Macrothink Institute™

Research in Applied Economics
ISSN 1948-5433
2014, Vol. 6, No. 2

Carbon Dioxide Emissions among African Countries: An Application of the Sequential Panel Selection Method

Emmanuel Anoruo[1,*]

[1]Dept. of Accounting and Management Information Systems, Coppin State University, Baltimore, USA

*Correspondence: 2500 West North Avenue, Baltimore, MD, USA. Tel: 1-410-951-3446 E-mail: eanoruo@coppin.edu

Received: February 14, 2014 Accepted: March 31, 2014 Published: April 8, 2014

doi:10.5296/rae.v6i2.5118 URL: http://dx.doi.org/10.5296/rae.v6i2.5118

Abstract

This paper investigates the existence of stochastic convergence in per capita carbon dioxide emissions for a panel of 15 African countries using the Sequential Panel Selection Method (SPSM) for the time period running from 1971 through 2011. This paper adopts the SPSM because it has the ability to separate the series in the panel into stationary and nonstationary groups. The results provide evidence in support of convergence in per capita carbon dioxide emissions for the panel as a whole. However, for the individual countries in the panel, the results suggest that the relative per capita carbon dioxide emissions for Niger, Mauritius, Nigeria, Swaziland, Madagascar, Kenya, Malawi, Morocco, Tanzania, Algeria and Zimbabwe have converged to the sample average emissions. For Congo, Zambia, Egypt and Botswana, the results show that their relative per capita carbon dioxide emissions have diverged from the sample average emissions. The findings of this study have implications for both national and international environmental policies.

Keywords: Per capita C02 emissions, SPSM, convergence, panel KSS unit root test, Fourier function, Africa

1. Introduction

In the past three decades, the issue of carbon dioxide emissions has attracted the attention of policymakers and academicians alike given its implications for global warning. According to OECD/IEA (2008), the global economy will grow by approximately a factor of four and a factor of 10 in developing countries between 2008 and 2050 which will unavoidably lead to an increase in energy consumption. Similarly, the International Energy Agency predicts that by 2050, oil demand and carbon dioxide emissions would increase by roughly 70% and 130%, respectively. The conventional wisdom stipulates that pressure on the environment tends to be high during the early stages of economic development and low as the economy develops. Hence the environment is expected to deteriorate during the early stages of economic development and improves over time as the economy grows. In the literature, this relationship is known as the Environmental Kuznets Curve (EKC).

Environmental experts and policymakers agree that carbon dioxide emissions reduction is necessary in an effort to curb global warning resulting from greenhouse gases. International cooperation is required in any effort to reduce carbon dioxide emissions given that global warming is a universal problem. It is therefore imperative to get a clear understanding of convergence in per capita carbon dioxide emissions in the global context. In essence, it is important for policymakers to know whether shocks to per capita carbon dioxide emissions are permanent or temporary.

Shocks to per capita carbon dioxide emissions are permanent if their time series are found to be unit root processes. On the other hand, shocks to per capita carbon dioxide emission are transitory if their time series are stationary processes signaling the presence of convergence. The existence of convergence in per capita carbon dioxide emissions suggests that countries under consideration are collectively moving towards a common standard of environmental target rather than pursuing a piece meal strategy in their pollution control endeavors.

The Kyoto Protocol(Note 1) recognizes that developed countries are the major contributors of the current global warning and as such calls on them to play vital role in curbing CO2 emissions. The existence of convergence further indicates that the CO2 emissions increment will mainly come from the developing countries which implies that developing countries should also take actions to reduce carbon dioxide emissions. By working together, developed and developing countries can achieve the goal of containing the rise in the world average temperature to under 2 centigrade.

Given its adverse effect on the environment, a number of studies have explored the existence of convergence in per capita carbon dioxide. For instance, Li and Lin (2013) examined the issue of global convergence in carbon dioxide emissions for the time period running from 1971 to 2008. They find evidence in support of absolute convergence in per capita carbon dioxide emissions for within subsamples classified by income levels. They further investigated the existence of the EKC hypothesis and find that per capita carbon dioxide emissions of high-income countries did not decline as their economies grew. Their finding contradicts the proposition of EKC.

