normally distributed, the $\tilde{\Delta}$ test has asymptotic standard normal distribution. The small sample properties of $\tilde{\Delta}$ test can be improved under the normally distributed errors by using the following bias adjusted version:

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - E(\tilde{z}_{it})}{\sqrt{\operatorname{var}(\tilde{z}_{it})}}\right) \tag{6}$$

where the mean $E(\tilde{z}_{it}) = k$ and the variance $\operatorname{var}(\tilde{z}_{it}) = 2k(T-k-1)/T+1$.

5.3. Panel Causality Test

Once the existence of cross-section dependency and heterogeneity across South Africa is ascertained, we apply a panel causality method that should account for these dynamics. The bootstrap panel causality approach proposed by Kónya (2006) is able to account for both cross-section dependence and region-specific heterogeneity. This approach is based on Seemingly Unrelated Regression (SUR) estimation of the set of equations and the Wald tests with individual specific region bootstrap critical values. Since region-specific bootstrap critical values are used, the variables in the system do not need to be stationary, implying that the variables are used in level form irrespectively of their unit root and cointegration properties. Thereby, the bootstrap panel causality approach does not require any pre-testing for panel unit root and cointegration analyses. Besides, by imposing region specific restrictions, we can also identify which and how many states exist in the Granger causal relationship.

The system to be estimated in the bootstrap panel causality approach can be written as:

$$
\begin{aligned}
y_{1,t} &= \alpha_{1,1} + \sum_{i=1}^{ly_1} \beta_{1,1,i} y_{1,t-i} + \sum_{i=1}^{lx_1} \delta_{1,1,i} x_{1,t-i} + \sum_{i=1}^{lz_1} \gamma_{1,1,i} z_{1,t-i} + \varepsilon_{1,1,t} \\
y_{2,t} &= \alpha_{1,2} + \sum_{i=1}^{ly_1} \beta_{1,2,i} y_{2,t-i} + \sum_{i=1}^{lx_1} \delta_{1,2,i} x_{2,t-i} + \sum_{i=1}^{lz_1} \gamma_{1,2,i} z_{2,t-i} + \varepsilon_{1,2,t} \\
&\vdots \\
y_{N,t} &= \alpha_{1,N} + \sum_{i=1}^{ly_1} \beta_{1,N,i} y_{N,t-i} + \sum_{i=1}^{lx_1} \delta_{1,N,i} x_{N,t-i} + \sum_{i=1}^{lz_1} \gamma_{1,N,i} z_{N,t-i} + \varepsilon_{1,N,t}
\end{aligned} \tag{1}
$$

$$
\begin{aligned}
x_{1,t} &= \alpha_{2,1} + \sum_{i=1}^{ly_2} \beta_{2,1,i} y_{1,t-i} + \sum_{i=1}^{lx_2} \delta_{2,1,i} x_{1,t-i} + \sum_{i=1}^{lz_2} \gamma_{2,1,i} z_{1,t-i} + \varepsilon_{2,1,t} \\
x_{2,t} &= \alpha_{2,2} + \sum_{i=1}^{ly_2} \beta_{2,2,i} y_{2,t-i} + \sum_{i=1}^{lx_2} \delta_{2,2,i} x_{2,t-i} + \sum_{i=1}^{lz_2} \gamma_{2,2,i} z_{2,t-i} + \varepsilon_{2,2,t} \\
&\vdots \\
x_{N,t} &= \alpha_{2,N} + \sum_{i=1}^{ly_2} \beta_{2,N,i} y_{N,t-i} + \sum_{i=1}^{lx_2} \delta_{2,N,i} x_{N,t-i} + \sum_{i=1}^{lz_2} \gamma_{2,N,i} z_{N,i} + \varepsilon_{2,N,t}
\end{aligned} \tag{2}
$$

