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Coal Consumption and Economic Growth Nexus: Evidence from Bootstrap Panel Granger Causality Test

Summary: This paper explores the causal relationship between coal consumption and economic growth for a panel of 15 African countries using bootstrap panel Granger causality test. Specifically, this paper uses the Phillips-Perron unit root test to ascertain the order of integration for the coal consumption and economic growth series. A bootstrap panel Granger causality test is employed to determine the direction of causality between coal consumption and economic growth. The results provide evidence of unidirectional causality from economic growth to coal consumption. This finding implies that coal conservation measures may be implemented with little or no adverse impact on economic growth for the sample countries as a group.

Key words: Coal consumption, Economic growth, Panel causality test.

JEL: Q30, Q40, Q50.

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The purpose of this paper is to examine the causal relationship between coal consumption and economic growth for a group of 15 African countries using a bootstrap panel Granger causality test. Coal usage is often associated with the production of goods and services and hence economic growth. By the same token, the need for coal as a source of energy may intensify as the economy grows. Coal possesses some attractive features which set it apart from other forms of energy. In particular, coal is abundant in supply and cheap compared to petroleum and natural gas. It also accounts for 41 percent of global electricity generation, according to the World Coal Association (2014). In addition, the political instability prevalent in most of the major oil exporting countries has encouraged dependency on coal as a source of energy. However, like most other sources of energy, coal is associated with the greenhouse effect attributable to carbon dioxide emissions and hence global warning.

A clear understanding of the causal relationship between coal consumption and economic growth is important to both policymakers and environmental experts as it has implications for national and international energy conservation policies. Seung-Hoon Yoo (2006) and Nicholas Apergis and James E. Payne (2010a) suggest that the existence of a unidirectional causality from coal consumption to economic growth suggests that a reduction in coal consumption could have a harmful effect on economic growth. However, a finding of a unidirectional causality from economic growth to coal consumption would imply that conservation policies directed at the reduction of coal consumption may be implemented with little or no adverse impact on economic growth. The neutrality hypothesis, which stipulates that there is no relationship between coal consumption and economic growth, is confirmed if there is no evidence of causality running in either direction. Finally, the existence of bidirectional causality between the two series would indicate that coal consumption and economic growth complement each other and as such, coal conservation strategies may be harmful to economic growth.

The rest of the paper is structured as follows: Section 1 offers the literature review. Section 2 details the methodology. Section 3 discusses the data and empirical results. Section 4 provides the conclusions and the implications of the study.

1. Literature Review

A number of studies have explored the causal relationship between coal consumption and economic growth in the literature. For instance, Jinke Li, Hauling Song, and Dianming Geng (2008) tested for Granger causality relationship between coal consumption and GDP for major Organisation for Economic Co-operation and Development (OECD) and non-OECD countries for the period 1980 through 2005. They find evidence of causality running from GDP to coal consumption for Japan and China. However for India, South Korea, and South Africa they failed to find evidence of a causal relationship between coal consumption and GDP. Apergis and Payne (2010a) explored the relationship between coal consumption and economic growth for a panel of 15 emerging market economies for the time period 1980 through 2006. They find evidence of bidirectional causality between coal consumption and economic growth in both short- and long-run. Yoo (2006) examined the short- and long-run relationships between coal consumption and economic growth in Korea for the period running from 1968 to 2002. Yoo (2006) finds evidence of bidirectional causality between coal consumption and economic growth for Korea. Based on this finding, he suggests that Korea should opt to mitigate the adverse effects associated with coal consumption in order to enhance its economic growth. He further concludes that his finding supports the proposition that increases in real income promotes coal consumption.

Yemane Wolde-Rufael (2005) using cointegration analysis and the Granger causality test examined the relationship between energy consumption and economic growth for a group of 19 African countries for the time period 1971 through 2001. He finds evidence of a long-run relationship between energy consumption and economic growth for 8 of the 19 African countries under study. In terms of causal relationship, he finds that causality runs from energy consumption to economic growth for Cameroon, Morocco, Nigeria, and Zambia. For Algeria, Congo Democratic Republic, Egypt, Gabon and Ivory Coast, he finds that causality runs from economic growth to energy consumption. However, for Gabon and Zambia, he finds evidence of bidirectional causality between energy consumption and economic growth. Harry Bloch, Shuddhasattwa Rafiq, and Ruhul Salim (2012) examined the relationship between coal consumption and income for China using cointegration analysis and the vector error correction models (VECM). They find evidence of long-run relationship between coal consumption and income based on the results from the cointegration tests. Further, they find evidence of causality running from coal consumption to income in both the short- and the long-run under the supply-side analysis. However, for demand-side analysis, they find evidence of causality running from income to coal consumption in both short- and long-run. They also find evidence of bidirectional causality between coal consumption and carbon dioxide in both the short- and the long-run.