Lee and Chang (2008) using the panel seeming unrelated regressions augmented Dickey-Fuller (SURADF) procedure and data from 1960 through 2000, examined the existence of β-convergence and stochastic convergence for OECD countries. They find evidence of relative per carbon dioxide emissions for only 7 out of the 21 OECD countries in the sample. They attributed their finding to the SURADF procedure and therefore concluded that the standard panel unit root tests tend to offer misleading inferences that are generally biased towards stationarity even when only one of the series in the panel is strongly stationary. Christidou *et al.* (2013) explored the time series properties of per capita carbon dioxide emissions for 36 countries for the time period 1870 through 2006 using nonlinear panel unit root test. They find that the per capita carbon dioxide emissions are stationary processes.

Panopoulou and Pantelidis (2009) examined the existence of convergence in carbon dioxide emissions among 128 countries for the period 1960–2003 using the convergence procedure proposed by Phillips and Sul (2007). They find evidence in support of convergence in per capita CO2 emissions among all the countries under study. Unlike the earlier studies, their methodology allowed them to identify groups of countries that have converged to different equilibria. Nguyen-Van (2005) applying the non-parametric approach explored the issue of convergence in carbon dioxide emissions among 100 countries. He failed to find evidence supportive of convergence in per capita emissions for the entire sample countries. However, he finds evidence of convergence in per capita carbon dioxide emissions for industrialized countries.

Aldy (2006) using different econometric methodologies examined the existence of convergence in per capita carbon dioxide emissions for a group of 88 countries. He finds evidence of convergence in per capita carbon dioxide emissions among 23 OECD countries. Similarly, Romero-Avila (2008) finds evidence consistent with stochastic convergence among 23 industrialized countries using panel unit root procedures that considers structural breaks in the data generating process. Westerlund and Basher (2008) investigated the existence of convergence in per capita carbon dioxide emissions for a group of developed and developing countries for the time period running from 1870 through 2002. They find evidence supportive of convergence in per carbon dioxide emissions among the panel members. They further furnished estimates for speed of convergence for the sample countries.

Yavuz and Yilanci (2013) examined the convergence of per capita carbon dioxide emissions for G7 countries for the period 1960 through 2005 using the threshold autoregressive (TAR) panel unit root tests. They find that the carbon dioxide emission series for the sample countries are nonlinear. They further find evidence of convergence in per capita carbon dioxide emissions in the first regime but not in the second regime. When they tested whether absolute or conditional convergence existed, they find that per capita carbon dioxide emissions were conditionally converging in the first regime but not in the second regime. Strazicich and List (2003) using data from 1960 through 1997 examined the existence of convergence in per capita carbon dioxide emissions for a panel of 21 industrialized countries. Implementing cross-section regressions and panel unit root test they find evidence supportive of stochastic and conditional convergence, respectively.

Most of the earlier studies on convergence in per capita carbon dioxide emissions were undertaken in the context of industrialized countries. African countries have not received adequate attention on this issue, even though their economies are not immune from the adverse effects of global warning. Unarguably, the findings of the earlier studies on the issue of convergence in per capita carbon dioxide emissions for developed countries cannot be generalized to Africa countries. After all, most African countries do not use the latest clean energy technologies in their farming and production processes. Further, African countries are often characterized by rapid population growth and increased consumption of coal and petroleum fuels; all which contribute to carbon dioxide emissions. Industrial pollution continues to present challenges in the region due to the absence of cohesive policies to mitigate carbon dioxide emissions. This paper extends the debate on convergence in per capita carbon dioxide emissions to 15 African countries. In addition, this paper employs the Sequential Panel Selection Method (SPSM) with KSS unit root test and Fourier function to examine the existence of convergence in per capita carbon dioxide emissions among the sample countries. The SPSM has been touted in the literature because of its ability to control for both structural breaks and nonlinearity in the data generating process.