and

$$
\begin{aligned}
z_{1,t} &= \alpha_{2,1} + \sum_{i=1}^{ly_3} \beta_{3,1,i} y_{1,t-i} + \sum_{i=1}^{lx_3} \delta_{3,1,i} x_{1,t-i} + \sum_{i=1}^{lz_3} \gamma_{3,1,i} z_{1,i} + \varepsilon_{2,1,t} \\
z_{2,t} &= \alpha_{2,2} + \sum_{i=1}^{ly_3} \beta_{2,2,i} y_{2,t-i} + \sum_{i=1}^{lx_3} \delta_{2,2,i} x_{2,t-i} + \sum_{i=1}^{lz_2} \gamma_{3,2,i} z_{2,t-i} + \varepsilon_{2,2,t} \\
&\vdots \\
z_{N,t} &= \alpha_{2,N} + \sum_{i=1}^{ly_3} \beta_{3,N,i} y_{N,t-i} + \sum_{i=1}^{lx_3} \delta_{3,N,i} x_{N,t-i} + \sum_{i=1}^{lz_3} \gamma_{3,N,i} z_{N,t-i} + \varepsilon_{2,N,t}
\end{aligned} \tag{3}
$$

where y denotes real income, x refers to electricity consumption, z refers to CO_2 emissions, l is the lag length. Since each equation in this system has different predetermined variables while the error terms might be contemporaneously correlated (i.e. cross-sectional dependency), these sets of equations are the SUR system.

In the bootstrap panel causality approach, there are alternative causal linkages for a country in the system that (i) there is one-way Granger causality from *x* to *y (z)* if not all $\delta_{1,i}$ are zero, but all $\beta_{2,i}$ (or $\gamma_{2,i}$)are zero, (ii) there is one-way Granger causality running from *y* (z) to *x* if all $\delta_{1,i}$ are zero, but not all $\beta_{2,i}$ ($\gamma_{2,i}$)are zero, (iii) there is two-way Granger causality between *x* and *y(z)* if neither $\delta_{1,i}$ nor $\beta_{2,i}$ ($\gamma_{2,i}$)are zero, and finally (iv) there is no Granger causality between x and y if all $\delta_{1,i}$ and $\beta_{2,i}$ ($\gamma_{2,i}$) are zero.[2]

6. Empirical Results

One important issue in a panel causality analysis is to take into account both cross-sectional dependency and country-specific heterogeneity in empirical analysis because BRICS countries are highly integrated and have a high degree of globalisation in economic relations.[3] Therefore, this empirical study goes further in examining the existence of cross-sectional dependency and heterogeneity across the countries in concern. To investigate the existence of cross-section dependence four different tests (LM, CD_{lm}, CD, LM_{adj}) were carried out and the results are illustrated in Table 4.

Table 4 Cross-sectional Dependence and Homogeneous Tests

CD_{BP}	29.786***
CD_{LM}	4.424***
CD	3.710***
LM_{adj}	5.489***
$\tilde{\Delta}$	9.375***
$\tilde{\Delta}_{adj}$	0.509
Swamy Shat	68.258***

From Table 4, it is clear that the null of no cross-sectional dependency across the countries is strongly rejected at the conventional levels of significance. This finding implies that a shock occurred in one of these BRICS countries seems to be transmitted to other countries.

[2] It is important to note here that since the results from the causality test may be sensitive to the lag structure, determining the optimal lag length(s) is crucial for robustness of findings. As indicated by Kónya (2006), the selection of optimal lag structure is of importance because the causality test results may depend critically on the lag structure. In general, both too few and too many lags may cause problems. Too few lags mean that some important variables are omitted from the model and this specification error will usually cause bias in the retained regression coefficients, leading to incorrect conclusions. On the other hand, too many lags waste observations and this specification error will usually increase the standard errors of the estimated coefficients, making the results less precise. For a relatively large panel, equation and variable with varying lag structure would lead to an increase in the computational burden substantially. In determining lag structure we follow Kónya's approach that maximal lags are allowed to differ across variables, but to be same across equations. We estimate the system for each possible pair of ly_1, lx_1, ly_2, lx_2 ly_3 and lx_3 respectively by assuming from *1* to *4* lags and then choose the combinations which minimize the Schwarz Bayesian Criterion.