Wolde-Rufael (2010) re-examined the relationship between coal consumption and real GDP for six major coal consuming countries for the time period running from 1965 to 2005 using the Hiro Y. Toda and Taku Yamamoto (1995) framework. He finds that coal consumption Granger-causes economic growth in the cases of India and Japan. For China and South Korea, he finds that economic growth Granger-causes coal consumption. However, for South Africa and the United States, he finds evidence of bidirectional causality between coal consumption and economic growth. Chien-Chiang Lee and Chun-Ping Chang (2005) examined the causal relationship between coal consumption and economic growth for Taiwan using the error correction model. They find evidence supportive of bidirectional causality between coal consumption and economic growth.

Similarly, Jin-Li Hu and Cheng-Hsun Lin (2008) using the asymmetric cointegraton technique proposed by Bruce E. Hansen and Byeongseon Seo (2002) find evidence of bidirectional causality relationship between coal consumption and economic growth for Taiwan. Saqlain Latif Satti et al. (2014) revisited the causal relationship between coal consumption and economic growth for Pakistan covering the period running from 1974 to 2010 using the VECM. They find evidence of bidirectional causality between coal consumption and economic growth. Muhammad Shahbaz and Smile Dube (2012) using the VECM and data from 1972 through 2009 re-examined the relationship between coal consumption and economic growth for Pakistan. They find that coal consumption and economic growth have a long-run relationship based on the cointegration test results. They also find evidence of bidirectional causality between the two variables based on the results from the VECM.

Inuwa Nasiru (2012) examined the relationship between coal consumption and economic growth in Nigeria using cointegration and Granger causality tests. He finds that coal consumption and economic growth share long-run relationship. He further finds evidence of causality running from economic growth to coal consumption. Based on the causality test results, he concludes that a reduction in coal consumption will not have adverse effects on the Nigerian economy. Oguz Ocal, IIhan Ozturk, and Alper Aslan (2013) explored the relationship between coal consumption and economic growth in Turkey using asymmetric causality tests for the time period running from 1980 to 2006. Their results confirm the neutrality hypothesis in the sense that coal consumption and economic growth in Turkey were found to have no causal influence on each other. They concluded that a reduction in coal consumption will not have harmful effects on economic growth and *vice versa*.

Melike E. Bildirici and Tahsin Bakirtas (2014) investigated the relationships between oil, natural gas and coal consumption and economic growth for

BRICTS (Brazil, Russia, India, China, Turkey, and South Africa) countries for the period 1980 through 2011 using the autoregressive distributed lag bounds (ARDL) model. They find evidence of bidirectional causality between oil consumption and economic growth for all of the sample countries. They also find evidence of bidirectional causality between coal consumption and economic growth for China and India. Finally, they find supportive evidence of bidirectional causality between natural gas consumption and economic growth for Brazil, Russia, and Turkey.

Hao-Yen Yang (2000) examined the causal relationship between coal consumption and economic growth for Taiwan using cointegration analysis and Granger causality test for the period 1954 through 1997. Yang (2000) finds evidence of a unidirectional causality from economic growth to coal consumption. Based on this finding, he concludes that coal conservation measures will not have harmful impact on economic growth for Taiwan. Similarly, Zahid Asghar Jr. (2008) using the VECM examined the relationship between coal consumption and economic growth for Pakistan. He finds evidence of causality running from economic growth to coal consumption in Pakistan.

Li and Zhongxue Li (2011) using Granger causality tests and data for the period from 1965 to 2006 examined the relationship between coal consumption and GDP for China and India. They find evidence supportive of a unidirectional causality from GDP to coal consumption for China. However, for India, they find evidence of a unidirectional causality from coal consumption to GDP. They stress the need for the sample countries to embark on the development of cleaner and more efficient technologies to reduce their carbon dioxide emissions in order to attain sustainable development. Raymond Li and Guy C. K. Leung (2012) re-examined the relationship between coal consumption and real GDP for China using panel data approach. They find evidence of bidirectional causal relationship between coal consumption and GDP in the Coastal and Central regions of China. However, for Western region of China, they find that causality runs from GDP to coal consumption. Based on these findings, they concluded that energy conservation measures will not adversely affect the economic growth of the Western region. Such measures however, will be detrimental to the economic growth of the Coastal and Central regions.