The structure of the paper is as follows. Section 2 discusses the methodology. Section 3 presents the data and the summary statistics. Section 4 discusses the results, while Section 5 furnishes the summary and the possible implications of the findings.

2. Methodology

There are mainly three types of convergence in the literature including sigma (σ) convergence, beta (β) convergence and stochastic convergence. This paper focuses on stochastic convergence which can be tested by using panel unit root procedures. To this effect, the empirical analysis of this study commences with the application of the first generation panel unit root tests namely the Levin-Lin-Chu (Levin *et al*., 2001), the Im-Pesaran-Shin (Im et al., 2003), and the MW (Maddala and Wu, 1999) procedures. It has been documented in the literature that the first generation panel unit root tests do not account for cross-sectional dependencies among series in a panel. To address this shortcoming, the study applies the second generation panel unit root tests proposed by Breitung and Das (2005) and Choi (2002). These second generation panel unit root tests also have some drawbacks. They do not account for nonlinearity and structural breaks in the data generating processes. In addition, they are not able to identify the number of series in a panel that are stationary processes especially when the researcher is not able to reject the null hypothesis of a panel unit root.

To overcome the shortcomings associated with the first and second generation panel unit root tests; this study uses the SPSM to examine the existence of convergence in relative per capita carbon dioxide emissions. Kapetanios, *et al*. (2003) (hereafter, KSS) modified the augment Dickey-Fuller (Dickey and Fuller, 1981) to incorporate nonlinearity in the data generating process. Kapetanios, *et al*. (2003) utilizing a Taylor's first-order approximation of the ESTAR process developed the following model:

$$\Delta x_t = \delta x_{t-1}^3 + \mu_t \tag{1}$$

To control for the presence of serial correlation in the error term, Kapetanios, *et al*. (2003) suggest the inclusion of the lagged values of x as follows:

$$\Delta x_t = \delta x_{t-1}^3 + \sum_{i=1}^{j} \Delta x_{t-1} + \mu_t \tag{2}$$

In equations (1) and (2), x is either the demeaned or de-trended data series and δ is the regression coefficient on x that is used to test for the presence of a unit root. The null hypothesis in both equations is that δ =0 (nonstationary) while the alternate hypothesis is that δ <0 (nonlinear ESTAR stationary).

Ucar and Omay (2009), combining the Kapetanios, *et al*. (2003) nonlinear time series test with the framework of Im *et al*. (2003) developed a nonlinear heterogeneous panel unit root procedure. The Ucar and Omay (2009) framework is based on the following auxiliary regression:

$$\Delta x_{i,t} = \delta x_{i,t-1}^3 + \sum_{i=1}^{j} \rho_{i,i} \Delta x_{t-i} + error_{i,t} \tag{3}$$

The hypotheses to be tested in equation (3) are:

H_0: δ_i =0, for all i, (linear nonstationarity)

H_A: δ_i <0, for some i, (nonlinear stationarity)

This study augments equation (3) with a Fourier function which yields the following KSS system of equations:

$$\Delta x_{i,t} = \alpha_i + \delta x_{i,t-1}^3 + \sum_{i=1}^{j} \rho_{i,i} \Delta x_{t-i} + \lambda_{i,t} \sin(2\pi kt/T) + \lambda_{2i,t} \cos(2\pi kt/T) + \upsilon_{i,t} \tag{4}$$

In equation (4), k represents the number of frequencies, while l represents the Fourier function which captures the number of smooth breaks by minimizing the residual sum of squares. T represents the sample size while t is the time trend and π = 3.1416. The sine and cosine terms are included in equation (4) since the Fourier function has the ability to accurately approximate integrable functions. One of the desirable features of equation (4) is that it reduces to a standard linear expression by setting $\lambda_1 = \lambda_2 = 0$. Another attractive feature of equation (4) is the fact that the presence of at least one frequency would indicate the existence of structural break in the data-generating process. The rejection of the null hypothesis that $\lambda_1 = \lambda_2 = 0$ in equation (4) suggests that x_t is a nonlinear process.

