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DETERMINANTS OF CO2 EMISSIONS: EVIDENCE FROM SOUTHERN AFRICA

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Abstract

This study investigates the time series and panel determinants of carbon dioxide emissions in six African countries. It also examines statistical evidence in favour of the environmental Kuznets curve for capita CO_2 emissions in the six countries individually as well as in a panel. Employing the autoregressive distributed lag model (ARDL), the relationship in which carbon dioxide emissions is the dependent variable is used to estimate the short-run and long-run elasticities of carbon emissions with respect to the identified explanatory variables for each country. The results suggest that the main driving force behind carbon emissions is income per capita in three of the countries (Botswana, Zambia and Zimbabwe), with a long-run elasticity ranging from 25 to 115. There is no evidence in support of the environmental Kuznets curve (EKC) hypothesis within our sample of individual countries. The fixed effects panel results indicate that income as well as its quadratic form, trade openness and service sector share in GDP are significant determinants of carbon emissions. The income and the quadratic income variables in the panel have the expected positive and negative signs as is expected in terms of the EKC hypothesis. Both variables are significant at levels of significance of 10 percent or lower. The significance of the quadratic income variable shows that this variable is non-linearly related to carbon emissions in the panel of countries.

1. Introduction

Global warming and climate change are global problems threatening to increase the long-run surface temperature of the earth. Amongst several environmental pollutants causing climate change, carbon dioxide (CO_2) is the most important greenhouse gas (GHG) and is believed to be responsible for 58.8% of the greenhouse gases in a report of the World Bank (2007). While emissions have grown rapidly in most countries over the years, the reasons for this growth vary from country to country.

The international community has also expressed its concern for and the need to effectively control of greenhouse gas emissions through its various protocols. For instance, in the Kyoto protocol the over all emissions of green house gases from the developed countries should have been at least 5% below 1990 levels in the commitment period 2008-2012 while the commitment of EU countries was an 8% reduction of emissions for the same period (Brannlund and Nordstrom, 2004). At the end of 2005 another round of environmental summit took place in Montreal, Canada, to push for further measures to reduce the emissions of greenhouse gases after the first year of the adoption of the Kyoto protocol.

The environmental Kuznets curve (EKC) describes the inverted U relationship between per capita income and environmental pollution. Its name was derived from Simon Kutznets who observed a similar relationship between income and poverty in the 1950s. The EKC relationship implies that environmental pollution increases in the early stages of growth, but it eventually decreases as income exceeds a threshold level. Although CO_2 is uniformly mixing and is therefore characterized by low levels of self-pollution, there are a number of studies which have confirmed the existence of an inverted U relationship for such a pollutant (Jalil and Mahmud, 2009; Iwata, Okada, and Samreth. (2010a); Iwata, Okada, and Samreth (2010b); Shahbaz, Jalil and Dube (2010); among others). These earlier results provide a motivation for this study.

This study is concerned with the determinants of carbon dioxide in six countries in southern Africa. In particular, we estimate the environmental Kuznets curve in individual country time series analyses (1971 to 2006) as well as in a panel of the countries, (Botswana, Democratic Republic of Congo, Mozambique, South Africa, Zambia and Zimbabwe) over the period 1981 to 2005.

The remainder of this paper is organized as follows: the next section gives the objectives which were addressed in this study. Section 3 provides an overview of the theoretical and empirical literature on the determinants of carbon dioxide emissions. Section 4 outlines the empirical model specifications and the methodology to be employed in this study. Section 5 gives the empirical analysis and results for both individual country time series and panel analyses. The concluding remarks are presented in section 6.

2. Objectives of the study

This study had two objectives, namely: to investigate the influence of various factors on CO_2 emissions in six southern African countries, and to test the Environmental Kuznets Curve (EKC) for carbon emissions in these countries, both individually and in a panel.

3. Theoretical and empirical literature overview

3.1The conceptual background of the environmental Kuznets Curve

Following Grossman and Krueger (1995), Borghesi and Vercelli (2008) identified three channels through which income growth can impact on the quality of the environment. These include a scale effect, a composition effect and a technique effect. The scale effect argues that a larger scale of economic activity leads to increased environmental degradation. The argument is that a higher rate of economic growth requires that more inputs and natural resources are used up and the resultant more waste and emissions worsen environmental quality.