Mehdi Behname (2011) investigated the long-run causal relationship between coal consumption and economic growth in the Greater Middle East zone including Egypt, Iran, Pakistan and Turkey for the time period running from 1965 to 2008. He finds that there is no long-run causal relationship between coal consumption and economic growth for the sample countries and therefore concluded that conservation policies may not be harmful to their economic growth. Apergis and Payne (2010b) explored the relationship between coal consumption and economic growth for a group of 25 OECD countries using a multivariate panel framework for the time period running from 1980 to 2005. They find evidence of bidirectional causality between coal consumption and economic growth in both the short- and long-run.

From the preceding literature review it is obvious that the earlier studies on the relationship between coal consumption and economic growth lack consensus regarding the direction of causality between the two variables. Furthermore, most of the studies were undertaken in the context of OECD and Asian countries. African countries have not received adequate attention on this issue even though their economies rely heavily on coal in their quest for economic development. This paper extends the debate on the relationship between coal consumption and economic growth to a group of 15 African countries using a newly developed bootstrap panel Granger causality test developed by Furkan Emirmahmutoglu and Nezir Kose (2011). This bootstrap panel Granger causality framework has a number of attractive features. First, it can be applied in mixed panels consisting of I(0), I(1), cointegrated, and non-cointegrated series. Second, the lag lengths on autoregressive coefficients and exogenous variables in the panel are not required to be the same. Third, the time periods of all panel members can be different. Fourth, the test uses the bootstrap procedure to obtain the empirical distribution of the Fisher test statistic to avoid the problem of cross-sectional dependency among panel members. To the best knowledge of the author, the Emirmahmutoglu and Kose (2011) framework has not been applied in the context of the relationship between coal consumption and economic growth.

2. Methodology

The empirical exposition of this study commences with the applications of the augmented Dickey-Fuller (ADF) (David A. Dickey and Wayne A. Fuller 1981) and the Phillips-Perron (Peter C. B. Phillips and Pierre Perron 1988) unit root tests to determine the order of integration for coal consumption and economic growth for each of the countries in the panel. The study also implements the panel unit root tests developed by G. S. Maddala and Shaowen Wu (1999) and Jörg Breitung (2001). These procedures have been extensively applied in the literature and as such details about them will not be repeated here. The details about these procedures can be found in Dickey and Fuller (1981), Phillips and Perron (1988), Maddala and Wu (1999) and Breitung (2001), respectively.

One issue that often arises in employing panel causality test is the possibility of the existence of cross-sectional dependency among the series in the panel. To test for cross-sectional dependency, this study applies the CD_{lm} and CD_{lm2} procedures proposed by M. Hashem Pesaran (2004). The test statistics are given by the Equations (1) and (2):

$$CD_{lm} = \sqrt{\frac{2T}{N(N-1)}} \sum_{t=1}^{N-1} \sum_{j=i+1}^{N} (T\hat{\rho}_{ij}^{2} - 1), \quad (1)$$

$$CD_{lm2} = \sqrt{\frac{1}{N(N-1)}} \sum_{t=1}^{N-1} \sum_{j=i+1}^{N} (T\hat{\rho}_{ij}^{2} - 1). \quad (2)$$

In Equations (1) and (2), N is the number of cross-sections, T is the sample size and $\hat{\rho}_{ij}$ stands for the correlation coefficient between the residuals obtained from individual OLS estimations. CD_{lm} is appropriate when N and T are large (i.e. $T \to \infty$ and $N \to \infty$). The CD_{lm} statistic is assumed to be asymptotically normally distributed. However, CD_{lm} can be applied when either $T > N$ or $N > T$. The CD_{lm} test is assumed to be asymptotically standard normally distributed. The null hypothesis under each procedure is that there is no cross-section dependence among the members of the panel. The null hypothesis is rejected if the calculated test statistic (CD_{lm} / CD_{lm2}) is greater than the critical value at the conventional levels. Details about these testing procedures can be found in Yusuf Ekrem Akbas, Mehmet Senturk, and Canan Sancar (2013, p. 796).