The Chortareas and Kapetanios (2009) SPSM involves the following three steps:

Step 1: the panel KSS test is applied to all the series in the panel. At this point, the process is stopped if the null hypothesis of a panel unit-root is accepted. In which case, all of the series in the panel are assumed to be unit root processes. If however, the null hypothesis of a panel unit root is rejected, the process continues to the second step.

Step 2: the series with the minimum KSS statistic is dropped from the panel given that it has been identified as a stationary process.

Step 3: the process returns to step 1 for the remaining series in the panel, or the test is terminated, if all of the series in the panel are removed. The final result of the SPSM involves the separation of the whole panel into a set of stationary and nonstationary series.

3. Data and Descriptive Statistics

The data consist of annual observations on per capita carbon dioxide emissions (millions of metric tons). The data were retrieved from the U.S. Energy Information Administration website at http://www.eia.gov. The countries in the sample are Algeria, Botswana, Congo, Egypt, Kenya, Madagascar, Malawi, Mauritius, Morocco, Nigeria, Niger, Swaziland, Tanzania, Zambia and Zimbabwe. The study period runs from 1971 through 2011. Following Strazicich and List (2003) and Lee and Chang (2008), the relative per capita carbon dioxide emissions is calculated as the natural logarithm of the ratio of per capita carbon dioxide emissions of country i relative to the average per capita carbon dioxide emissions of the 15 sample countries. The expression for relative per capita carbon dioxide emissions is given by:

$$y_{it} = \ln (C02_{it}/\text{average } C02_t) \tag{6}$$

Convergence in per capita carbon dioxide emissions for each country relative to the sample average CO2 emissions is indicated with the stationarity of y_{it}. On the other hand, the acceptance of the null hypothesis of a unit root would suggest that the relative per carbon dioxide emissions have diverged from the sample average emissions.

Table 1 presents the summary statistics for per capita carbon dioxide emissions measured in millions of metric tons. The mean values of per capita carbon dioxide emissions for the sample countries ranged from a high of 9.39 tons for Zimbabwe to a low of 0.03 tons for Madagascar. Congo (1.33) recorded the highest standard deviation while Niger (-1.84) exhibited the lowest. The maximum and minimum values reveal that per capita carbon dioxide emissions have fluctuated over the study period for the sample countries.

The skewness of per capita carbon dioxide emissions for most of the sample countries is positive suggesting that the upper deviations from the mean are larger than the lower deviations. These results imply that there is a greater probability of large increases than decreases in per capita carbon dioxide emissions for the countries under study. The Kurtosis coefficients for Congo, Egypt, Kenya, Madagascar, Nigeria, Niger, and Swaziland are greater than 3 indicating that the normality assumption with regard to the distribution of per capita carbon dioxide emissions should be rejected. Similarly, the Jarque-Bera test statistics are statistically significant at conventional levels for Congo, Mauritius, Nigeria, and Niger indicating that per capita carbon dioxide emissions for these countries are not normally distributed.

Table 1. Summary Statistics for Per Capita C02 Emissions (Millions of Metric Tons)

Country	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability
Algeria	2.37	3.90	1.32	0.62	0.01	2.51	0.32	0.85
Botswana	1.79	2.45	0.83	0.55	-0.59	1.96	3.30	0.19
Congo	0.71	0.97	0.60	0.10	1.33	3.83	10.32***	0.01
Egypt	2.77	3.80	2.03	0.42	0.58	3.06	1.78	0.41
Kenya	0.25	0.42	0.05	0.08	0.03	3.23	0.07	0.96
Madagascar	0.03	0.04	0.01	0.01	-0.38	3.67	1.37	0.50
Malawi	0.09	0.16	0.03	0.05	-0.14	1.46	3.27	0.19
Mauritius	0.48	1.56	0.00	0.53	0.99	2.49	5.58*	0.06
Morocco	8.56	12.93	3.64	3.13	-0.07	1.62	2.58	0.28
Nigeria	0.12	0.45	0.01	0.11	1.15	3.61	7.59**	0.02
Niger	0.40	0.55	0.05	0.12	-1.84	6.18	31.49***	0.00
Swaziland	0.38	0.52	0.12	0.09	-0.80	3.74	4.14	0.13
Tanzania	0.10	0.25	0.00	0.09	0.13	1.45	3.28	0.19
Zambia	0.63	1.44	0.00	0.47	0.24	1.65	2.74	0.25
Zimbabwe	9.39	13.64	6.23	2.24	0.29	1.78	2.44	0.30