The composition effect argues that income growth has a positive impact on the environment. It says economic growth involves structural changes in the economy which lead to gradual increases in the share of cleaner activities in the gross domestic product. Arrow et al*.,* (1995) suggested that the pattern of environmental degradation is the natural progression from a basic agrarian process free of environmental impact to high polluting industrial economies and then to clean economies of services.

Finally, economic growth involves technological progress. The technique effect of growth on the environment suggests that as an economy grows there is substitution of obsolete and dirty technologies with cleaner ones, which improves the quality of the environment.

3.2 An overview of empirical literature

There are numerous empirical studies which analyze the determinants of carbon emissions. Some studies employed a decomposition technique (Hamilton and Turton, 2002). Most studies employ time series analysis (Friedl and Getzner, 2003; Jalil and Mahmud, 2009; Halicioglu, 2009; Iwata et al., 2010a and 2010b; and Kearsley and Riddel, 2010). Others employ panel data analysis (Musolesi, Mazzanti, and Zoboli (2010); Sharma, (2011)). Despite the extensive empirical literature on the determinants of carbon emissions most of these studies focus on developed economies with none focussing on African economies.

The environmental Kuznets curve (EKC) hypothesis claims that an inverted U-shaped relationship exists between income per capita and emissions (environmental pressure). This hypothesis has received a lot of attention in the empirical literature[1]. The empirical evidence has been very inconclusive in the case of CO_2 (Friedl and Getzner, 2003). Studies on the EKC hypothesis for CO_2 emissions include Jalil and Mahmud (2009), Musolesi et al*.,* (2010) Halicioglu (2009), Iwata et al*.,* (2010a and b) and Kearsley and Riddel (2010).

Jalil and Mahmud (2009) examine the long-run relationship between carbon emissions and energy consumption, income and foreign trade in the case of China using time series data for the period 1975-2005. They employ the autoregressive distributed lag methodology to test for the existence of an EKC in the long-run. Their empirical results suggest the existence of a robust long-run relationship between the variables. Their results also confirm the existence of an EKC for carbon dioxide emissions. They conclude that carbon dioxide emissions are mainly determined by income and energy consumption in the long-run.

Halicioglu (2009) examines the relationships between carbon emissions, energy consumption, income and foreign trade in Turkey over the period 1960-2005. The study employs the bounds testing approach to cointegration. The study's empirical results suggest that income, energy consumption and foreign trade are all significant determinants of carbon emissions in Turkey.

Iwata et al., (2010a) estimate the environmental Kuznets curve in the case of France, taking into account the role of nuclear energy in electricity production. They also included trade openness, energy consumption and urbanization as additional variables in some of their estimations. They employed the autoregressive distributed lag estimation method. Their empirical results provide evidence in support of the EKC hypothesis. Their causality test results suggest unidirectional causality from other variables to CO_2 emissions.

[1] See Martinez-Zarzoso, Bengochea-Morancho, and Morales-Lage (2007) for a summary of CO_2 EKC studies.

Iwata et al., (2010b), using the autoregressive distributed lag approach to cointegration, investigate the determinants of carbon dioxide in 11 OECD countries by estimating the environmental Kuznets curve for carbon dioxide using time series over different time periods. The countries which were included are Belgium, Canada, Finland, Germany, Japan, Korea, Spain, Sweden, Switzerland, United Kingdom and United States of America. They took into account the role played by nuclear energy in electricity production, energy consumption and foreign trade in the sample countries. Their empirical results suggest that energy consumption was the main determinant of carbon dioxide emissions in most countries in their study. The EKC was confirmed only in the cases of Finland, Japan, Korea and Spain, with the turning point falling inside the sample period only in the case of Finland.

Shahbaz et al., (2010) examine the relationship between environmental degradation and income for Portugal over the period 1971- 2008. They apply the autoregressive distributed lag methodology. Their estimation includes trade openness, energy consumption and urbanization as additional variables. Their empirical results suggest the presence of an EKC in both the short and long-run periods.

Kearsley and Riddel (2010) investigate the role played by international trade in the relationship between economic growth and its impact on the environment in a panel of 27 OECD member countries. They tested the pollution haven hypothesis, which suggests that emission reductions that have been observed in developed nations are partly due to the fact that they have been shifting “dirty” production to developing countries where environmental laws are lax. They estimated EKCs for seven pollutants (including carbon dioxide). For carbon dioxide the time span was 1980- 2004. For the other pollutants the time span was 1990-2004. Their empirical findings support the existence of an EKC. The manufacturing share and trade openness are not significant in the carbon dioxide estimations. Overall, their findings suggest little evidence that pollution havens play a significant role in shaping the EKC.