[3] It is worthwhile noting here that ignoring cross-section dependency leads to substantial bias and size distortions (Pesaran, 2006), implying that testing for the cross-section dependence is a crucial step in a panel data analysis.

Table 4 also reports the results from the slope homogeneity tests of both Swamy (1970) and Pesaran and Yamagata (2008). Both tests reject the null hypothesis of the slope homogeneity hypothesis, supporting the country-specific heterogeneity.[4] The rejection of slope homogeneity implies that the panel causality analysis by imposing homogeneity restriction on the variable of interest results in misleading inferences. Therefore, direction of causal linkages between electricity consumption, economic growth and CO_2 emissions in the BRICS countries seems to be heterogeneous, implying that the direction of causal linkages among the variables of interest may differ across the BRICS countries. The existence of the cross-sectional dependency and the heterogeneity across states support evidence on the suitability of the bootstrap panel causality approach. The results from the bootstrap panel Granger causality analysis[5] are reported in Tables 5, 6, 7, 8, 9 and 10.

The results for the testing of the existence and direction of causality between electricity consumption and economic growth are presented in Tables 5 and 6. The findings from these tables indicate that a feedback hypothesis is found to hold for Russia and a conservation hypothesis holds for South Africa. However, a neutrality hypothesis holds for Brazil, China and India, indicating neither electricity consumption nor economic growth is sensitive to each other in these three countries.

Table 5 Electricity Consumption does not Granger Cause GDP

	Wald Statistics	Bootstrap Critical Value		
		10%	5%	1%
Brazil	5.772	7.301	10.739	20.666
Russia	42.155***	4.924	7.494	14.839
India	0.036	5.451	8.177	16.261
China	3.019	5.158	7.732	14.377
South Africa	1.194	4.384	6.651	14.112

Note: 1.*** indicates significance at the 0.01 level.

2. Bootstrap critical values are obtained from 10,000 replications.

[4] Though $\tilde{\Delta}_{adj}$ fails to reject the null hypothesis of slope homogeneity, both $\tilde{\Delta}$ and $\tilde{S}$ reject the null hypothesis of slope homogeneity.

[5] We refer to Kónya (2006) for the bootstrap procedure on how the country specific critical values are generated.

Table 6 GDP does not Granger Cause Electricity Consumption

	Wald Statistics	Bootstrap Critical Value		
		10%	5%	1%
Brazil	1.129	5.039	7.409	14.558
Russia	72.749***	5.451	8.183	16.927
India	0.756	6.997	10.282	19.666
China	2.945	15.782	20.971	35.006
South Africa	5.312*	4.660	6.375	11.613

Note: 1. * and *** indicate significance at the 0.1 and 0.01 levels, respectively.

2. Bootstrap critical values are obtained from 10,000 replications.

Table 7 CO_2 Emissions does not Granger Cause GDP

	Wald Statistics	Bootstrap Critical Value		
		10%	5%	1%
Brazil	12.144**	5.275	7.688	15.446
Russia	85.259***	5.128	7.671	14.961
India	0.301	4.819	7.267	15.024
China	1.192	5.145	7.784	15.747
South Africa	1.014	4.577	6.739	14.181

Note: 1.** and *** indicate significance at the 0.05 and 0.01 levels, respectively.

2. Bootstrap critical values are obtained from 10,000 replications.

Table 8 GDP does not Granger Cause CO_2 Emissions

	Wald Statistics	Bootstrap Critical Value		
		10%	5%	1%
Brazil	0.079	5.301	7.784	15.466
Russia	22.387***	5.532	8.254	15.499
India	1.904	7.516	11.010	20.851
China	7.711*	6.476	10.082	21.377
South Africa	9.215**	5.185	7.619	14.013

Note: 1.* ,**, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

2. Bootstrap critical values are obtained from 10,000 replications.

Regarding GDP-CO_2 emissions nexus (see Tables 7 and 8), evidence of a feedback hypothesis is found for Russia, a one-way Granger causality running from GDP to CO_2 emissions in South Africa and the reverse relationship from CO_2 emissions to GDP is found for Brazil. Furthermore, electricity consumption is found to Granger cause CO_2 emissions in India only (see Tables 9 and 10).