The study next applies the Emirmahmutoglu and Kose (2011) Granger causality test in heterogeneous mixed panels in order to ascertain the causal relationship between coal consumption and economic growth. This test is based on Meta-analysis for testing Granger causality between variables in heterogeneous mixed panels. Christopher A. Sims, James H. Stock, and Mark W. Watson (1990) and Toda and Phillips (1993) suggest that the standard asymptotic theory is not valid relative to hypothesis testing in level vector autoregressive model (VAR), when the variables in the system are either integrated or cointegrated. Toda and Yamamoto (1995) attempted to find a solution by proposing an alternative method which is applicable for testing coefficient restrictions in a level VAR model of integrated or cointegrated variables. Toda and Yamamoto (1995) suggest the application of a modified Wald (MWALD) test in a lag augmented VAR (LA-VAR). The MWALD testing procedure has a conventional asymptotic Chi-square distribution when a VAR($p + d_{max}$) is implemented. Emirmahmutoglu and Kose (2011) improve on the LA-VAR model by developing a framework which incorporates the Meta-analysis. The Emirmahmutoglu and Kose (2011) LA-VAR model with $ly + d_{maxj}$ lags in heterogeneous mixed panels is given by:

$$
\begin{aligned}
y_{1,t} &= \alpha_{1,1} + \sum_{i=1}^{ly+d\max} \beta_{1,1,i} y_{1,t-i} + \sum_{j=1}^{lx+d\max} \phi_{1,1,j} x_{1,t-1} + \mu_{1,1,t} \\
y_{2,t} &= \alpha_{1,2} + \sum_{i=1}^{ly+d\max} \beta_{1,2,i} y_{2,t-i} + \sum_{j=1}^{lx+d\max} \phi_{1,2,j} x_{2,t-1} + \mu_{1,2,t} \\
&\vdots \\
y_{N,t} &= \alpha_{1,N} + \sum_{i=1}^{ly+d\max} \beta_{1,N,i} y_{N,t-i} + \sum_{j=1}^{lx+d\max} \phi_{1,N,j} x_{N,t-1} + \mu_{1,N,t}
\end{aligned}
\tag{3}
$$

and

$$
\begin{aligned}
x_{1,t} &= \alpha_{2,1} + \sum_{i=1}^{ly+d\max} \beta_{2,1,i} y_{1,t-i} + \sum_{j=1}^{lx+d\max} \phi_{2,1,j} x_{1,t-1} + \mu_{2,1,t} \\
x_{2,t} &= \alpha_{2,2} + \sum_{i=1}^{ly+d\max} \beta_{2,2,i} y_{2,t-i} + \sum_{j=1}^{lx+d\max} \phi_{2,2,j} x_{2,t-1} + \mu_{2,2,t} \\
&\vdots \\
x_{N,t} &= \alpha_{2,N} + \sum_{i=1}^{ly+d\max} \beta_{2,N,i} y_{N,t-i} + \sum_{j=1}^{lx+d\max} \phi_{2,N,j} x_{N,t-1} + \mu_{2,N,t} ,
\end{aligned}
\tag{4}
$$

where $y_{i,t}$, $i = 1, \dots, N$ represents coal consumption, $x_{i,t}$, $i = 1, \dots, N$ stands for economic growth. N represents the number of series in the panel ($j = 1, \dots, N$), t denotes time period ($t = 1, \dots, T$), and l represents the optimal lag while d_{maxi} denotes the most likely maximum order of integration for each of the series in the VAR system. Given this system, there is unidirectional Granger causality from x to y if in Equation (3) all the regression coefficients on x (i.e. $\phi_{1,j,i}s$) are not zero, but in Equation (4) all $\beta_{2,j,i}s$ are zero. Similarly, there is unidirectional Granger causality from y to x if in Equation (4) all of the regression coefficients on y (i.e. $\beta_{2,j,i}s$) are not zero but in Equation (3) all $\phi_{1,j,i}s$ are zero. To test for Granger non-causality hypothesis in heterogeneous mixed panels, Emirmahmutoglu and Kose (2011) used the test statistic advanced by Ronald A. Fisher (1932). Fisher (1932) testing procedure involves the combination of several significant levels (p-values) of identical but independent tests. The p-values (i.e. p_i, $i = 1, \ldots, N$) are assumed to be independently uniform (0, 1) variables if the test statistics are continuous. In which case, the Fisher test statistic (λ) is given by:

$$\lambda = -2\sum_{i=1}^{N} \ln(p_i)\,,\ i = 1, \ldots, N, \tag{5}$$

where p_i represents the p-value associated with the Wald statistic of the i^{th} individual cross-section. The test statistic of Equation (5) has a Chi-square distribution with $2N$ degrees of freedom. According to Emirmahmutoglu and Kose (2011), the test statistic of Equation (5) is valid only when N is fixed as T approaches infinity (i.e. $T \rightarrow \infty$). However, the Fisher test statistic is not valid in the presence of cross-sectional dependence among the members of the panel. To overcome this problem, Emirmahmutoglu and Kose (2011) proposed a bootstrap methodology that can be used to test for Granger causality for cross-sectional dependent panels. Details pertaining to the bootstrap panel Granger causality tests can be found in Emirmahmutoglu and Kose (2011).