Friedl and Getzner (2003) analyse the relationship between economic development and carbon dioxide emissions for Austria over the period 1960-1999. They test whether the EKC relationship holds for Austria. Their results show that a cubic relationship between GDP and CO_2 emissions existed for the period 1960-1999. Two additional variables were found to be significant: import shares and the share of the tertiary sector in GDP.

Musolesi et al*.,* (2010) estimate the EKC for CO2 emissions in a panel of 109 countries during the period 1959 to 2001. The looked at the full sample of countries as well as sub-samples of G7, EU15, OECD, non-OECD countries, 40 poorest countries and those classified as the umbrella countries. They tested both the quadratic and the cubic forms of the EKC hypothesis. Their results show that different EKC dynamics are associated with the different sub-samples considered. Both specifications lead to an EKC dynamic for the more developed countries, while monotonously rising CO_2 emissions with respect to GDP are observed for the less-developed countries. Accordingly to their results the EU shows a clear EKC shape. They concluded that the full sample analysis hides critical dynamics and recommended further research to be carried out on specific countries.

In another panel study, Sharma (2011) investigates the determinants of carbon dioxide emissions for a panel of 69 countries over the period 1985-2005. The author subdivides the panel according to income into high income, middle income and low income panels. The author's findings were that trade openness, per capita GDP and per capita energy consumption have positive effects on CO_2 emissions in all sub-panels. Urbanization was found to have a negative impact on CO_2 emissions in all sub-panels. For the global panel, the author finds that only per capita GDP and total primary energy consumption are statistically significant determinants of CO_2 emissions.

Most time series studies included the following variables: energy consumption, income as well as its quadratic term, foreign trade or openness variable (Halicioglu, 2009; Jalil and Mahmud, 2009, Iwata et al., 2010a, Iwata et al., 2010b). These are the most common variables that have been included in the empirical literature. Other variables that have been included in some of the studies include electricity production from nuclear sources (Iwata et al., 2010a, Iwata et al., 2010b), rate of urbanization (Shahbaz et al., 2010). Friedl and Getzner (2003) included a variable to capture the value added in the service sector and temperature deviation from the long-run average temperature. Other studies have analysed the impact of population and other demographic factors on air pollution (Cole and Neumayer, 2004; Dietz and Rosa, 1997; and Martinez-Zarzoso et al, 2007).The most dominant methodology used in these studies is the bounds test which falls under the autoregressive distributed lag framework.

4. Methodology

4.1 Individual country time series analysis

Following the standard empirical literature reviewed above the present study analyzes the determinants of CO_2 emissions in the selected countries (Botswana, Democratic Republic of Congo, Mozambique, South Africa, Zambia and Zimbabwe) individually as well as in a panel. The sample of countries was limited by the availability of time series data spanning more than 25 observations for all the relevant variables. Based on the reviewed literature, two estimations were done and these are represented by equations (2) and (4).

The traditional EKC is specified as

$$co2_t = \lambda_0 + \lambda_1 y_t + \lambda_2 y_t^{\,2} + \lambda_3 y_t^{\,3} + \lambda_4 z_t + \mu_t \qquad (1)$$

Where CO_{2t} represents CO_2 emissions per capita in year t, y is real GDP per capita, and z stands for a vector of other variables that are supposed to influence emissions. Following Iwata et al., (2010a and 2010b), Shahbaz et al., (2010) and Halicioglu (2009) this study includes foreign trade in vector z. We also include the ratio of service sector value added to GDP as suggested by Freidl and Getzner (2003).

Our empirical model is specified as follows

CO2 = f(Y, Tr, S), in log-linear form it becomes:

$$co2_t = \alpha_0 + \alpha_1 y_t + \alpha_2 y_t^{\,2} + \alpha_3 tr_t + \alpha_4 s_t + \varepsilon_t \qquad (2)$$

Where co_{2t} is the natural logarithm of CO_2 emissions per capita in year t, y is the natural logarithm of real GDP per capita, ε is the classical error term, tr is the natural logarithm of the share of total trade in GDP (%), and s represents the natural log of the share of service sector value added in GDP (%). Carbon emissions per capita are measured in metric tons; and real GDP per capita measured in constant 2000 US$. Data were obtained from World Development Indicators. Although most studies have included energy consumption as one of the variables, it is excluded from our analysis because it was found to be highly correlated with carbon emissions. The correlation coefficient was as high as 0.99 in some cases. Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. These activities are directly related to energy consumption levels over time in the sample countries. This study excludes the energy consumption variable as a way of minimizing the endogeneity between carbon emissions and gross domestic product.