***, ** and * indicate the rejection of the null hypothesis of normality assumption

4. Empirical Results

The empirical analysis of the study begins with the implementation of the first generation panel unit root tests namely the LLC (Levin, *et at*., 2002), IPS (Im *et al*., 2003), Breitung (2000), and Maddala and Wu (Maddala and Wu, 1999). The results from these procedures are presented in Table 2. The results from the first generation panel unit root tests indicate that the null hypothesis of a panel unit root should be rejected at least at the 10 percent level of significance. For instance, the computed test statistics from the LLC and Choi (PP-Fisher Chi-Square) procedures are -4.13 and 108.90, respectively with p-values of 0.00 and 0.00. Similar results are provided by Maddala-Wu, IPS and Breitung panel unit root procedures. As has been reported in the literature, the first generation panel unit root tests do not account for cross-sectional dependencies among members of a panel. According to O'Connell (1998), failure to account for contemporaneous correlations among panel members could lead to the rejection of the joint unit root hypothesis.

To overcome the problem of cross-sectional dependencies among panel members, the study next implements the second generation panel unit root procedures namely the Breitung and Das (Breitung and Das, 2005), and Choi (Choi, 2002). Table 3 displays the results from the second generation panel unit root tests. The results from the procedures reveal that the null hypothesis of a panel unit root should be rejected at least, at the 1 percent level. The test statistic from the Breitung and Das (2005) panel unit root procedure is -2.82, with a p-value of 0.00. The test statistics for the Choi (2002) panel unit root tests are 4.16, -2.37 and -2.76, respectively for P_m, Z and L^* procedures. These test statistics are statistically significant at the

1 percent level of significance as indicated by the p-values. In a nutshell, the results from both the first and second generation panel unit root tests reveal that per capita carbon dioxide emissions among the 15 sample countries have converged.

Table 2. First Generation Panel Unit Root Test Results

Method	Statistic	P-Value.	Cross-sections	Observations
Panel A: Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t	-4.13***	0.00	15	463
Breitung t-stat	-1.59*	0.06	15	448
Panel A: Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-3.89***	0.00	15	463
Maddala-Wu (ADF - Fisher Chi-square)	75.05***	0.00	15	463
Choi (PP - Fisher Chi-square)	108.90***	0.00	15	465

*** and * indicate rejection of the null hypothesis of a panel unit root at the 1 and 10 levels of significance, respectively.

One of the shortcomings of the second generation panel unit root procedures is their inability to indicate which panel members or how many panel members are responsible for the rejection of the null hypothesis of a panel unit root. They also do not account for nonlinearity and structural breaks in the data generating process. Simply put, the second generation panel unit root tests lack the ability to classify panel members into stationary and nonstationary groups.

Table 3. Second Generation Panel Unit Test Results

Breitung and Das (2005)	Choi (2002)		
t-stat	P_m	Z	L^*
-2.82***	4.16***	-2.37***	-2.76***
(0.00)	(0.00)	(0.01)	(0.00)

*** indicates level of significance at the 1% level. Choi (2002): the *m P* test is a modified Fisher's inverse chi-square test (Choi 2002). The *Z* test is an inverse normal test. The L^* test is a modified logit test. The p-values associated with the various tests are in parentheses.

This study implements the SPSM to remedy the problems associated with the conventional panel unit root tests. The SPSM enhances the ability of the researcher to identify which and how many panel members belong to the stationary and nonstationary groups. In particular, the study applies the panel KSS unit root test with a Fourier function. Under the panel KSS procedure, a grid-search is conducted to determine the optimal frequency, given that there is a priori knowledge relative to the shape of the breaks in the data. Equation (4) is estimated for each integer k = 1, 2, ….5; as suggested by Enders and Lee (2012) and asymptotic p-values are computed by means of bootstrap simulations using 10,000 replications. The study determines the optimal frequencies (k) using the residual sum of squares (RSS) statistic.