3. Data and Descriptive Statistics

The annual data on coal consumption were retrieved from the U.S. Energy Information Administration (EIA)[1]. The data on GDP *per capita* were obtained from the Penn World Tables version 8 (PWT8.0)[2]. The economic growth variable for the various countries was calculated as percentage changes in GDP *per capita*. The coal consumption data are expressed in natural logarithms. The sample period runs from 1980 through 2012. The sample includes 15 African countries namely Algeria, Botswana, Egypt, Kenya, Madagascar, Malawi, Mauritania, Morocco, Nigeria, Niger, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe.

Table 1 displays the descriptive statistics for the logarithm of coal consumption and economic growth rates for the sample countries. The mean values of coal consumption ranged from a high of 11.990 for South Africa to a low of 2.518 for Madagascar. Zambia (1.998) posted the highest standard deviation relative to coal consumption while Egypt (0.143) documented the least. The mean values of econom-

[1] **U.S. Energy Information Administration (EIA).** 2014. Annual Coal Report. https://www.eia.gov/coal/annual/ (accessed May 24, 2014).
[2] **Groningen Growth and Development Centre.** 2014. Penn World Tables (PWT8.0). http://www.rug.nl/ggdc/productivity/pwt/pwt-releases/pwt8.0 (accessed May 24, 2014).

ic growth rate varied from a high of 5.199 percent for Botswana to a low of -1.291 percent for Niger. Algeria (12.622%) documented the highest standard deviation in terms of economic growth, while Kenya (2.123%) displayed the least. The Jarque-Bera statistics for coal consumption show that the null hypothesis of normal distribution should be rejected at the 10 percent level or better in the cases of Botswana, Egypt, Kenya, Madagascar, Mauritania, Niger, Swaziland, Tanzania and Zambia. Similarly, for economic growth, the normality assumption is rejected in the cases of Botswana, Egypt, Madagascar, Mauritania, Niger, Swaziland and Tanzania at least at the 10 percent level of significance. From the minimum and maximum statistics reported in Table 1, it can be surmised that coal consumption and economic growth for the various sample countries varied for the time period under study.

Table 1 Descriptive Statistics

Country	Coal consumption (natural logarithm)					Economic growth (percent)				
	Mean	Max	Min	STD	J-Bera	Mean	Max	Min	STD	J-Bera
Algeria	6.888	7.415	6.314	0.279	2.208	4.297	25.110	-26.429	12.622	1.010
Botswana	6.706	7.044	6.014	0.322	4.996*	5.199	29.261	-6.112	5.508	159.984***
Egypt	7.202	7.450	6.762	0.143	5.865**	3.671	12.926	-0.444	2.584	27.193***
Kenya	4.619	5.166	2.988	0.416	80.907***	0.440	4.298	-3.971	2.123	1.120
Madagascar	2.518	2.934	1.484	0.267	56.651***	-1.212	6.505	-15.284	4.342	18.789***
Malawi	3.589	4.318	2.495	0.638	3.790	1.646	14.275	-7.149	4.395	1.789
Mauritania	4.460	6.602	0.097	1.756	5.445*	0.291	15.725	-10.255	4.699	10.894***
Morocco	8.116	8.659	7.286	0.435	2.555	2.146	10.595	-7.984	4.523	1.200
Nigeria	3.404	5.290	1.196	1.152	1.705	1.041	18.424	-15.435	6.717	1.923
Niger	5.091	5.543	3.093	0.547	86.739***	-1.291	8.840	-19.082	4.988	21.623***
South Africa	11.990	12.287	11.559	0.184	0.736	0.643	4.442	-4.545	2.672	2.443
Swaziland	5.118	5.493	4.004	0.289	51.670***	1.500	13.308	-3.447	2.920	81.477***
Tanzania	3.050	4.751	0.791	1.559	4.588*	1.627	4.986	-5.394	2.472	4.923*
Zambia	4.871	6.504	0.097	1.998	17.939***	-0.126	4.202	-10.852	3.555	4.411
Zimbabwe	8.318	8.715	7.942	0.235	2.291	0.147	16.734	-9.207	5.886	2.812

Note: ***, ** and * indicate the rejection of the null hypothesis of normality distribution at the 1%, 5% and 10% levels, respectively.

Source: Author's calculations.