As for the expected signs in equation (2), one expects that under the EKC hypothesis $\alpha_1 > 0$, while $\alpha_2 < 0$. The coefficient α_3 is expected to be positive since we are analyzing developing countries which tend to have dirty industries with heavy pollutants, as discussed in Grossman and Krueger (1995). The coefficient α_4 is expected to be negative as a growing share of service sector value added in GDP reduces pollution-intensive industries and thus CO_2 emissions. The income level at which emissions begin to decline is called income turning point (ITP). This point of an EKC is given by the exponential of $(-\alpha_1/2\alpha_2)$. This point was obtained by setting the first derivative (with respective to income) of equation (2) equal to zero and solving for income.

The bounds testing approach to cointegration involves estimating the following unrestricted error correction model (UECM):

$$\Delta co2_t = \alpha_0 + \alpha_1 y_{t-1} + \alpha_2 y_{t-1}{}^2 + \alpha_3 tr_{t-1} + \alpha_4 s_{t-1} + \alpha_5 co2_{t-1} + \sum_{i=1}^{n} \delta_{1i} \Delta co2_{t-i} + \sum_{i=0}^{n} \delta_{2i} \Delta y_{t-i} + \sum_{i=0}^{n} \delta_{3i} \Delta y_{t-i}^2 + \sum_{i=0}^{n} \delta_{4i} \Delta tr_{t-i} + \sum_{i=0}^{n} \delta_{5i} \Delta s_{t-i} + \mu_t \quad (3)$$

,

where Δ represents the first difference operator and all the other variables are as defined before.

The bounds test methodology suggests analysing the null hypothesis of no co-integration through a joint significance test of the lagged levels of the variables. The null hypothesis of no cointegration among the variables in equation (3) is (H_0: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$) against an alternative of long-run relationship (H_1: $\alpha_1 \neq 0$ or $\alpha_2 \neq 0$, or $\alpha_3 \neq 0$, or $\alpha_4 \neq 0$ or $\alpha_5 \neq 0$). There are two ways of testing for the long-run relationship, namely, the F-test and the Wald test. This approach is most suitable if none of the variables are integrated of order two.

If the computed *F*-statistic, for a chosen level of significance, lies outside the critical bounds, a conclusive decision can be made regarding cointegration without knowing the order of integration of the regressors. If the calculated *F* statistic is higher than the upper bound, the null hypothesis of no cointegration is rejected. If the *F*-statistic is lower than the lower bound, then the null hypothesis cannot be rejected. If the *F*-statistic lies between the lower and the upper bounds, conclusive inferences cannot be made.

4.2 Panel analysis

The study also considers a panel analysis of the determinants of CO_2 emissions in the six African countries. The panel analysis has the advantage that it increases the observations which increases efficiency unlike the individual country time series analyses. The panel model (with variables defined as before) to be estimated can be written as follows:

$$co2_{it} = \beta_{0i} + \beta_{1i} y_{it} + \beta_{2i} y_{it}^2 + \beta_{3i} tr_{it} + \beta_{4i} s_{it} + \varepsilon_{it} \qquad (4)$$

Where i = 1,……….,N for each country in the panel and t = 1,………..T represents the time period. The parameters β_{ij} allow for country- specific fixed effects. The estimated residuals ε_{it} represent deviations from the long-run relationship. With all variables expressed in natural logarithms, the estimated β_{ij} parameters represent elasticity estimates. The income turning points for the individual countries in the panel were calculated as the exponential of $(\beta_{1i}/2\beta_{2i})$.

In terms of panel analysis, the study uses a balanced panel (t = 1981 to 2005 for the six countries) with 150 observations. We test for panel unit roots using the Levin, Lin, and Chu (2002) test. Panel cointegration was tested using the approach proposed by Pedroni (1999).