The results from the panel KSS unit root test with a Fourier function are presented in Table 4. The results suggest that the null hypothesis of a panel unit root in relative per carbon dioxide emissions should be rejected when the KSS unit root test was applied to the whole panel. The test statistic, -4.30 with a p-value of 0.00 suggests that the null hypothesis of a panel unit root should be rejected at 1 percent significance level. The result from the SPSM test reveals that the relative per capita carbon dioxide emissions for Niger are stationary with minimum KSS value of -9.04 within the panel. Given this result, Niger was removed from the panel. Once again, the test was applied to the remaining panel members. This time, the relative per carbon dioxide emissions for Mauritius was found to be stationary with minimum KSS value of -6.72. Following this result, Mauritius was removed from the panel and the panel KSS unit root test conducted again. The relative per capita carbon dioxide emissions for Nigeria are found to be stationary. Again, Nigeria with minimum KSS value of -5.60 is removed from the panel. This process is continued until the null hypothesis of a unit root could not be rejected at the 10 percent significance level.

Table 4. Panel KSS Unit Root Test Results with Fourier Function

Sequence	OU stat	P-Value	Min KSS	Fourier(k)	I(0) series
1	-4.30^{***}	0.00	-9.04	1	Niger
2	-3.99^{***}	0.00	-6.72	5	Mauritius
3	-3.84^{***}	0.00	-5.60	4	Nigeria
4	-3.47^{***}	0.00	-4.68	5	Swaziland
5	-3.26^{***}	0.00	-3.40	5	Madagascar
6	-3.04^{***}	0.00	-3.38	5	Kenya
7	-2.57^{***}	0.00	-2.62	2	Malawi
8	-2.33^{***}	0.01	-2.51	4	Morocco
9	-2.11^{**}	0.02	-1.83	5	Tanzania
10	-2.02^{***}	0.01	-1.62	5	Algeria
11	-2.01^{**}	0.03	-1.58	3	Zimbabwe
12	-1.36	0.26	-1.24	4	Congo
13	-1.37	0.43	-1.20	4	Zambia
14	-0.02	0.91	-0.90	5	Egypt
15	0.37	0.96	0.60	5	Botswana

*** and ** indicate levels of significance at the 1% and 5% respectively. The critical values were obtained by 10,000 bootstrapping replications in the spirit of Enders and Lee (2009).

We can infer from the results from the SPSM that the relative per capita carbon dioxide emissions for Niger, Mauritius, Nigeria, Swaziland, Madagascar, Kenya, Malawi, Morocco, Tanzania, Algeria, and Zimbabwe have converged to the sample average emissions, as the series are found to be stationary. However for Congo, Zambia, Egypt and Botswana the results provide evidence supportive of divergence in relative per capita carbon dioxide emissions. The robustness of the results from the panel KSS unit root procedures is checked by continuing the process until the last sequence of the panel is considered. The finding of this study is consistent with Panopoulou and Pantelidis (2009), Nguyen-Van (2005) and Westerlund and Basher (2007) who found evidence of panel convergence in per capita carbon dioxide emissions. The stationarity of the relative per capita carbon dioxide emissions implies that shocks to the series are temporary and that the series have the tendency to revert to their past mean values.

5. Summary and Implications

This paper has explored the existence of stochastic convergence in per capita carbon dioxide emissions among 15 African countries using the Sequential Panel Selection Method (SPSM) for the time period 1971 through 2011. The sample countries are Algeria, Botswana, Congo, Egypt, Kenya, Madagascar, Malawi, Mauritius, Morocco, Nigeria, Niger, Swaziland, Tanzania, Zambia and Zimbabwe. The study applied a battery of unit root tests including the first and second generation panel unit root procedures in addition to the SPSM. Specifically, this study adopted the SPSM given its superiority over the first and second generation panel unit root tests. In short, the SPSM can detect both nonlinearity and structural breaks in the data generating process. In addition, the SPSM has the ability to separate panel members into stationary and nonstationary groups.