Table 9 Electricity Consumption does not Granger Cause CO_2 Emissions

	Wald Statistics	Bootstrap Critical Value		
		10%	5%	1%
Brazil	0.319	5.901	8.538	17.729
Russia	1.737	6.114	9.313	17.569
India	22.343***	6.409	9.449	17.304
China	1.877	5.465	7.987	15.547
South Africa	0.087	5.775	8.264	15.163

Note: 1.*** indicates significance at the 0.01 level.
2. Bootstrap critical values are obtained from 10,000 replications.

Table 10 CO_2 Emissions does not Granger Cause Electricity Consumption

	Wald Statistics	Bootstrap Critical Value		
		10%	5%	1%
Brazil	2.317	5.283	7.691	14.351
Russia	1.571	6.513	9.723	18.332
India	2.804	5.522	8.122	16.266
China	0.267	10.809	15.462	28.054
South Africa	0.001	5.660	8.181	15.864

Note: 1. Bootstrap critical values are obtained from 10,000 replications.

6. Discussion of results and conclusions

This study reexamines causal link between electricity consumption, economic growth and CO_2 emissions in BRICS countries for the period 1990-2010, using panel causality analysis, which accounts for dependency and heterogeneity across countries. The results of the panel bootstrap method suggest that the existence and direction of Granger causality differ among the different BRICS countries. Each of these results has different and important policy implications and recommendations. Table 11 summarises the findings of the exercise.

Table 11 Summary of results

	Brazil	Russia	India	China	South Africa
EC vs GDP	None	EC $\leftrightarrow$ GDP	None	None	GDP $\rightarrow$ EC
EC vs CO_2	None	None	EC $\rightarrow$ CO_2	None	None
GDP vs CO_2	CO_2 $\rightarrow$ GDP	CO_2 $\leftrightarrow$ GDP	None	None	GDP $\rightarrow$ CO_2

Note: EC=electricity consumption; and the direction of the arrows denote the direction of the causal relationship.

These results are partially consistent with Li *et al.* (2011), Pao *et al.* (2011), Ozturk and Uddin (2012) and Chang and Wolde-Rufael (2013). The results of this paper are, however, contrary to those obtained by Pao and Tsai (2011) who find bidirectional causality between energy consumption, economic growth and CO_2 emissions; and Apergis and Payne (2010) who found unidirectional causality to run from energy consumption to economic growth in Brazil. The results also differ to those obtained by Odhiambo (2009) who finds bidirectional causality between electricity consumption and economic growth; and Menyah and Wolde-Rufael (2010) who found unidirectional causality running from energy consumption to economic growth, pollutant emissions to economic growth and from energy consumption to CO_2 emissions in South Africa.

The differences between the results for these papers can be attributed to differing time periods, methodology and additional variables used. Especially, causality analysis is sensitive on the choice of methodology and the inclusion of extra variables. In this paper, we used CO_2 as a third variable to avoid certain biases in the mechanism of the causality between electricity consumption and economic growth. In addition, in this paper, the cross-sectional dependence is taken into account which is considered of high importance for groups of countries with relations in terms of their economic policies and trends of key variables.