A panel vector error correction model is estimated in order to examine the casual relationships. We undertake the Engle and Granger (1987) two-step procedure by first estimating the long-run model specified in equation (4) to obtain the estimated residuals. In the second step we define the lagged residuals as the error correction term and estimate the following dynamic error correction model:

$$\Delta co2_{it} = \psi_{1i} + \sum_{k=1}^{n}\alpha_{11ik}\Delta y_{it-k} + \sum_{k=1}^{n}\alpha_{12ik}\Delta y_{it-k}^{2} + \sum_{k=1}^{n}\alpha_{13ik}\Delta tr_{it-k} + \sum_{k=1}^{n}\alpha_{14ik}\Delta s_{it-k} + \sum_{k=1}^{n}\alpha_{15ik}\Delta co2_{it-k} + \lambda_{1i}\varepsilon_{it-1} + \mu_{1it} \quad (5a)$$

$$\Delta y_{it} = \psi_{2i} + \sum_{k=1}^{n}\alpha_{21ik}\Delta y_{it-k} + \sum_{k=1}^{n}\alpha_{22ik}\Delta y_{it-k}^{2} + \sum_{k=1}^{n}\alpha_{23ik}\Delta tr_{it-k} + \sum_{k=1}^{n}\alpha_{24ik}\Delta s_{it-k} + \sum_{k=1}^{n}\alpha_{25ik}\Delta co2_{it-k} + \lambda_{2i}\varepsilon_{it-1} + \mu_{2it} \quad (5b)$$

$$\Delta y^{2}{}_{it} = \psi_{3i} + \sum_{k=1}^{n}\alpha_{31ik}\Delta y_{it-k} + \sum_{k=1}^{n}\alpha_{32ik}\Delta y_{it-k}^{2} + \sum_{k=1}^{n}\alpha_{33ik}\Delta tr_{it-k} + \sum_{k=1}^{n}\alpha_{34ik}\Delta s_{it-k} + \sum_{k=1}^{n}\alpha_{35ik}\Delta co2_{it-k} + \lambda_{3i}\varepsilon_{it-1} + \mu_{3it} \quad (5c)$$

$$\Delta tr_{it} = \psi_{4i} + \sum_{k=1}^{n}\alpha_{41ik}\Delta y_{it-k} + \sum_{k=1}^{n}\alpha_{42ik}\Delta y_{it-k}^{2} + \sum_{k=1}^{n}\alpha_{43ik}\Delta tr_{it-k} + \sum_{k=1}^{n}\alpha_{44ik}\Delta s_{it-k} + \sum_{k=1}^{n}\alpha_{45ik}\Delta co2_{it-k} + \lambda_{4i}\varepsilon_{it-1} + \mu_{4it} \quad (5d)$$

$$\Delta s_{it} = \psi_{5i} + \sum_{k=1}^{n}\alpha_{51ik}\Delta y_{it-k} + \sum_{k=1}^{n}\alpha_{52ik}\Delta y_{it-k}^{2} + \sum_{k=1}^{n}\alpha_{53ik}\Delta tr_{it-k} + \sum_{k=1}^{n}\alpha_{54ik}\Delta s_{it-k} + \sum_{k=1}^{n}\alpha_{55ik}\Delta co2_{it-k} + \lambda_{5i}\varepsilon_{it-1} + \mu_{5it} \quad (5e)$$

where Δ is the first difference operator, n is the lag length set at 2 given our sample size and μ is the serially uncorrelated error term. From equations (5a) to (5e), short-run causality is determined by the statistical significance of the partial F-statistics associated with the corresponding right hand side variables. Long-run causality is indicated by the statistical significance of the respective error correction terms using a *t*-test. Our causality test results are discussed in section 5.3.3.

5. Empirical analysis and results

5.1Time series data and their properties

The study uses time series data for each of the selected countries. The included countries have different time periods (indicated after the country name) over the annual period 1971-2007. The included countries are Botswana (1981-2007), Democratic Republic of Congo (1980-2007), Mozambique (1980-2007), South Africa (1971-2007), Zambia (1971-2007) and Zimbabwe (1975-2005). The major data source for this study was the World Bank's World Development Indicators CD-ROM (2010).

Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant U.S. dollars.

Service sector share is measured by value added as a percentage of GDP. Services correspond to ISIC divisions 50-99 and they include value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services. Also included are imputed bank service charges, import duties, and any statistical discrepancies noted by national compilers as well as discrepancies arising from rescaling. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The industrial origin of value added is determined by the International Standard Industrial Classification (ISIC).

Trade openness is measured by the sum of exports and imports of goods and services measured as a share of gross domestic product.