The results from the first and second generation panel unit root tests indicate that the relative per capita carbon dioxide emissions have converged as a group. As alluded to earlier, these procedures are not able to identify stationary from nonstationary members in a panel setting. The results from the SPSM suggest that carbon dioxide emissions for the entire panel have converged. The results however indicate that for individual panel members, the relative per capita carbon dioxide emissions for Niger, Mauritius, Nigeria, Swaziland, Madagascar, Kenya, Malawi, Morocco, Tanzania, Algeria and Zimbabwe have converged. In contrast, the evidence points to divergence in relative per capita carbon dioxide emissions for Congo, Zambia, Egypt and Botswana.

The finding of convergence in per capita carbon dioxide emissions for the entire panel members implies that the sample countries are collectively moving towards a common standard of environmental target rather than pursuing piece meal strategies in their quest to curb global warming. In other words, it is possible for these countries to mutually benefit by engaging in some sort of international cooperation mechanisms such as joint implementation projects, clean development strategies, and international emissions trade; all of which are aimed at reducing carbon dioxide emissions and hence global warming.

Acknowledgement

The author is grateful to the editor and two anonymous referees of this journal for their constructive comments and suggestions that helped to improve the quality of this paper. The usual disclaimer applies.

References

Aldy, J. E. (2006). Per capita carbon dioxide emissions: convergence or divergence? *Environmental Resource Economics*, *33*, 533–555. http://dx.doi.org/10.1007/s10640-005-6160-x

Bai, J., & Ng, S. (2004). A panic attack on unit roots and cointegration. *Econometrica*, *72*, 1127-1177. http://dx.doi.org/10.1111/j.1468-0262.2004.00528.x

Breitung, J. (2000). The local power of some unit root tests for panel data. In *Advances in Econometrics*, Volume 15: Nonstationary Panels, Panel Cointegration, and Dynamic Panels, ed. B. H. Baltagi, 161–178. Amsterdam: JAI Press.

Byeongyong, P. C. (2010). The US property and liability insurance industry: firm growth, size and age. *Risk Management and Insurance Review, 13*, 207-224. http://dx.doi.org/10.1111/j.1540-6296.2010.01181.x

Choi, I. (2002). Combination unit root tests for cross-sectionally correlated panels. In *The Econometric Theory and Practice: Frontiers of Analysis and Applied Research*, ed. Peter C. B. Phillips, Dean Corbae, Steven N. Durlauf, and Bruce E. Hansen, 311-333. Cambridge: Cambridge University Press.

Chortareas, G., & Kapetanios, G. (2009). Getting PPP right: identifying mean-reverting real exchange rates in panels. *Journal of Banking and Finance*, *33*, 390-404. http://dx.doi.org/10.1016/j.jbankfin.2008.08.010

Christidou, M, Panagiotidis, T., & Sharma, A. (2013). On the stationarity of per capita carbon dioxide emissions over a century. *Economic Modelling*, *33*, 918-925. http://dx.doi.org/10.1016/j.econmod.2013.05.024

Dickey, D.A., & Fuller, W.A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica, 49*, 1057-72. http://dx.doi.org/10.2307/1912517

Enders, W., & Lee, J. (2004). Testing for a unit root with a nonlinear Fourier function. Working paper, Department of Economics, Finance and Legal Studies, University of Alabama, Tuscaloosa, AL, USA. Retrieved December 13, 2013 from http://www3.nd.edu/~meg/MEG2004/Lee-Junsoo.pdf

Enders, W., & Lee, J. (2009). The flexible Fourier form and testing for unit roots: an example of the term structure of interest rates. Working paper, Department of Economics, Finance and Legal Studies, University of Alabama, Tuscaloosa, AL, USA.