In Brazil, no evidence of causality running in any direction between electricity consumption and economic growth is found, thus supporting the neutrality hypothesis. Similarly, no causality was found to exist between electricity consumption and CO_2 emissions. This result makes sense as electricity only accounts for a marginal amount of Brazil's total GHG emissions, the majority coming from land usage. This relatively small contribution made by the electricity sector may also be as a result of increasing levels of infrastructure in and usage of renewable energy sources, particularly hydro electricity in Brazil. Brazil is home to the Itaipu hydro power facility along the Panama River and the Belo Monte facility (under construction) in the Amazon Basin, which are the second and third (upon completion) largest hydro power plants in the world, respectively (EIA, 2012). With respect to the CO_2 emissions – economic growth nexus, causality was found to run from CO_2 emissions to economic growth. This result may be due the rapid and large-scale deforestation of the Amazon rain forest. This deforestation is being done in order to increase the area available for agriculture and human settlement. The increased agriculture and the resulting employment have helped to increase economic growth but at the expense of raising the levels of CO_2, not just in Brazil but globally. The vast majority (83%) of Brazil's GHG emissions come from agriculture, land-use change and deforestation (Hallding *et al.*, 2011). However, raising the levels of CO_2 emissions may indirectly cause economic growth to deteriorate in the long-run. Brazilian policy makers should promote mitigation strategies with aim to reduce CO_2 emissions impacting thus the economic growth of the country. An increasing level of CO_2 emissions will cause a reduction in environmental quality, thus negatively affecting the workforce's health and therefore causing a reduction in productivity levels in the long-run

With respect to Russia, bidirectional causality was found to exist between electricity consumption and economic growth, thus supporting the feedback hypothesis. This result could be because of the fact that Russia's GDP is still fairly dependent on fossil fuels and electricity generation, mainly for exports. An increase in electricity consumption will lead to increased electricity production, which implies an expansion in employment and infrastructure in the electricity sector. This will result in raised levels of disposable income which will, in turn, raise the demand for electricity as more electronic gadgets are bought for entertainment and comfort reasons. There is no causal relationship between electricity consumption and CO_2 emissions. This result could have something to do with the fact that Russia is endowed with vast reserves natural gas which the country uses for energy generation and for exporting purposes (EIA, 2012). While natural gas is a fossil fuel and therefore non-renewable, it releases much lower levels of CO_2 than coal and oil do in the electricity production process (EPA, 2013), thus electricity consumption does not result in increased CO_2 emissions. Russia is the only one of the BRICS countries to have shown a marked decrease in CO_2 emissions levels over the period of this study. With regards to the GDP-CO_2 emissions nexus, there is a feedback causal relationship between CO_2 emissions and economic growth for Russia. Therefore, energy conservation policies may have an adverse effect on economic growth. This result makes sense as the Russian government is planning to increase the number of coal-fired power plants (EIA, 2012). This will result in an increase in employment, thus increasing economic growth. However, due to the increased levels of coal-fired power plants, levels of CO_2 emissions will increase. CO_2 emissions levels can be decreased with an improvement in the techniques of production, these improvements will help to increase productivity, while decreasing pollution levels. Raising the levels of infrastructure investment to improve energy efficiency and reduce unnecessary waste of energy will also help to decrease emissions without negatively impacting economic growth.

In terms of India, no evidence of causality running in any direction between electricity consumption and economic growth was found to exist. This may be as a result of the lack of predictability of the publicly supplied electricity which has caused investors not to depend on it for their production plans. This lack of predictability can be attributed to the rapid increases in total demand for electricity that is far outpacing growth in generation capacity, causing frequent blackouts throughout India's main cities. Coal shortages are further straining power generation capabilities (EIA, 2011). Therefore, India needs to improve energy efficiency and needs to invest in the research and development of renewable energy in order to help lift the strain on the economy caused by electricity shortages. With regards to the relationship between CO_2 emissions and electricity consumption, in India there is evidence of unidirectional causality running from electricity consumption to CO_2 emissions. This implies that an increase in electricity consumption results in an increase in CO_2 emissions. Since the majority of India's commercial energy comes from coal, approximately 42% of India's total energy use in 2009 was accounted for by coal (EIA, 2012), and coal produces vast quantities of CO_2 emissions, this result makes sense. Since there is no causal relationship between electricity consumption and economic growth, India may consider decreasing electricity consumption, especially the consumption of fossil fuels, as a viable option for reducing CO_2 emissions without retarding the country's economic growth in the long-run. Alternatively, policies that focus on improving energy efficiency and increasing renewable energy use would also help combat the high levels of CO_2 emissions. In India, no evidence of causality running in any direction between economic growth and CO_2 emissions is found. Hence, India does not seem to need to reduce economic growth levels in order to decrease CO_2 emissions. This may reflect the fact that while there are steadily increasing levels of CO_2 emissions with economic growth in India, the levels of CO_2 emissions are still relatively low in per capita terms.