The methodological approach employed in this study is as follows: First, we analyzed the univariate properties of the data in each country using the Dickey-Fuller Generalized Least Squares (GLS) unit root test. All the variables were found to be non-stationary in levels except trade openness which was found to be stationary in four of the countries (DRC, Mozambique, Zambia and Zimbabwe). The unit root test results are reported in table 1 in the appendix. Second, we explored if there is cointegration among the variables. Lastly, we checked for the most appropriate functional form to describe the time path of CO_2 emissions in each country as well as in the panel of countries.

5.2 Time series cointegration and long-run results

The F-statistics are computed from the estimation of equation (3). For all countries with the exception of Mozambique, the null hypothesis of no long-run relationship is rejected. This confirms the existence of a long-run relationship among the variables in equation (2). In the case of Mozambique we could not reject the null hypothesis of no long-run relationship at 10 per cent level of significance. In this case we had to resort to the residuals from the estimation of equation (2).

Our short-run results confirm our long-run findings. The coefficients of the error correction terms are statistically significant, negative and smaller than unity in absolute terms. We also conducted the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) stability tests (results not reported here) for the cases of countries in which the cointegration relationship is confirmed from the results of short-run estimated coefficients. The results support the stability of the estimated models.

The long-run elasticities were estimated using the autoregressive distributed lag model. The optimal lag length was determined on the basis of the Akaike information criterion. The income variable is positive and its quadratic term is negative for all countries (except for Mozambique). The results of a positive impact of income on CO_2 emissions are consistent with those of previous studies (e.g., Jalil and Mahmud, 2009; Halicioglu, 2010; Iwata et al., 2010a; Iwata et al., 2010b; Shahbaz et al., 2010). The income variable and its quadratic term are however, both statistically significant only for Botswana and Zimbabwe. Foreign trade has a negative impact on CO_2 emissions in Botswana, South Africa and Zambia. These results are in line with Jalil and Mahmud (2009). Foreign trade has a positive impact on CO_2 emissions in the remaining three countries, although it is significant only in the case of South Africa. This result is in line with Halicioglu (2009). Jalil and Mahmud (2009) discussed that the net effect of trade on pollution could depend on the relative strength of several opposing factors and therefore the insignificance of the foreign trade variable can be justified on these grounds. The share of service sector value added in GDP, which measures the impact of structural change on CO_2 emissions, has a negative impact in four of the countries (Mozambique, South Africa, Zambia, and Zimbabwe). These results are in line with Friedl and Getzner (2003). It has a significant negative impact on CO_2 emissions in the cases of South Africa and Zimbabwe. These results indicate that a growing share of service sector value added in GDP reduces pollution-intensive industries and thus CO_2 emissions in these countries.

For Botswana and Zimbabwe, the statistical significance of the square of per capita income rules out the suggestion that output rises monotonically with the level of CO_2 emissions. The results provide some support for the EKC hypothesis that the level of environmental pollution initially increases with income, until it reaches a threshold point, then declines. However, this hypothesis could not be confirmed with a graphical representation in both countries when emissions are plotted against income per capita. Therefore, it is concluded that the EKC does not hold for all the sample countries.

In the short-run, income has a significant positive impact on carbon emissions in two of the countries (South Africa and Zambia). The EKC hypothesis is not supported in the short-run. Trade openness has a significant negative impact on carbon emissions only in the case of South Africa. The other variables were generally insignificant or had the wrong signs. The error correction term is negative and statistically significant in the cases of Botswana, DRC, South Africa and Zimbabwe. However, it is smaller than unity in absolute terms only in the cases of South Africa and Zimbabwe.

5.3 Panel estimation results

5.3.1 Panel unit root test

Before checking for panel cointegration we first conducted panel unit root tests, using Levin et al., (2002) test to establish whether our variables [ce, y, y^2, s, tr] contain a panel unit root. This test assumes that the individual processes are cross-sectionally independent. It allows for two-way fixed effects, namely unit specific fixed effects and unit specific time effects. The unit specific fixed effects are important in the sense that they allow for heterogeneity (Asteriou and Hall, 2011 p. 443). Our panel unit root test results indicate that each of the variables contains a panel unit root.

5.3.2 Panel cointegration test

Having tested for a panel unit root, we proceeded to test for panel cointegration. We used the ADF and Phillips-Perron (PP) versions of panel cointegration suggested by Pedroni (1999). The Pedroni cointegration test requires that all the variables should contain a panel unit root. We found that the null hypothesis of no cointegration is rejected at 5% level or lower. We therefore concluded that there exists a long-run cointegration relationship among the five variables for this panel of countries.