4. Empirical Results

The results from the ADF and the Phillips-Perron unit root tests on the levels and first differences of coal consumption and economic growth are displayed in Tables 2 and 3, respectively. The ADF test results in Table 2 show that coal consumption for Egypt, Madagascar, Niger, and Swaziland are level stationary, at least at the 5 percent significance level. However, coal consumption for the rest of the sample countries is first difference stationary. The economic growth series is level stationary in all of the cases with the exception of Tanzania, where it is first difference stationary. The results from the Phillips-Perron unit root test presented in Table 3 also reveal that coal consumption in most of the cases is first difference stationary. However, the economic growth variable for all of the countries, with the exception of Tanzania is level stationary. Taken together, the unit root test results presented in Tables 2 and 3 indicate that the maximum order of integration should be set to one (i.e. $d_{max} = 1$) in all of the cases for the LA-VAR system. The study uses the Maddala and Wu (1999) and Breitung (2001) panel unit root procedures to check the robustness of the results regarding the order of integration of the variables. The results from the panel unit root tests are presented in Table 4. The results from the Maddala and Wu (1999) panel unit root tests indicate that coal consumption and economic growth are level stationary. However the results from the Breitung (2001) panel unit root test suggest that coal consumption is level stationary while economic growth is first difference stationary. These results collaborate those from the ADF and Phillips-Perron unit root tests in the sense that the maximum order of integration is found to be one (i.e. $d_{max} = 1$).

Table 2 ADF Unit Root Test Results (*p*-values)

Country	Coal consumption		Economic growth		d_{max}
	Level	1st difference	Level	1st difference	
Algeria	0.124	0.001***	0.000***	-	1
Botswana	0.140	0.021**	0.002***	-	1
Egypt	0.007***	-	0.007***	-	1
Kenya	0.156	0.008***	0.021**	-	1
Madagascar	0.028**	-	0.000***	-	1
Malawi	0.618	0.002***	0.000***	-	1
Mauritania	0.168	0.022**	0.001***	-	1
Morocco	0.376	0.003***	0.000***	-	1
Nigeria	0.406	0.000***	0.000***	-	1
Niger	0.000***	-	0.012***		1
South Africa	0.418	0.002***	0.020***	-	1
Swaziland	0.043**	-	0.002***	-	1
Tanzania	0.671	0.002***	0.222	0.000***	1
Zambia	0.937	0.019**	0.007***	-	1
Zimbabwe	0.476	0.006***	0.009***	-	1

Note: *** and ** indicate the rejection of the null hypothesis of a unit at the 1% and 5% levels of significance, respectively

Source: Author's calculations.

Table 3 Phillips-Perron Unit Root Test Results (*p*-values)

Country	Coal consumption		Economic growth		d_{max}
	Level	1st difference	Level	1st difference	
Algeria	0.260	0.000***	0.000***	-	1
Botswana	0.129	0.000***	0.002***	-	1
Egypt	0.000***	-	0.013**	-	1
Kenya	0.000***	-	0.021**	-	1
Madagascar	0.025**	-	0.000***	-	1
Malawi	0.399	0.000***	0.000***	-	1
Mauritania	0.135	0.000***	0.000***	-	1
Morocco	0.216	0.000***	0.000***	-	1
Nigeria	0.328	0.001***	0.000***		1
Niger	0.000***	-	0.012**	-	1
South Africa	0.141	0.000***	0.020**	-	1
Swaziland	0.008***	-	0.002***	-	1
Tanzania	0.686	0.000***	0.279	0.000***	1
Zambia	0.997	0.016**	0.004***	-	1
Zimbabwe	0.609	0.001***	0.009***	-	1

Note: *** and ** indicate the rejection of the null hypothesis of a unit at the 1% and 5% level of significance, respectively.

Source: Author's calculations.

In conducting the bootstrap panel Granger causality tests, it is important to account for the presence of cross-sectional dependency in the data as this has implication for the validity of the Fisher test statistic. The presence of cross-sectional dependence in the data implies that the standard Chi-square distribution is no longer valid. In which case, the bootstrapping methodology proposed by Emirmahmutoglu and Kose (2011) should be used to obtain the appropriate critical values for the Fisher test statistic. In addition to the Pesaran (2004) CD_{lm2} and CD_{lm} cross-sectional dependency tests, the study also applies the bias adjusted LM_{adj} test developed by Pesaran, Aman Ullah, and Takashi Yamagata (2008). Table 5 presents the results from the various cross-sectional dependence tests. The results clearly provide evidence supportive of the existence of cross-section dependence in the data. In other words, the results suggest that the null hypothesis of no cross-sectional dependence across the countries in the panel should be rejected at the conventional levels of significance. This finding entails that shocks to either coal consumption or economic growth in one of the sample countries are easily transmitted to the other countries.