With respect to China, no evidence of causality running in any direction between electricity consumption and economic growth was supported. Thus, electricity consumption related policies (both conservative and expansive) have no effect on the level of economic growth in the long-run. Similarly, no causality was found to exist between electricity consumption and CO_2 emissions in China. This result may be due to the great strides China is making in terms of installation and increased usage of renewable, cleaner energy sources, particularly hydro (China is home to the Three Gorges Dam hydro power plant, the largest hydro power facility in the world (EIA, 2012)), wind (China accounts for more than half of the world market in new wind turbines (Hallding *et al.*, 2011)) and nuclear (China accounts for over half the world's nuclear capacity being built (EIA, 2012)). The lack of a causal relationship between economic growth and CO_2 emissions can be explained by the fact that China's total energy intensity has decreased between 1990 and 2010 (ABB, 2012). Thus, China is on the right track for reaching the 16% reduction in energy intensity target set out in the Twelfth Five-Year Plan (2011 – 2015) (Hallding *et al.* (2011). The country's CO_2 intensity has also decreased between 2000 and 2010 (ABB, 2012). Therefore, the combination of China's decreasing energy intensity and CO_2 intensity has resulted in China being able to achieve relatively high economic growth rates with lowering amounts of energy input required and minimum CO_2 emissions. The result of non-causality can also be explained by China's increasing dependency on non-fossil fuels as the source of electricity, again resulting in growth without raised levels of CO_2 emissions. Hence, according to these results where cross-section dependence is taken into account, the environmental performance and electricity trends of the country do not affect or get affected by the increasing rates of growth. The policy makers, thus, need to focus on them separately aiming to improve the environmental conditions of the country and maintain the high rates of growth.

In the case of South Africa, the results show a unidirectional causality running from economic growth to electricity consumption, thus favouring the conservation hypothesis. This indicates that energy conservation policies have little or no adverse effect on economic growth. Economic growth leads to growth in the commercial and industrial sectors where electricity is a basic input, it also results in higher disposable income which, in turn, raises the demand for household electronic gadgets. This results in higher electricity consumption levels in the country. The unidirectional causality may also imply that electricity consumption is not sufficient to cause economic growth; this could be due to insufficient infrastructure or power facilities to meet the demand caused by economic growth. This has shown to be the case in South Africa as in 2007/8 the country experienced a power crisis resulting in load shedding and several blackouts (EIA, 2013). There is no causal relationship between electricity consumption and CO_2 emissions. This result although puzzling at first place has an explanation: the electricity consumption in the country has minimum effect to the total emissions relatively to the immense emissions emitted by the generation of energy, which in its high majority depends on coal-burning (EIA, 2013). With regards to the economic growth-CO_2 emissions nexus, there was evidence of a unidirectional causal relationship running from economic growth to CO_2 emissions. Thus, expansion of the economy causes CO_2 emissions levels to increase. This can be explained by the fact that South Africa's economy relies heavily on its energy sector, which accounted for 15% of GDP in 2008 (Menyah and Wolde-Rufael, 2010). However, the increase in CO_2 emissions as a result of economic growth can have negative effects on human health, therefore causing productivity to decrease over a period of time. This implies that policies aimed at promoting energy efficiency should be implemented in order to decrease CO_2 emissions without adversely affecting economic growth.

The main recommendation for the BRICS countries in general is to increase investment in electricity infrastructure. This will expand electricity production capabilities in order to keep up with supply, while at the same time improving electricity efficiency. This will result in higher levels of electricity production and lower levels of CO_2 emissions. The results for the BRICS countries differ to each other and thus an overall "umbrella" policy recommendation would not be appropriate but individually-designed strategies will be mostly welcome appreciating the overall targets of increasing and sustainable economic growth and development, energy security and climate change prevention.

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