When equation (4) was estimated with fixed effects while allowing for individual effects the results indicate that income as well as its quadratic form, trade openness and service sector share in GDP are significant determinants of carbon emissions. The income and the quadratic income variables have the expected signs in terms of the EKC hypothesis. Trade openness appears to reduce carbon emissions for this panel of countries which is contrary to what we would expect for developing countries. The share of service sector value added has the expected negative sign, suggesting that increases in the share of this sector in GDP would help reduce carbon emissions.

When the model was estimated with random effects our results indicate that both income and its quadratic term are significant and have the expected signs according to the EKC hypothesis. Again, trade openness appears to have a significant negative impact on carbon emissions. The service sector value added share is, however, insignificant. After estimating the model with a common intercept we tested the null hypothesis of non-significance of the individual effects. This was rejected according to the Wald test outcomes. Therefore we cannot accept a common constant term for all the countries (OLS results), since each country starts from a different level of carbon emissions. For the random effects estimations, we applied the Hausman test in order to test for the orthogonality between the random effects and the regressors. Our Hausman test results indicate that only the coefficients of the model specified with fixed effects are consistent in this panel of countries.

We proceeded and estimated the model with fixed effects while allowing for individual income elasticities. The results suggest that the income variable and its quadratic form are both significant and carry the expected signs only in the case of the Democratic Republic of Congo. Although the EKC hypothesis appears to hold for the panel of countries, there is little evidence at the individual country level.

5.3.3 Panel Granger causality

The short-run panel Granger causality test results can be summarized as follows: First, there is bi-directional causality between income and the quadratic income term in the short-run. Second, there is bi-directional causality between income and trade openness variables in the short-run. Third, there is evidence of short-run bi-directional causality between the quadratic income variable and trade openness. Fourth, there is no long-run evidence of Granger causality among the variables since none of the lagged error correction terms is significant.

6. Conclusions

The main motivation of this study was to investigate the time series and panel determinants of carbon dioxide emissions in six African countries. We also examined statistical evidence in favour of the environmental Kuznets curve for capita CO2 emissions in the six African countries, individually as well as in a panel. Employing the autoregressive distributed lag model (ARDL), the long-run relationship in which carbon dioxide emissions is the dependent variable is used to estimate the short-run and long-run elasticities of carbon emissions with respect to the chosen explanatory variables for each country. The results suggest that the main driving force behind carbon emissions in the sample of countries is income per capita. Our results also show that CO_2 emissions are not determined by short-term fluctuations in real GDP per capita. We find that the growth of the service sector, other things being equal does not reduce CO_2.

The EKC hypothesis requires that the estimated long-run coefficients for income and its quadratic term alternate in sign starting with a positive. Our results indicate that both these variables were statistically significant and had the expected signs only in two of the countries (Botswana and Zimbabwe). However, the EKC hypothesis could not be confirmed with graphical representations in both these countries. Based on these results we conclude that there is no evidence in support of the EKC hypothesis within our sample.

The main policy conclusion from our time series results is that the sample countries need to introduce radical changes in their environmental policies in order to break the time series of CO_2 emissions. There is no automatic mechanism which would bring down CO_2 emissions as they grow. Our results indicate that these African countries should incorporate environmental concerns into their macroeconomic policies more intensely to reduce the carbon emissions which accompany economic growth and switch to less polluting energy mix.

In our panel analysis our goal was to investigate the determinants of carbon dioxide emissions in a panel of six African countries, (Botswana, Democratic Republic of Congo, Mozambique, South Africa, Zambia, and Zimbabwe), over the period 1981- 2005. We found that carbon emissions, income, the quadratic income variable, trade openness and the share of service sector in GDP are panel-cointegrated. Our empirical results indicate that income as well as its quadratic form, trade openness and service sector share in GDP are significant determinants of carbon emissions. The income and the quadratic income variables have the expected signs in terms of the EKC hypothesis. Trade openness appears to reduce carbon emissions for this panel of countries.

Furthermore, this paper presents a dynamic error correction model capturing the short-run dynamics of the relationship between carbon emissions and the other variables. Our panel Granger causality results indicate that there is no evidence of Granger causality between carbon emissions and all the other variables in both the short-run and long-run.