Table 4 Panel Unit Root Test Results

	Level		First difference	
	Statistic	***p*-value**	**Statistic**	***p*-value**
Panel A: Coal consumption (CC)				
Maddala and Wu (1999) ADF – Fisher Chi-square	67.016***	0.000	319.292***	0.000
Maddala and Wu (1999) ADF – In Choi (2001) Z-stat	-3.273***	0.001	-15.367***	0.000
Breitung (2001) *t*-stat	-1.079	0.140	-6.481***	0.000
Panel B: Economic growth (EG)				
Maddala and Wu (1999) ADF – Fisher Chi-square	226.141***	0.000	381.158***	0.000
Maddala and Wu (1999) ADF – Choi (2001) Z-stat	-11.871***	0.000	-17.269***	0.000
Breitung (2001) *t*-stat	-4.664***	0.000	-11.293***	0.056

Note: *** indicates rejection of the null hypothesis of a unit at the 1% level of significance.

Source: Author's calculations.

Table 5 Cross-Sectional Dependence Test Results

	Test stat	**Probability**
Panel A: Coal consumption (CC)		
CD_{lm2} Pesaran (2004) CD_{lm}	-2.601***	0.005
CD_{lm} Pesaran (2004) CD	-3.307***	0.000
Bias adjusted CD test Pesaran, Ullah, and Yamagata (2008)	-2.012***	0.022
Panel B: Economic growth (EG)		
CD_{lm2} Pesaran (2004) CD_{lm}	-3.304***	0.000
CD_{lm} Pesaran (2004) CD	-3.688***	0.000
Bias adjusted LM_{adj} test Pesaran, Ullah, and Yamagata (2008)	0.666	0.253
Panel C: CD model test		
CD_{lm2} Pesaran (2004) CD_{lm}	-0.321	0.374
CD_{lm} Pesaran (2004) CD	3.167***	0.001
Bias adjusted LM_{adj} test Pesaran, Ullah, and Yamagata (2008)	33.141***	0.000

Note: *** indicates the rejection of the null hypothesis of no cross-sectional dependence at the 1% level of significance.

Source: Author's calculations.

The next step in the empirical analysis of the study involves the estimation of the LA-VAR system of Equations (3) and (4). Table 6 displays the results from the bootstrap panel Granger causality tests. Beginning with the test results for the individual countries in the panel, the null hypothesis that economic growth does not Granger-cause coal consumption is rejected for Egypt and Zambia at least at the 5 percent level of significance. The results show evidence of bidirectional causality between economic growth and coal consumption in the case of Nigeria. As the results indicate, the null hypothesis that economic growth does not Granger-cause coal consumption should be rejected and *vice versa*. However, the results fail to reject the null hypothesis that economic growth does not Granger-cause coal consumption in the cases of Algeria, Botswana, Kenya, Malawi, Mauritania, Morocco, Niger, South Africa, Swaziland, Tanzania and Zimbabwe. In all of these cases, the computed Wald statistics are not statistically significant at the conventional levels as indicated by the *p*-values. For example, in the case of Algeria, the computed Wald statistic is 0.291 with a *p*-value of 0.589. The results further reveal that the null hypothesis that coal consumption does not Granger-cause economic growth should be rejected for Niger and Zimbabwe at the 10% and 5% levels, respectively. However, the results suggest that the null hypothesis that coal consumption does not Granger-cause economic growth should not be rejected in the cases of Algeria, Botswana, Egypt, Kenya, Madagascar, Malawi, Mauritania, Morocco, South Africa, Swaziland, Tanzania, and Zambia. In all of these cases, the computed Wald statistics are not statistically at the conventional levels. For example, for Botswana, the computed Wald statistic is 0.859 while the *p*-value is 0.354. However, the Granger causality test results for individual panel members should be taken with caution as they were obtained with limited number of observations and hence fewer degrees of freedom compared to those from panel-based tests.

The results for the Fisher test statistic value obtained by combining the *p*-values of the various series in the panel are presented in Table 6. The Fisher test statistic is used to assess the overall hypothesis of Granger non-causality for the sample countries. The Fisher procedure provides a test statistic that is distributed as X^2_{2N} under the cross-section assumption. However, the limit distribution of the Fisher test statistic is not valid if there is evidence supportive of cross-sectional dependency in the panel. Given the finding of the presence of cross-section dependence in the data as evidenced by the results presented in Table 6, the paper uses the bootstrap method to generate the empirical distributions of the Fisher test statistic. The bootstrapped critical values at the 1%, 5%, and 10% levels are obtained from 10,000 replications. Based on the computed Fisher test statistic value, the null hypothesis that economic growth does not Granger-cause coal consumption for the entire panel is rejected at the 5% level of significance. However, the null hypothesis that coal consumption does not Granger-cause economic growth for the whole panel cannot be rejected not even at the 10% level of significance. The finding of this study is consistent with Yang (2000) and Asghar Jr. (2008) who found that economic growth Granger-causes coal consumption for Taiwan and Pakistan, respectively.