Im, K. S., Pesaran, H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*, 53-74. http://dx.doi.org/10.1016/S0304-4076(03)00092-7

Jobert, T, Karanfil, F., & Tykhonenko, A. (2010). Convergence of per capita carbon dioxide emissions in the EU: legend or reality? *Energy Economics*, *32*, 1364-1373. http://dx.doi.org/10.1016/j.eneco.2010.03.005

Kapetanios, G., Shin, Y., & Snell, A. (2003). Testing for a unit root in the nonlinear STAR

Framework. *Journal of Econometrics*, *112*, 359-379. http://dx.doi.org/10.1016/S0304-4076(02)00202-6

Lee, C., & Chang, C. (2008). New evidence on the convergence of per capita carbon Dioxide emissions from panel seemingly unrelated regressions augmented Dickey–Fuller tests. *Energy, 33*, 468-1475. http://dx.doi.org/10.1016/j.energy.2008.05.002

Levin, A, Lin, C., & Chu, C. (2002). Unit root in panel data: asymptotic and finite-sample Properties. *Journal of Econometrics*, *108*, 1-24. http://dx.doi.org/10.1016/S0304-4076(01)00098-7

Li, X'., & Lin, B. (2013). Global convergence in per capita CO2 emissions. *Renewable and Sustainable Energy Reviews*, *24,* 357-363. http://dx.doi.org/10.1016/j.rser.2013.03.048

Maddala, G. S., & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, *61*, 631-652. http://onlinelibrary.wiley.com/doi/10.1111/1468-0084.0610s1631/abstract

Moon, R. H., & Perron, B. (2004). Testing for a unit root in panels with dynamic factors. *Journal of Econometrics*, *122*, 81-126. http://dx.doi.org/10.1016/j.jeconom.2003.10.020

Nguyen-Van, P. (2005). Distribution dynamics of CO2 emissions. *Environmental Resources Economics*, *32*, 495–508. http://dx.doi.org/10.1007/s10640-005-7687-6

OECD/IEA (2008). *Energy Technology Perspectives, 2008 Scenarios & Strategies to 2050: in support of the G8 Plan of Action.* Group of Eight, International Energy Agency and Organization of Economic Co-operation and Development Paris, France. Retrieved December 2013 from https://www.iea.org/media/etp/ETP2008.pdf

Panopoulou, E., & Pantelidis, T. (2009). Club convergence in carbon dioxide emissions. *Environmental Resource Economics*, *44*, 47–70. http://dx.doi.org/10.1007/s10640-008-9260-6

Pesaran, H. (2007). A simple unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*, 265-312. http://dx.doi.org/10.1002/jae.951

Phillips, P. C. B., & Sul, D. (2007). Transition modeling and econometric convergence tests. *Econometrica*, *75*, 1771–1855. http://dx.doi.org/10.1111/j.1468-0262.2007.00811.x

Romero-Avila, D. (2008). Convergence in carbon dioxide emissions among industrialized countries revisited. *Energy Economics*, *30*, 2265–2282. http://dx.doi.org/10.1016/j.eneco.2007.06.003

Strazicich, M. C., & List, J. A. (2003). Are CO2 emission levels converging among industrialcountries? *Environmental and Resource Economics*, *24*, 263–271. http://dx.doi.org/10.1023/A:1022910701857

Ucar, N., & Omay, T. (2009). Testing for unit root in nonlinear heterogeneous panels. *Economics Letters, 104*, 5-8. http://dx.doi.org/10.1016/j.econlet.2009.03.018

Westerlund, J., & Basher, S.A. (2008). Testing for convergence in carbon dioxide emissions using a century of panel data. *Environmental and Resource Economics, 40*, 109–120. http://dx.doi.org/10.1007/s10640-007-9143-2

Yavuz, N. C., & Yilanci, V. (2013). Convergence in per capita carbon dioxide emissions among G7 countries: a TAR panel unit root approach. *Environmental and Resource Economics*, *54*(2), 283-291. http://dx.doi.org/10.1007/s10640-012-9595-x

Note

Note 1. The Kyoto Protocol was established on 11 December 1997 in Kyoto, Japan. It basically represents a commitment on the part of industrialized nations to reduce carbon dioxide emissions.