7. References

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Appendix

Table 1. Individual time series Unit root tests (D-F GLS)

Country	Variable	Levels		First differences	
		Intercept	Trend & intercept	Intercept	Trend & intercept
Botswana	y	-0.642	-2.386	-1.985**	-3.498**
		(-1.609)	(-2.890)	(-1.955)	(-3.190)
	co2	-0.433	-1.241	-7.883***	-8.027***
		(-1.609)	(-2.890)	(-2.661)	(-3.770)
	t	-0.780	-2.482	-5.361***	-5.861***
		(-1.609)	(-2.890)	(-2.661)	(-3.770)
	s	-1.475	-1.965	-4.632***	-3.874***
		(-1.607)	(-2.890)	(-2.686)	(-3.770)
	y^2	-0.682	-2.628	-2.524**	-3.537**
		(-1.609)	(-2.890)	(-1.957)	(-3.190)
DRC	y	-0.740	-2.374	-2.354**	-2.398
		(-1.611)	(-2.890)	(-1.951)	(-2.890)
	co2	-0.129	-1.950	-6.601***	-6.714***
		(-1.611)	(-2.890)	(-2.633)	(-3.770)
	t	-2.280**	-3.825***	-7.247***	-7.695***
		(-1.950)	(-3.770)	(-2.633)	(-3.770)
	s	-0.937	-3.804***	-7.351***	-8.284***
		(-1.611)	(-3.770)	(-2.633)	(-3.770)
	y^2	-0.650	-2.360	-2.497**	-2.548
		(-1.611)	(-2.890)	(-1.951)	(-2.890)
Mozambique	y	-0.444	-1.715	-3.000***	-3.677**
		(-1.609)	(-2.890)	(-2.657)	(-3.190)
	co2	-1.518	-1.334	-3.837***	-5.758***
		(-1.610)	(-2.890)	(-2.657)	(-3.770)
	t	-1.939*	-3.613**	-3.580***	-3.645**

		(-1.609)	(-3.190)	(-2.657)	(-3.190)
	s	-1.923*	-2.888	-6.231***	-3.863***
		(-1.609)	(-2.890)	(-2.657)	(-3.770)
	y^2	-0.353	-1.637	-2.968***	-3.728**
		(-1.609)	(-2.890)	(-2.657)	(-3.190)
RSA	y	-1.645*	-1.638	-3.658***	-3.849***
		(-1.611)	(-2.890)	(-2.633)	(-3.770)
	co2	-1.084	-1.235	-4.903***	-4.852***
		(-1.611)	(-2.890)	(-2.633)	(-3.770)
	t	-1.849*	-1.917	-4.557***	-4.613***
		(-1.611)	(-2.890)	(-2.633)	(-3.770)
	s	-0.126	-1.753	-3.550***	-3.985***
		(-1.611)	(-2.890)	(-2.633)	(-3.770)
	y^2	-1.643*	-1.637	-3.661***	-3.853
		(-1.611)	(-2.890)	(-2.633)	(-3.770)
Zambia	y	-0.636	-0.445	-1.562	-5.805***
		(-1.611)	(-2.890)	(-1.611)	(-3.770)
	co2	-0.131	-1.476	-5.522***	-6.234***
		(-1.611)	(-2.890)	(-2.633)	(-3.770)
	t	-2.619**	-3.385**	-5.945***	-5.967***
		(-1.950)	(-3.190)	(-2.635)	(-3.770)
	s	-2.261**	-2.654*	-6.290***	-6.439***
		(-1.950)	(-2.890)	(-2.633)	(-3.770)
	y^2	-0.631	-0.459	-1.542	-5.876***
		(-1.611)	(-2.890)	(-1.611)	(-3.770)
Zimbabwe	y	-0.456	-1.156	-3.796***	-3.955***
		(-1.610)	(-2.890)	(-2.647)	(-3.770)
	co2	-0.817	-1.709	-3.782***	-5.718***
		(-1.610)	(-2.890)	(-2.647)	(-3.770)
	t	-2.779***	-3.831***	-4.763***	-4.560***

	(-2.647)	(-3.770)	(-2.653)	(-3.770)
s	-1.96**	-2.483	-6.523***	-6.530***
	(-1.952)	(-2.890)	(-2.647)	(-3.770)
y^2	-0.503	-1.186	-3.812***	-3.965***
	(-1.610)	(-2.890)	(-2.647)	(-3.770)

Notes: The numbers in the parentheses are critical values. (*), (**), (***) indicate rejection of the null hypothesis at 10%, 5%, and 1% levels of significance, respectively.