Table 6 Granger Causality Test Results

Country	EG ↛ CC			CC ↛ EG		
	Lags	Wald stat	*p*-value	Lags	Wald stat	*p*-value
Algeria	1	0.291	0.589	1	0.038	0.846
Botswana	1	0.461	0.497	1	0.859	0.354
Egypt	1	9.983***	0.002	1	1.104	0.293
Kenya	2	0.463	0.793	2	0.363	0.834
Madagascar	1	0.046	0.830	1	0.233	0.629
Malawi	2	0.030	0.172	2	0.227	0.064

Mauritania	1	1.692	0.193	1	0.022	0.881
Morocco	1	1.316	0.251	1	0.010	0.921
Nigeria	2	17.804***	0.000	2	4.957*	0.084
Niger	1	0.007	0.934	1	2.885*	0.089
South Africa	1	0.303	0.582	1	0.003	0.957
Swaziland	1	0.092	0.761	1	0.639	0.424
Tanzania	1	0.062	0.803	1	0.237	0.626
Zambia	2	6.466**	0.039	2	0.031	0.615
Zimbabwe	1	0.314	0.575	1	4.650**	0.031
Fisher test Stat (λ)		50.111**			27.252	
Bootstrap critical values for Fisher test stat (λ)						
1%		59.637			59.553	
5%		50.034			49.247	
10%		45.559			44.498	

Note: ***, ** and * indicate the rejection of the null hypothesis at the 1%, 5%, and 10% levels of significance, respectively. The optimal lags for the Fisher test statistics were determined *via* the Akaike Information Criterion (AIC).

Source: Author's calculations.

5. Conclusions and Implications

This paper has investigated the causal relationship between coal consumption and economic growth for a panel of 15 African countries using the bootstrap panel Granger causality test, for the time period 1980 through 2011. The countries in the sample include Algeria, Botswana, Egypt, Kenya, Madagascar, Malawi, Mauritania, Morocco, Nigeria, Niger, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. The study implemented the ADF and Phillips-Perron unit root tests to ascertain the time series properties of coal consumption and economic growth for the sample countries. This study adopted the bootstrap panel Granger causality test advanced by Emirmahmutoglu and Kose (2011) which is based on Fisher (1932) Meta-analysis.

The results from the ADF and Phillips-Perron unit root tests indicate that the economic growth series for all of the sample countries are level stationary, with the exception of Tanzania. However, the results also show that coal consumption for most of the sample countries are first difference stationary. The panel unit root tests reveal that economic growth is level stationary while coal consumption is first difference stationary. Based on these results, the number of augmenting terms in the MWALD tests was set equal to 1 (i.e. $d_{max} = 1$). The results from the Pesaran (2004) and Pesaran, Ullah, and Yamagata (2008) tests indicate the presence of cross-section dependence among the series. Hence the bootstrap method was applied to determine the appropriate sampling distributions for the Fisher test statistic.

The results for individual panel members indicate that causality runs from economic growth to coal consumption in the cases of Egypt and Zambia implying that energy conservation policies in these countries may not be detrimental to their economic growth. In contrast, it was found that causality runs from coal consumption to economic growth in the cases of Niger and Zimbabwe implying that reduction in coal consumption will have a harmful effect on their economic growth. However, the results provide evidence of neutrality between economic growth and coal consumption in the cases of Algeria, Botswana, Kenya, Madagascar, Malawi, Mauritania, Morocco, Niger, South Africa, Swaziland, Tanzania and Zimbabwe. This result implies that coal consumption and economic growth do not have causal influence on each other in these countries. For Nigeria, there is evidence of bidirectional causality between coal consumption and economic growth, implying that coal consumption and economic growth are complementary and hence, coal conservation strategies may negatively affect its economic growth.

For the entire panel, the results from the Fisher test and their associated bootstrapped critical values indicate that causality runs from economic growth to coal consumption but not *vice versa*. As a group, the finding of causality running from economic growth to coal consumption lends credence to the notion that demand for coal for industrial purposes tends to increase as the economy develops. It also implies that coal conservation strategies can be implemented with little or no adverse impact on economic growth for the panel members, as a group.

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